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IEEE Recommended Practice for Installation, Maintenance, Testing, and Replacement of Vented Nickel-Cadmium Batteries for Stationary Applications

Sponsor

Stationary Battery Committee
of the
IEEE Power Engineering Society

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IEEE-SA Standards Board

Abstract: This recommended practice provides recommendations for installation design and for installation, maintenance, and testing procedures that can be used to optimize the life and performance of vented nickel-cadmium batteries used in stationary standby applications.

Keywords: battery tests, capacity test methods, stationary applications, vented nickel-cadmium batteries

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Introduction

(This introduction is not part of IEEE Std 1106-2005, IEEE Recommended Practice for Installation, Maintenance, Testing, and Replacement of Vented Nickel-Cadmium Batteries for Stationary Applications.)

Today, stationary storage batteries play an ever-increasing role in industry by providing normal control and instrumentation power and backup energy for emergencies. This recommended practice fulfills the need within the industry to provide common or standard practices of installation, maintenance, testing, and replacement of vented nickel-cadmium batteries. The methods described are applicable to all installations and battery sizes for stationary standby applications.

The installations considered herein are designed for continuous-float operation with a battery charger serving to maintain the battery in a charged condition and to supply the normal dc load. Applications wherein the battery is not fully recharged after every discharge (e.g., alternative energy applications) are beyond the scope of this recommended practice.

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IEEE Recommended Practice for Installation, Maintenance, Testing, and Replacement of Vented Nickel-Cadmium Batteries for Stationary Applications

1. Overview

1.1 Scope

This recommended practice is applicable to all stationary standby applications. However, specific applications, such as emergency lighting units and semiportable equipment, may have other appropriate practices and are beyond the scope of this recommended practice. Stationary cycling applications, such as those found in alternative energy applications, are also beyond the scope of this document.

Sizing, qualification, and other battery types are beyond the scope of this recommended practice.

This recommended practice does not include any other component of the dc system, nor does it include inspection and testing of the overall dc system. Preoperational 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 will depend on the requirements of the dc system and are beyond the scope of this recommended practice.

1.2 Purpose

This recommended practice provides recommendations for installation design and for installation, maintenance, and testing procedures that can be used to optimize the life and performance of vented nickel-cadmium batteries used in stationary standby applications. This recommended practice also provides guidance for determining when these batteries should be replaced.

2. Normative references

The following referenced documents are indispensable for the application of this recommended practice. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments or corrigenda) applies.

IEEE Std 1115™, IEEE Recommended Practice for Sizing Nickel-Cadmium Batteries for Stationary Applications.[1]

3. Definitions

For the purposes of this recommended practice, the following terms and definitions apply. *The Authoritative Dictionary of IEEE Standards Terms* [B2][2] 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 determine 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 float charge: A constant potential normally applied to a battery to maintain it in a charged condition.

3.4 high-rate charge: The application of a constant-potential charge, at a higher level than the float charge, to a partially or fully discharged battery to recharge it.

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

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

3.7 standby operation (battery): Operation with a battery charger serving to maintain a battery in a charged condition and to supply the normal dc load. *Syn*: **continuous-float operation**.

3.8 vented cell: A cell in which the products of electrolysis and evaporation are allowed to escape to the atmosphere as they are generated. *Syn*: **flooded cell**.

4. Safety

4.1 General

The safety precautions listed herein are considered to be mandatory and shall be followed in all battery installation and maintenance activities. Work on batteries shall be performed only by knowledgeable personnel with proper, safe tools and protective equipment.

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[1] IEEE publications are available from the Institute of Electrical and Electronics Engineers, Inc., 445 Hoes Lane, Piscataway, NJ 08854, USA (http://standards.ieee.org/).

[2] The numbers in brackets correspond to those in the bibliography in Annex H.

4.2 Methods

Work performed on a battery in service shall use methods to preclude arcing in the vicinity of the battery.

4.3 Protective equipment

The following protective equipment for safe handling of the battery and protection of personnel shall be available:

a) Goggles and face shields.

b) Chemical-resistant gloves.

c) Protective aprons and overshoes.

d) Portable or stationary water facilities for rinsing eyes and skin in case of contact with alkaline electrolyte. The use of pH buffered neutralizing eyewash solution is recommended.

e) Spill absorbing/neutralizing materials, or other suitable neutralizing agent recommended by the manufacturer for alkaline electrolyte spillage.[3]

f) Class C fire extinguisher.[4]

g) Adequately insulated tools.

h) Lifting devices of adequate capacity, when required.

4.4 Precautions

The following protective procedures shall be observed during installation and maintenance:

a) Ensure that metal racks are connected to ground in accordance with applicable codes.

b) Inspect all lifting equipment for functional adequacy.

c) Restrict all unauthorized personnel from the battery area.

d) Prohibit the use of acid-contaminated tools and equipment such as hydrometers and thermometers in or on the battery.

e) Provide signs prohibiting smoking and open flames and avoiding arcing in the immediate vicinity of the battery.

f) Keep the top of the battery clear of all tools and other foreign objects.

g) Ensure that illumination requirements are met.

h) Ensure unobstructed egress from the battery area.

i) Ensure that the battery area is adequately ventilated.

j) Avoid wearing metallic objects, such as jewelry, while working on the battery.

k) Avoid excessive tilting of the cells to prevent spillage.

l) Neutralize static buildup just before working on the battery by contacting the nearest effectively grounded surface.

m) Ensure that load test leads are connected with a length of cable sufficient to prevent accidental arcing in the vicinity of the battery.

n) Ensure that all connections to load test equipment include short-circuit protection.

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[3] The removal and/or neutralization of an alkali spill may result in production of a hazardous waste. The user should comply with all applicable codes and regulations.

[4] Some battery manufacturers do not recommend the use of CO_2-type fire extinguishers due to the potential for thermal shock on the battery cases.

5. Installation design criteria

5.1 General

Considerations that should be included in the design of the battery installation depend on the requirements or function of the system of which the battery is a part. The general installation design criteria for all nickel-cadmium batteries are given in 5.2 – 5.6. Other applicable codes should also be observed as appropriate to the installation.

5.2 Location

The following criteria should be observed regarding location:

a) Space and floor supports allocated for the battery and associated equipment should allow for present and future needs. Calculations should be performed to ensure that floor loading capabilities are not exceeded.

b) The general battery area selected should be clean, dry, and ventilated and should provide adequate space and illumination for inspection, maintenance, testing, and cell replacement. Space should also be provided above the cells to allow for operation of lifting equipment, addition of water, and taking of measurements (e.g., voltages, temperature, etc.).

c) The battery should be protected against natural phenomena such as earthquakes, winds, and flooding, as well as induced phenomena such as fire, explosion, missiles, pipe whips, discharging fluids, CO_2 discharge, and other hazards.

d) The optimum range for cell electrolyte temperature is 20 °C to 25 °C, and it is the basis for rated performance. A location where this temperature can be maintained will contribute to optimum battery life, performance, and cost of operation. Although nickel-cadmium batteries are tolerant of extreme temperatures, low temperatures will decrease battery capacity, whereas prolonged high temperatures will shorten battery life (see A.4). Installation in a location with an ambient temperature below the optimum operating temperature will affect sizing. Refer to IEEE Std 1115.[5]

e) The location and arrangement of cells should result in no greater than a 5 °C temperature differential between cells at a given time. Avoid conditions that result in spot heating or cooling, as temperature variation will cause the battery to become electrically unbalanced.

f) The battery location should be such that direct sunlight on the cells is avoided, as this may damage plastic cell cases and create localized heating.

g) For personnel safety in the event of electrolyte spillage, portable or stationary water facilities shall be provided. Provisions for neutralizing, containing, and/or safely disposing of electrolyte should be included. The floor surface should be alkali-resistant.

h) The charger and main power distribution center should be as close as practical to the battery, consistent with item j).

i) Illumination in the battery area should equal or exceed the interior lighting recommendations in Figure 11-1 of the *Lighting Handbook* [B5].

j) Nearby equipment with arcing contacts shall be located in such a manner as to avoid those areas where hydrogen pockets could form.

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[5] For information on references, see Clause 2.

5.3 Mounting

The most common practice is to mount cells on a steel rack with chemical-resistant insulation between the cells and the steel of the rack. Metal racks should be connected solidly to the grounding system in accordance with applicable codes. The cells may also be mounted on adequately insulated supports secured to a floor or base.

The number of tiers or steps selected should result in a minimum temperature differential between cells [see 5.2, item e)] and allow for adequate maintenance.

5.4 Seismic

Where applicable building codes require seismic protection, the racks, cabinets, anchors, and installation thereof shall be able to withstand the calculated seismic forces. For utility substations, IEEE Std 693™-1997 [B4] provides guidance for seismic installation design and seismic qualification of battery racks. To minimize the effect of seismic forces, the battery should be located at as low an elevation as practical. The following criteria should be observed regarding mounting:

a) All cells should be restrained. Using side and end rails is one method that can be used to prevent loss of function due to a seismic event.

b) Where more than one rack section is used, the rack sections should be rigidly joined, or the adjacent end cells in each rack should be connected with flexible connectors as provided by or recommended by the manufacturer. Connections between cells at different levels of the same rack should also be flexible.

c) Racks shall be firmly connected to the building structure in accordance with applicable codes by using approved fastening techniques such as embedded anchor bolts or racks welded to structural steel faceplates (sized to accommodate a range of battery rack sizes).

CAUTION

Anchoring a rack to both the floor and the wall may cause stress due to conflicting modes of vibration.

5.5 Ventilation

The battery area shall be ventilated, either by a natural or mechanical ventilation system, to prevent accumulation of hydrogen. The ventilation system should limit hydrogen accumulation to less than 2% of the total volume of the battery area and should be sufficient to prevent the formation of local pockets of hydrogen external to the battery that exceed this limit. The maximum hydrogen evolution rate at standard temperature and pressure[6] is

$$1.27 \times 10^{-7} \times I_{\text{charge}} \times n \ \ \text{m}^3/\text{s}$$

where

I_{charge} is the charge current in amperes

n is the number of cells per battery string

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[6] The phrase “standard temperature and pressure” in this recommended practice is defined as referring to the values 0 °C and 101.325 kPa.

The worst-case condition exists when maximum current is forced into a fully charged battery. At a minimum, the above ventilation calculation should be based on the maximum current that will be forced into the battery based on the high-rate charge (see Definition 3.4) or the initial charge (see 6.3).

A battery area that meets the above ventilation requirements should not be considered a classified (hazardous) location; thus, special electrical equipment enclosures to prevent fire or explosion should not be necessary.

5.6 Instrumentation and alarms

The following general recommendations for instrumentation and alarms apply to the battery installation only. Requirements for the charger, dc system design, and so on, are beyond the scope of this recommended practice.

Each battery installation should include the following instrumentation and alarms:

a) Voltmeter
b) High- and low-battery-voltage alarm
c) Ground detector (for ungrounded systems)
d) Ammeter

6. Installation procedures

6.1 General

See Clause 4 for safety precautions.

6.2 Receiving and storage

6.2.1 Receiving inspection

Upon receipt, and at the time of actual unloading, each package should be inspected visually for apparent damage and electrolyte leakage. If either damage or leakage is evident, a more detailed inspection of the entire shipment should be conducted, and results should be noted on the bill of lading. Cell repair or replacement should be instituted as required. Record receipt date and inspection data.

6.2.2 Unpacking

a) When lifting cells, a strap and strap spreader should be used, as applicable.
b) If the cells are supplied filled, check electrolyte levels for evidence of leakage and to ensure that the plates are covered. Electrolyte should be added to any cell in which the electrolyte level is below the top of the plates.
c) If the cells are supplied unfilled, do not remove the plastic transportation seals until the cells are to be filled.
d) All cells with visible defects such as cracked jars, loose terminal posts, or improperly aligned plates should be repaired or replaced.

6.2.3 Storage

Cells should be stored indoors in a clean, level, dry, and cool location; localized sources of heat should be avoided. In most cases, a period of at least 12 months storage is allowable. Contact the battery manufacturer for specific instructions for longer storage periods.

6.3 Assembly

6.3.1 Rack assembly

The assembly of the rack should be in accordance with the manufacturer’s recommended procedure.

6.3.2 Cell mounting and connections

The following sequence should be used:

a) If cells are supplied unfilled, they should be filled in accordance with the manufacturer’s recommendations before mounting on the rack.

b) Lift the individual cells onto the rack following the procedures outlined in 6.2.2, step a). Mount the cells in accordance with the manufacturer’s recommendations. Do not apply lubricant on rack rails unless approved by the manufacturer.

c) Where necessary, remove transport seals and ensure that flame-arrester vents are properly installed.

d) Check the cell polarity for positive-to-negative connections throughout the battery.

e) If potassium carbonate crystals (gray-white deposits) have formed on the top of a cell, remove the deposits with a soft brush and rinse the cell with water.

f) Ensure that the terminal post and intercell connector contact surfaces are clean, and then apply a thin film of corrosion-inhibiting compound to all contact surfaces.

g) Make intercell connections using manufacturer-approved connectors (normally furnished with the battery). All cable connectors should be prechecked to ensure that their lug-to-lug resistance is acceptable for the expected discharge current. This should be done with a digital low-resistance ohmmeter.

h) Tighten connections to battery manufacturer’s recommended torque value. If routine intercell connection resistance readings will be performed (see 7.2.3), take baseline readings at this point. Consult the manufacturer of the battery and/or test equipment for details.

i) Clean all cell covers and containers. Use a water-moistened clean wipe to remove dust and dirt. Avoid the use of hydrocarbon-type cleaning agents (oil distillates), which may cause plastic containers and covers to crack or craze.

j) Read the voltage of the battery to ensure that individual cells are connected correctly; i.e., the total voltage should be approximately equal to the number of cells times the measured voltage of one cell. If the measurement is less, recheck the individual cell polarities.

k) For future identification, apply individual cell numbers starting at one of the main battery terminals and following the connection sequence through to the other main battery terminal; also add any required operating identification.

l) When 6.3.2, step a) through step k), have been satisfactorily completed, make final connections from the battery to the charger and dc system.

6.4 Initial charge

An initial charge should be applied after installation. Filled and charged nickel-cadmium cells require recharging to compensate for self-discharge losses during shipment and storage. Cells shipped in a discharged condition have to be given a complete charge.

Typically, the initial charge consists of the following procedures:

a) Inspect all cells to ensure that the electrolyte level is between the high-level and the low-level lines.

b) Follow the manufacturer's recommendations for applying an initial charge. If the charge voltage exceeds the system voltage limit, perform the initial charge off-line from the dc system.

c) Upon completion of the initial charge, return the charger to float voltage.

d) At the end of 72 hours, read and record all individual cell voltages, and the electrolyte temperatures of every tenth cell [see 7.3.1, item c) for corrective action and Clause 11 for records].

e) Add distilled or other approved-quality water to bring the electrolyte level of all cells up to the high-level line.

WARNING

The initial charge may cause a significant amount of hydrogen to be generated. Ensure that the room is ventilated in accordance with 5.5 using the maximum current possible for this activity.

7. Maintenance

7.1 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 also serve as a valuable aid in determining the need for battery replacement. Battery maintenance shall be performed by personnel knowledgeable about nickel-cadmium batteries and the safety precautions involved.

7.2 Inspections

7.2.1 General

All inspections should be made under normal float conditions. Refer to the annexes for more information. Inspection of the battery should be performed on a regularly scheduled basis (at least once per quarter). The interval should be selected depending on site conditions, charging equipment, and monitoring devices providing remote indications of abnormal operations. This inspection should include checking and recording the following:

a) Float voltage measured at the battery terminals

b) General appearance and cleanliness of the battery, the battery rack, and the battery rack area

c) Charger output current and voltage

d) Electrolyte levels

e) Cracks in cells or leakage of electrolyte

f) Any evidence of corrosion at terminals, connectors, or rack

g) Adequacy of ventilation

h) Pilot-cell electrolyte temperature

7.2.2 Semiannually

At least once every six months a general inspection should be augmented by checking and recording the voltage of each cell.

7.2.3 Yearly

At least once each year a semiannual inspection should be augmented by checking and recording the following:

a) Integrity of the battery rack
b) Intercell connection torque
c) Condition and resistance of cable connections [see 6.3.2, item g)]

Intercell connection torque should be checked at least once after the initial installation. In vibration-free environments, subsequent checks may be performed in accordance with the manufacturer's recommendations. Intercell connection resistance readings may be substituted for connection torque checks, if the cell design allows. Consult the manufacturer of the battery and/or test equipment for details.

7.2.4 Special inspections

If the battery has experienced an abnormal condition (e.g., a severe discharge or severe overcharge), an inspection should be made to ensure that the battery has not been damaged. Include the requirements of 7.2.1 and 7.2.2.

7.3 Corrective actions

7.3.1 Conditions requiring correction

The following items indicate conditions that should be corrected before the next general 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 all cells to the high-level line. Water quality should be in accordance with the manufacturer's instructions.
b) When the float voltage, measured at the battery terminals, is outside of its recommended operating range, the charger voltage should be adjusted.
c) If the voltage of an individual cell in a floating battery is found to be below the minimum limit (see C.1), apply a high-rate charge. Applying the high-rate charge to the individual cell concerned is generally more effective.
d) When corrosion, excessive dirt, or potassium carbonate (gray-white deposits) are noted on cells or connectors, wipe the cells with a wet cloth, wipe dry, and then coat metal parts with corrosion inhibitor as recommended by the manufacturer. Avoid the use of hydrocarbon-type cleaning agents (oil distillates), which may cause containers and covers to crack or craze.
e) When a bolted connection is found loose (more than half a turn to reach full torque), disassemble, clean, reassemble, and retorque the connection. The reassembly should be made using corrosion inhibitor and following the instructions of the manufacturer.

See Annex C for a more detailed discussion of these abnormalities and the urgency of corrective actions.

7.3.2 Other abnormalities

Correct and document any other abnormal conditions noted.

8. Test schedule

8.1 General

The following schedule of tests 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, as found, is within acceptable limits.

c) Determine, if required, whether the battery, as found, meets the design requirements of the system to which it is connected.

8.2 Acceptance

8.2.1 General

An acceptance test of the battery capacity (see 9.5) should be made, as determined by the user, either at the factory or in the field after installation.

8.2.2 Factory acceptance test

Factory acceptance tests should be performed in accordance with IEC 60623 [B1]. This standard is used by most nickel-cadmium battery manufacturers to demonstrate compliance with factory standards and specifications. The results of such a test are not appropriate as a baseline for future capacity tests. See Annex G for an outline of the IEC capacity test.

In nickel-cadmium batteries, approximately 12 weeks is needed after a previous discharge for the "float effect" to reach its full extent (see Annex D). Therefore, results of capacity tests that are carried out after less than 12 weeks has elapsed will not be representative of normal operation with prolonged float charging. This condition makes performing a factory acceptance test that accurately reflects operation in float charging mode impractical.

8.2.3 Field acceptance test

Acceptance tests may be carried out in the field, preferably after the battery has been on float charge for at least 12 weeks without discharging. Although a field acceptance test carried out after less than 12 weeks on float charge will confirm that a battery has adequate capacity, the acceptance test results cannot easily be compared with future performance test results because of the float effect (see Annex D for further discussion). Field tests should be made at a specific discharge rate and for a duration relating to the manufacturer's rating or to the purchase specification's requirements. For a stationary standby application, published data based on prolonged constant-potential charging should be used (see 9.3.2).

If a field acceptance test is used to verify conformance to the manufacturer's published data, the rate adjustment method of 9.4.2 should be used, except the rate should not be adjusted for the end-of-life condition, i.e., at the full published rate adjusted for temperature only. If the test is to establish a baseline for future testing, all requirements of 9.4.2 should be observed, and the battery preferably should have been on float charge for at least 12 weeks without discharging.

8.3 Performance

Performance testing should be carried out as follows:

a) A performance test of battery capacity (see 9.5) should be made within the first two years of service. For comparison purposes, having the performance test be similar in duration to the battery duty cycle is desirable.

b) Additional performance tests should be made at five-year intervals until the battery shows signs of excessive capacity loss. Excessive capacity loss is indicated when the battery capacity drops more than an average of 1.5% per year of rated capacity from its capacity on the previous performance test.

c) Annual performance tests of battery capacity should be made on any battery that shows signs of excessive capacity loss.

d) If performance testing is to be used to reflect baseline capacity of the battery, then perform 9.2, step a) through step g). If performance testing is to be used to reflect maintenance practices as well as trending, then omit 9.2, step a) and step b); perform 9.2, step c) but take no corrective action; and perform 9.2, step d) through step g). 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 9.2, step a) through step c), have been completed.

8.4 Service

A service test of battery capability (see 9.6) may be required by the user to meet a specific application requirement upon completion of the installation, and periodically thereafter. This is a test of the battery's ability, as found, to satisfy the battery duty cycle. When a service test is being used on a regular basis, it will reflect maintenance practices. If the system design changes, sizing will have to be reviewed, and the service test may have to be repeated.

8.5 Modified performance

A modified performance test is a test of the battery capacity and its ability to provide a high-rate, short-duration load (usually the highest rate of the duty cycle). This test will often confirm the battery's ability to meet the critical period of the load duty cycle, in addition to determining its percentage of rated capacity. Initial conditions for the modified performance test should be identical to those specified for the service test. A modified performance test can be used in lieu of a service test or performance test at any time. A full discussion of modified performance tests is included in IEEE Std 450™-2002 [B3].

A modified performance test may be performed if the test's discharge rate envelopes the duty cycle of the 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. The acceptance criteria for this test should be determined by the system design. Typically this test is a simulated duty cycle consisting of just two rates: a short-duration, high rate as published for the battery, or the largest current load of the duty cycle, followed by the test rate employed for the performance test. If the ampere-hours removed by the high-rate discharge represent a very small portion of the battery's capacity, the test rate can be changed to that rate for the performance test without compromising the results of the performance test.

9. Procedure for battery tests

9.1 General

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

9.2 Initial conditions

For an accurate representation of the battery's capability in float service, having the battery on float charge for at least 12 weeks since its last discharge is desirable. See Annex D for details.

The initial procedures for all battery tests, except as otherwise noted, are as follows:

a) Verify that the battery has had a high-rate charge completed more than 1 day and less than 30 days before the start of the test.

b) Check all battery connections to make sure that they are correctly torqued, or that the connection resistance is within range (see 7.2.3). Check all connections for corrosion, and correct if there is evidence that the connection integrity has been compromised.

c) Read and record the float voltage of each cell just before the test. Take action as necessary to correct any low-voltage cells (see C.1).

d) Read and record the temperature of the battery electrolyte to determine an average temperature (every tenth cell is suggested).

e) Read and record the battery terminal float voltage.

f) Disconnect the charger from the battery.

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

9.3 Test length and discharge rate

9.3.1 Test length

Field 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.

a) Procedures for field acceptance and performance tests are described in 9.5, and the duration is recommended to be approximately the same as the duty cycle. For trending purposes, the same test length should be used throughout the battery's life. 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. However, the results of these tests can be used to compare battery capacity to manufacturer's data. These results would also be used to predict the end of battery life.

b) Procedures for the modified performance test are described in 9.5, and the recommended duration is the duty cycle duration multiplied by the aging factor used in sizing the battery.

c) See 9.6 for determining the length of a service test.

9.3.2 Test discharge rate

The discharge rate depends on the type of test selected. For the field 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. The charging method used as a basis for published data is an important factor. For a stationary float application, data based on prolonged constant-potential charging should be used. If constant-current charging has been used to establish the published data, appropriate float-charging correction factors should be obtained from the manufacturer. See 9.4 for information on determining the discharge rate for capacity tests.

9.4 Capacity test methods

9.4.1 General

Two basic methods for capacity testing are described. The recommended method is the rate adjustment method in 9.4.2, which gives accurate results for all test lengths. The time adjustment method in 9.4.3 was the basis for capacity tests in previous versions of this document. The time adjustment method should be used only for tests of longer duration. The applicability of this alternative method for a particular test length varies according to the cell design and end-of-discharge voltage. Consult with the manufacturer for the applicability of this method.

9.4.2 Rate-adjusted tests

9.4.2.1 Rate-adjustment methods

This method is recommended for performance and acceptance tests. See Annex F for a discussion on the rate adjustment and alternative methods. Battery capacity for the rate adjustment method is determined in accordance with 9.4.2.2.

When testing a relatively new battery using this method, the actual test time may be considerably longer than the nominal time. For trending purposes having the test always run to the final voltage is important [see 9.5, item c)].

For test times of longer than one hour, perform the test at the full published rate. The test rate is not adjusted before the test except in the case of extremely low temperatures (<10 °C). For lower temperatures, adjust the discharge rate for the initial battery temperature as described in the following paragraph.

For test times of one hour or less, the published rating for the selected test length is 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 1115) or, if this is not known, on the accepted end-of-life capacity for the battery. In no case 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. The final test discharge rate is equal to the calculated discharge rate (after adjusting for the end-of-life condition) divided by the temperature correction factor for the initial electrolyte temperature. Above 25 °C there is no meaningful increase in capacity. Consult the manufacturer for correction factors for the battery to be tested. Also refer to A.4.

9.4.2.2 Rate-adjusted capacity calculation

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

$$\%\text{ capacity at }25^{\circ}\text{C} = \frac{X_a \times K_c}{X_t} + 100$$

where

X_a	is the actual rate used for the test
X_t	is the published rating for time t
t	is the time of test to specified terminal voltage [see 9.5, step d)]
K_c	is the temperature correction factor

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

9.4.3 Time-adjusted tests

9.4.3.1 Time-adjusted method

This method is used for tests of longer duration only. Consult with the manufacturer for applicability and refer to 9.4 and Annex F for additional discussion.

When using this method, no correction is applied for the initial temperature or end-of-life capacity. The test rate is the full published rate for the time and end-of-discharge voltage chosen. The temperature correction factor (K_c) used in the capacity calculation of 9.4.3.2 is the same as in 9.4.2.2. This rate correction factor technically should not be applied to the discharge time, but limiting this method to tests where the initial battery temperature is greater than or equal to 10 °C minimizes any errors that might result. Above 25 °C there is no meaningful increase in capacity. Consult the manufacturer for correction factors for the battery to be tested. Also refer to A.4.

9.4.3.2 Time-adjusted capacity calculation

The following equation is used to calculate the battery capacity for a time-adjusted test:

$$\%\text{ capacity at }25^{\circ}\text{C} = \frac{t_a \times K_c}{t_s} + 100$$

where

t_a	is the actual time of test to specified terminal voltage
t_s	is the rated time to specified terminal voltage
K_c	is the temperature correction factor (see 9.4.3.1)

9.5 Capacity test procedures

Perform the following procedures for field acceptance, performance, and modified performance tests:

a) Set up a load and the necessary instrumentation to maintain the test discharge rate determined in 9.4.

b) Disconnect the charging source, connect the load 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 has to be increased to compensate for the current being supplied by the charging source to the battery.

c) Read and record the individual cell voltages and the battery terminal voltage. The readings should be taken while the load is applied at the beginning and at the completion of the test, and at specified intervals. There should be a minimum of three sets of readings. Individual cell voltage readings should be taken between respective posts of like polarity of adjacent cells, so as to include the voltage drop of the intercell connectors.

d) Maintain the discharge rate, and record the elapsed time at the point when the battery terminal voltage decreases to a value equal to the minimum average voltage per cell as specified by the design of the installation (e.g., 1.10 V) times the number of cells per string. If the battery does not pass the normal criteria for capacity testing, additional data may be beneficial for evaluation or for determining corrective action. If installation conditions permit, the testing should be continued to the original test time or a lower final voltage (e.g., 95% of the specified minimum) to acquire this information. Nickel-cadmium cells are generally not damaged as a result of cell reversal, so no provisions are required for bypassing weak cells.

e) If one or more cells are approaching reversal of their polarity (0.5 V or less), and the test is at 90–95% of the expected completion time, continue the test until the specified terminal voltage is reached.

f) If earlier in the test one or more cells are approaching reversal of their polarity, the test may be continued so as to determine the capacity of the remainder of the battery. Bypassing of cells is not recommended. Because the reversed cell(s) will be making a negative contribution to the overall battery voltage, adjust the minimum terminal voltage to compensate. The new minimum terminal voltage will be the minimum cell voltage multiplied by the number of non-reversed cells, plus the negative voltage of the reversed cell(s). If a modified performance test is being performed in lieu of a service test, the minimum terminal voltage should not be recalculated.

   For example, a 95-cell battery is being tested to a minimum terminal voltage of 105 V (1.10 V per cell). During the discharge, two weak cells go into reversal and stabilize at –0.30 V The new minimum terminal voltage is 93 cells × 1.10 V/cell – (2 × 0.3) = 101.7 V.

g) Observe the battery for abnormal intercell connector heating.

h) At the conclusion of the test, determine the battery capacity according to the procedure outlined in 9.4.

9.6 Service test

A service test is a special battery test that may be required to determine whether the battery will meet the battery duty cycle (see 8.4). The system designer should establish the test procedure and acceptance criteria before the test. The battery should be tested in its “as found” condition, and the test discharge rate should not be corrected for temperature or age. If the battery was sized in accordance with IEEE Std 1115, the margins added for temperature, 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 load cycle will provide the user with a means of predicting when the battery will no longer meet the duty cycle. If the system design changes, sizing (IEEE Std 1115) has to be reviewed, and the service test will have to be 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 should be as identified in 9.2, except that step a) and step b) should be omitted; perform step c) but take no corrective action.

b) The discharge rates 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 whether it is properly sized. High-rate charge the battery, inspect it as discussed in 7.2, take necessary corrective action, and repeat the service test. A battery performance test (see 8.3) may also be required to determine whether the problem is with the battery or the application.

9.7 Restoration

Disconnect all test apparatus. High-rate charge the battery and return it to normal service.

10. Replacement criteria

The timing of battery replacement is a function of the sizing criteria used and the capacity margin available, compared with the load requirements (see Annex E). Whenever replacement is required, the recommended maximum time for replacement is one year. Other factors, such as unsatisfactory battery service test results (see 8.4), require battery replacement, unless a satisfactory service test can be obtained following corrective actions.

Replacement cells, if used, should be compatible with existing cells and should be tested before installation. Replacement cells are not usually recommended as the battery nears the end of its life.

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

11. 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 Clause 6 should be recorded at the time of receiving and installation and as specified in 7.2 during each inspection. Records should also contain reports on corrective actions (see 7.3) and on tests indicating discharge rates, their duration, and results.

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

12. Reapplication and recycling

12.1 General

All batteries have a useful life and eventually have to be either repaired or recycled. The constituents of the nickel-cadmium cell, such as the corrosive potassium hydroxide electrolyte and the toxic cadmium metal, are hazardous. Therefore, a nickel-cadmium battery that is not of any use or value should be recycled in a proper fashion.

12.2 Reapplication

Nickel-cadmium batteries retain their ability for service, albeit at a lower capacity level, for many years (see Annex E). Therefore, when nickel-cadmium batteries reach the end-of-service life in a particular application, they may be used in another application whose requirements are met by the lower capacity. Pocket-plate batteries may require replacement of the electrolyte at this time.

12.3 Recycling

Nickel-cadmium batteries that cannot be reapplied must be recycled. Seek advice from the battery manufacturer on how to proceed with battery recycling. All applicable governmental regulations should be followed.

Annex A

(informative)

Nickel-cadmium battery

A.1 Construction

The nickel-positive active materials and the cadmium-negative active materials are firmly contained in plates of alternate polarity, insulated by separators, and formed into plate groups. Plate groups are assembled into cells with either plastic or steel containers. One or more cells connected together constitute a battery.

A.2 Electrolyte

Nickel-cadmium battery electrolyte is an aqueous solution of potassium hydroxide (KOH). Lithium hydroxide is sometimes added. The alkaline electrolyte does not enter into the electrochemical charge/discharge reactions; it merely acts as an ionic conductor. Consequently, the specific gravity does not change significantly with the state of charge of the cell.

Specific gravity readings are not required as part of the normal maintenance routine for nickel-cadmium batteries.

The nominal specific gravity of electrolyte furnished by the manufacturers may vary slightly (1.180–1.210). The specific gravity also varies with temperature and electrolyte level. Each manufacturer publishes specific gravity correction factors for temperature.

In most stationary battery applications, the electrolyte will retain its effectiveness for the life of the battery. However, under special battery service conditions, such as high temperature or frequent cycling, potassium carbonate buildup in the electrolyte may reach a level that will influence battery performance. If the electrolyte is found to be carbonated (using the manufacturer’s test kit), battery performance can be improved by replacing the electrolyte.

A.3 Charging voltage

The nominal voltage for the nickel-cadmium cell is 1.2 V per cell. The manufacturers of nickel-cadmium batteries provide charging recommendations for each battery type. These recommendations typically fall within the following ranges:

1.40 V to 1.47 V per cell: Float voltage per cell. Charged batteries will be maintained in a charged condition with low water consumption.

1.45 V to 1.55 V per cell: High-rate charge voltage per cell. A practical voltage to be used in recharging a partially or fully discharged battery without exceeding system limitations.

1.56 V to 1.74 V per cell: Maximum high-rate charge voltage per cell for most rapid recharge of a partially or fully discharged battery. This voltage should be used for all installations where the connected equipment is not affected by the resultant high overall voltage or where voltage-sensitive equipment can be either disconnected during recharge, or isolated by a voltage-regulating device. Do not exceed system voltage limits.

NOTE—Continuous high-rate charging is not recommended because of high water consumption.

A.4 Temperature

Nickel-cadmium batteries can operate over a temperature range of –55 °C to +60 °C; however, the typical operating range is –20 °C to +45 °C. At temperatures lower than +20 °C, the battery's capacity is reduced. High-density electrolyte is required for operation at temperatures below –20 °C. The typical high-temperature operating limit is +45 °C, but the battery will operate if subjected to intermittent higher temperatures of up to +60 °C. At temperatures higher than +25 °C, there is no meaningful increase in capacity, but the life may be shortened. The rule of thumb for high-temperature operation is that the life of a nickel-cadmium battery is reduced 20% for each 10 °C increase in the average operating temperature above 25 °C.

For battery testing purposes, the temperature correction factor for +20 °C to +45 °C is 1.0. The reduction in capacity below 20 °C depends on the plate design and discharge rate. Contact the manufacturer for specific values.

Annex B

(informative)

State of charge determination and charging

A nickel-cadmium battery maintained at the recommended float voltage will remain in a charged condition subject to the limitations described in Annex D. When the battery's state of charge is in question because of a recent discharge, the following procedure may be used to ensure that the battery is in a high state of charge. This procedure presupposes that the battery charger is a two-rate (float and high-rate), constant-potential type, with sufficient current capacity to carry both the connected loads and the charging current required by the battery.

With the battery on float charge:

a) Read and record the current output of the charger in amperes. (This value may include the connected dc load plus battery charging current.)
b) Read and record the voltage at the battery terminals.
c) Note the time when step a) and step b) were performed.

Place the charger in the high-rate charge mode:

d) Read and record the current output of the charger [at least momentarily this value will be significantly higher than noted in step a)].
e) Read and record the voltage at the battery terminals. Continue the high-rate charge until the voltage reaches the high-rate maximum voltage previously established for the system. The state of charge may then be determined as follows:
    1) If the high-rate charge voltage is reached in less than 1 min and the current output from the charger drops to approximately the float current found in step a), the battery is charged.
    2) If the high-rate charge voltage is not reached rapidly, this condition indicates that the charger is in current limit and that the battery is in need of a charge.
    3) If the charge current is unaccountably greater than the charge current output found in step a), the battery is in need of a charge.

Continue the high-rate charge, if required, until such time as the charge current is essentially the same as the current recorded in step a); normally no longer than 72 hours are required. At completion of high-rate charging, return the charger to float voltage.

Annex C

(informative)

Corrective actions

C.1 Low-voltage cell

If the voltage of an individual cell in a floating battery is found to be below the minimum limit, apply a high-rate charge. Applying the high-rate charge to the individual cell concerned is generally more effective.

The minimum limit is typically 1.35 V but can vary according to the cell design. For example, some manufacturers of cells with sintered positive plates and plastic-bonded negatives specify 1.32 V as the minimum limit. Consult the battery manufacturer for the appropriate voltage limit.

C.2 Water consumption

Unusual water consumption is an indication of excessive charge voltage. When adding water becomes necessary, fill all cells to the maximum level with distilled or other approved-quality water. Check the charger voltage setting at the battery terminals.

If the level of electrolyte has dropped so low as to expose plates, add water immediately. If visual inspection shows no evidence of leakage, then charge the battery and test it in accordance with the manufacturer’s recommendations.

C.3 Low-voltage battery

If the total battery float voltage is found to be less than the manufacturer’s recommended minimum value, the battery is not being charged properly. At 1.30 V per cell, the battery is in a discharging state. Follow the instructions in Annex B to determine the state of charge and take corrective action.

Annex D

(informative)

Effect of prolonged float charging on battery capacity

Nickel cadmium batteries experience a “float effect”—a lowering of the average discharge voltage-during long-term float operation. This effect starts to set in as soon as the charge input exceeds the level required to reach a fully charged state, and it reaches its full effect after about three months of float operation. This effect is an inevitable consequence of float charging in which the long-term overcharge causes the nickel hydrate-positive active material to gradually change its crystalline structure. This phenomenon is normal, but it can reduce the available capacity to a specified end-of-discharge voltage.

Battery manufacturers account for the float effect in their cell performance specifications with a derating factor or separate specifications (non-float corrected and float corrected). Cell performance specifications that are designated as the capacity “after prolonged float charging” have accounted for the float effect. Cell performance specifications that are designated as the “fully charged” or “IEC 60623” [B1] capacity have not accounted for the float effect. Figure D.1 shows the effect of prolonged float charging on a medium-rate cell discharged at $0.1C_5$ (10 A per 100 Ah of rated capacity).[7] The curves show that float charging actually generates a higher capacity, but that the average voltage on discharge is reduced.

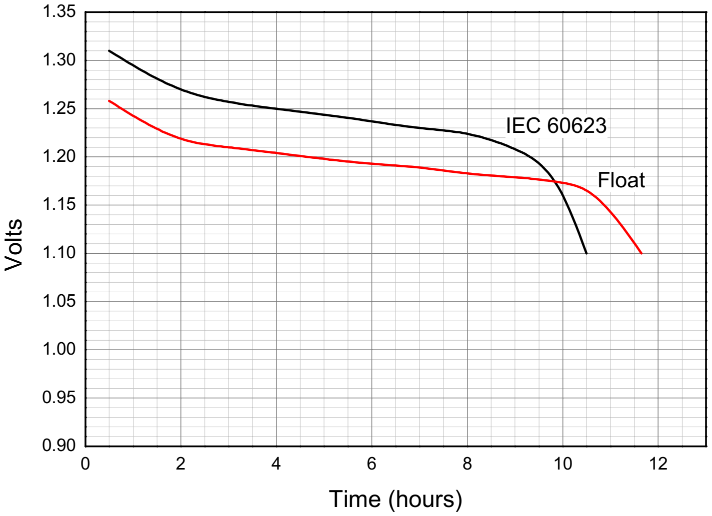

Figure D.1—Medium-performance cells discharged at $0.1C_5$

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[7] By convention in the nickel-cadmium battery industry, charge and discharge currents are often expressed as multiples of the rated ampere-hour capacity. C_5 is a current that is numerically equivalent to the rated capacity at the 5-hour rate.

For such long discharges, the “knee” of the discharge curve is well above the end-of-discharge voltage. However, when the discharge rate is increased the knee of the curve may be reduced below the end-of-discharge voltage and the available capacity may be reduced. This condition is shown in Figure D.2, which shows the same medium-rate cell discharged at $0.5C_5$ (50 A per 100 Ah of rated capacity).

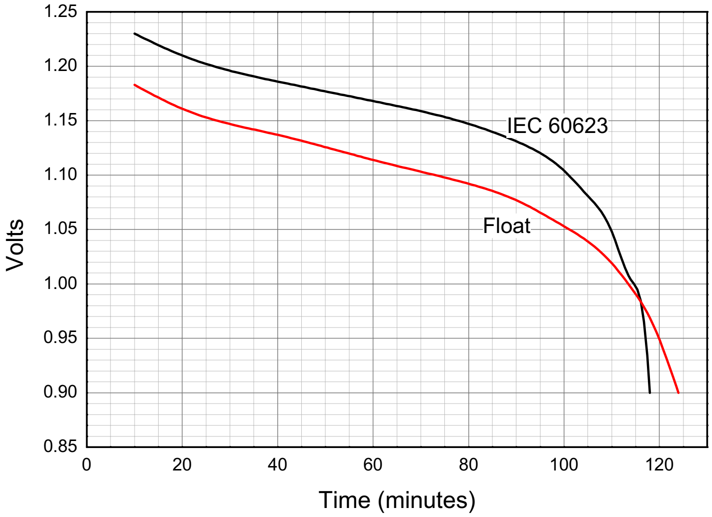


Figure D.2—Medium-performance cells discharged at $0.5C_5$

The increased capacity due to float charging can still be observed, but the crossover point between the two curves is below 1.0 V; so the extra capacity cannot be realized at this rate. At most typical end-of-discharge voltages, the available capacity is reduced. For an end-of-discharge voltage of 1.10 V/cell, for example, the discharge time is reduced from about 101 minutes to 75 minutes.

With regard to battery capacity testing, the float effect should be considered as follows:

a) A capacity test should be based on the appropriate cell performance specifications, depending on whether the float effect has had time to develop.

b) Factory acceptance testing should be based on non-float-corrected cell performance specifications because the float effect will not yet be present (see 8.2.2).

c) Although a field acceptance test carried out after less than 12 weeks on float charge (see 8.2.3) will confirm that a battery has adequate capacity, the acceptance test results cannot easily be compared to future performance test results because of the float effect. For this reason, completing the first field performance test after 12 weeks on float charge to provide a separate baseline for subsequent trending is recommended.

Discharging a battery tends to remove the float effect. The degree to which the float effect is removed depends on the depth of discharge. The active material that is converted to nickel hydroxide during discharge will have the float effect temporarily removed, and the active material that has not converted will still have the float effect. Upon recharge, the float effect again fully returns over the next few weeks or months, depending on the amount of active material converted during the discharge. For this reason, a performance test should not be conducted for some period of time after the battery has been discharged and subsequently recharged; the battery could perform better than would really be expected for prolonged float charging. Furthermore, there is no practical method of scaling between float-corrected and non-float-corrected data.

Annex E

(informative)

Typical aging characteristics and end-of-life criteria of nickel-cadmium batteries

Figure E.1 shows typical capacity degradation over time for a nickel-cadmium battery operated at 20 °C to 25 °C. The graph shows quite linear degradation of about 1% loss of capacity over most of the battery life, with no sudden drop at the end of life. This condition means that there is no defined point at which a nickel-cadmium battery should be replaced.

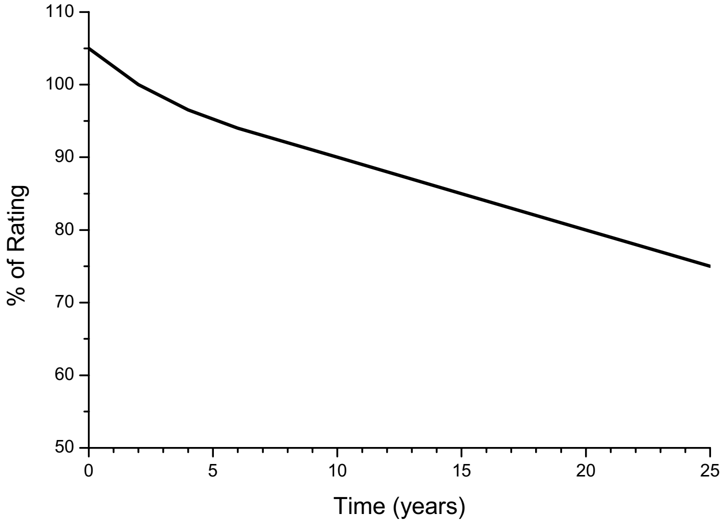


Figure E.1—Typical nickel-cadmium aging at 20 °C to 25 °C

Clause 10 provides guidance on replacement criteria. In many cases, replacement is based on application-specific parameters, such as cranking time in an engine starting duty or reserve time at normal load in a telecommunications application. Under such circumstances, discharge test data may not be interpreted based on sizing calculations or set percentage criteria as discussed in Annex F, but simply on the continued ability of the battery to support the load as it currently exists.

When a nickel-cadmium battery is no longer capable of supporting its connected loads as required, it may be reapplied in another duty (see 12.1).

Depending on battery design and charging parameters, the available capacity of a nickel-cadmium battery may be reduced when it is subjected to repetitive deep discharges. This capacity loss is temporary. Capacity can be recovered to its original level by applying a reconditioning charge as recommended by the battery manufacturer.

Annex F

(informative)

Comparison of capacity testing methods

F.1 General

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 whether the battery requires replacement (see Clause 10). Subclause 9.4 describes two methods for calculating capacity, and the purpose of this annex is to discuss their applicability and to provide example calculations.

F.2 Comparison of time- and rate-adjusted performance test methods

Clause 10 provides criteria for battery replacement. Although there is no fixed capacity at which a nickel-cadmium battery should be replaced (see Annex E), the following discussion will be based on an end-of-life condition at 80% of rated capacity. 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 300 minutes, the end-of-life capability will be 80 A for 300 minutes. This is the basis of the rate-adjusted performance test method.

As demonstrated in F.3, a calculation of battery capacity using the rate-adjusted method can be somewhat complex. However, because the rate-adjusted method gives correct results for all test times, it is the basis for this recommended practice. For longer test times, using the simpler time-adjusted method that was included in earlier versions of this recommended practice may be possible. In the time-adjusted method, the capacity is calculated using 100% of published current. Thus, a cell rated at 100 A for 300 minutes would have an end-of-life capability of 100 A for 300 min × 0.8 = 240 min. The calculation of capacity is a simple ratio of the test time to the published time (ignoring temperature adjustments).

The time-adjusted method, however, does not take into account changes in battery efficiency with discharge time. Data from a hypothetical medium-rate cell will be used to illustrate this point. Table F.1 shows the float-corrected performance of the KM438P cell type from the ABC Company, based on an end-of-discharge voltage of 1.10 V/cell. These data are plotted in Figure F.1.

Table F.1—KM438P cell performance to 1.10 V/cell after prolonged float charging

Cell type	Rated Ah	Discharge current (A)									
		1 s	60 s	15 min	30 min	60 min	90 min	120 min	180 min	300 min	480 min
KM438P	438	1041	743	396	315	246	198	164	127	85	54

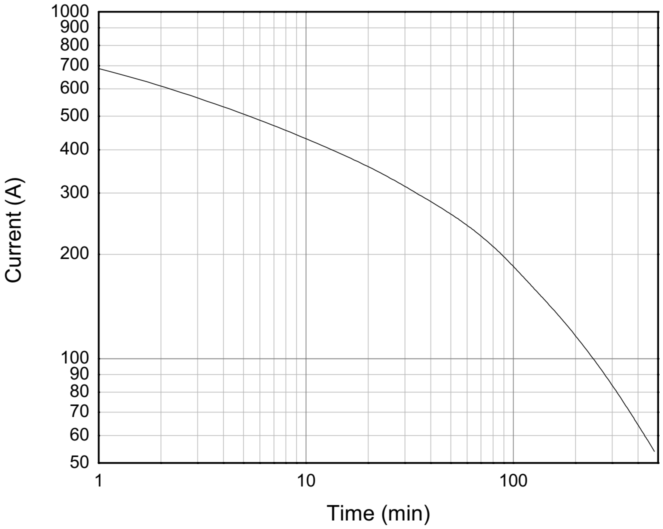


Figure F.1—Graph of KM438P performance from Table F.1

For an 8-hour discharge, the cell rating is 54 × 8 = 432 Ah. The 80% point in a time-adjusted test corresponds to 6.4 hours (80% of 8 hours). An analysis of the graph shows that in a 6.4-hour discharge (or 384 minutes), a new battery gives about 66.7 A, for a discharged capacity of 427 Ah or 99% of its 8-hour capacity. This 1% reduction is due to a loss of battery efficiency at the shorter discharge time. The loss of efficiency is expected to be approximately the same for a battery at end-of-design life (80%). Thus, when a KM438P battery is discharged at the 8-hour rate of 54 A, and gives 6.4 hours, almost all of the shortfall is due to battery degradation.

This performance is not the case as the discharge time becomes shorter. For a 30-minute test, for example, the 80% point by the time-adjusted method would be 24 minutes. However, a rate-adjusted capacity calculation for the same discharge (see F.3.3) shows that the actual capacity at this point is 94%. The 14% difference between the two calculations is simply due to the lower efficiency of the battery at the 24-minute rate.

As the loss of capacity in a nickel-cadmium battery operating under moderate temperature conditions averages around 1% per year, the use of the time-adjusted method in the example of an 8-hour test above would mean that the battery would be replaced one year sooner than necessary. For the 30-minute example, the 14% loss in efficiency at 24 minutes would result in the battery being replaced 14 years earlier than necessary when the time-adjusted method is used.

The assumption is that 1% capacity differential, or one year, is the upper limit to the degree of conservatism for battery replacement. On this basis, the lower time limit for the applicability of the time-adjusted method corresponds to the point at which the available capacity at 80% of a desired test time falls below 99% of the capacity available at the full test time. In the example above, the lower time limit would be 8 hours, but this figure will change by manufacturer, cell type (H, M, or L), and end-of-discharge voltage. The use of the time-adjusted method for high-rate cells discharged to a relatively lo- end voltage, for example, may be valid for test times of 90 minutes or less.

Because of this variability, the rate-adjusted method is used as the basis for this recommended practice. Consult the manufacturer for information on the applicability of the time-adjusted method for specific battery types and conditions.

F.3 Capacity calculation examples

F.3.1 General

Application of the formula for rate-adjusted capacity calculation in 9.4.2.2 requires that a published performance rate be established for the actual test time *t*. Simple interpolation between published rates for different times does not yield correct results. Instead, it is best to interpolate on the basis of capacity figures calculated from the published rates.

Based on the actual test time *t*, two published data points are chosen for times t_1 and t_2, which bracket time *t*. The published rate for time *t* is as follows:

$$X_t = \frac{\frac{t - t_1}{t_2 - t_1}(X_2 t_2 - X_1 t_1) + X_1 t_1}{t}$$

where

t	is the actual test time
t_1	is published data point 1
t_2	is published data point 2
X_1	is the published rate for data point 1
X_2	is the published rate for data point 2
X_t	is the published rate for time t

This equation can then be combined with the capacity calculation in 9.4.2.2. Figure F.2 shows how this combination can be done in a spreadsheet program.

F.3.2 Example—30-minute duty

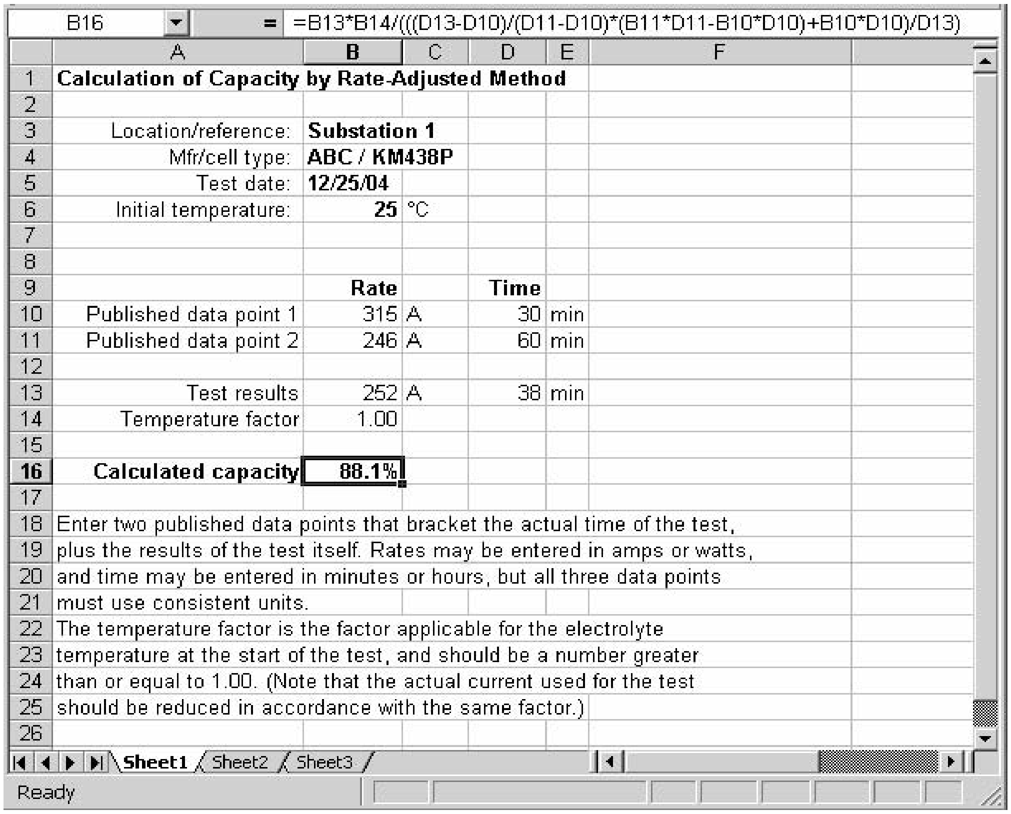
A KM438P battery has been installed for a 30-minute duty. The original sizing included a 1.25 aging factor. The discharge rate for the performance test is therefore 80% of the published 30-minute rate of 315 A, or 252 A. (The test temperature is assumed to be 25 °C, so there is no adjustment for temperature.) After 12 years of operation, the performance test duration is 38 minutes.

The 30- and 60-minute published rates are used for the interpolation, and application of the above formula gives a published rate of 286 A for 38 minutes. The temperature correction factor for 25 °C is 1.00. The calculated capacity is therefore:

$$\frac{252 \times 1.00}{286} \times 100 = 88.1\%$$

This example has been used in the spreadsheet in Figure F.2.

From this example, a test time of 30 minutes will result in a calculated capacity of 80%, because the test rate is 80% of the published 30-minute rate. Therefore, the rate-adjusted performance test method gives results that are exactly in accordance with the sizing parameters.



B16 = =B13*B14/(((D13-D10)/(D11-D10)*(B11*D11-B10*D10)+B10*D10)/D13)

	A	B	C	D	E	F
1	**Calculation of Capacity by Rate-Adjusted Method**					
2						
3	Location/reference:	**Substation 1**				
4	Mfr/cell type:	**ABC / KM438P**				
5	Test date:	**12/25/04**				
6	Initial temperature:	**25**	°C			
7						
8						
9		**Rate**		**Time**		
10	Published data point 1	315	A	30	min	
11	Published data point 2	246	A	60	min	
12						
13	Test results	252	A	38	min	
14	Temperature factor	1.00				
15						
16	**Calculated capacity**	**88.1%**				
17						
18	Enter two published data points that bracket the actual time of the test,					
19	plus the results of the test itself. Rates may be entered in amps or watts,					
20	and time may be entered in minutes or hours, but all three data points					
21	must use consistent units.					
22	The temperature factor is the factor applicable for the electrolyte					
23	temperature at the start of the test, and should be a number greater					
24	than or equal to 1.00. (Note that the actual current used for the test					
25	should be reduced in accordance with the same factor.)					
26						

Figure F.2—Spreadsheet showing rate-adjusted capacity calculation using interpolation method

F.3.3 Interpretation of data from tests carried out at full published rates

Applying 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, is possible. For example, if a test of a KM438P battery at the full 30-minute rate of 315 A yielded a 24-minute test time (for which the published current by interpolation is 335 A), the calculated capacity is

$$\frac{315 \times 1.00}{335} \times 100 \; = \; 94.0\%$$

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 (24 minutes as a percentage of 30 minutes), but most of this apparent capacity shortfall is due to the lower efficiency of the battery at the 24-minute rate. Depending on the design of the cell being tested and the chosen test time, the results of a time-adjusted test may be extremely misleading, as demonstrated in Figure F.3. This graph shows the same published rating curve for the KM438P cell type (from Figure F.1), along with a curve corresponding to 80% of the published ratings. This represents the end-of-life condition if a 1.25 aging margin has been used.

From the 80% curve in Figure F.3, a test of an 80% battery at the published 15-minute rate of 396 A will result in a discharge time of just over 6 minutes. Although this result may seem to indicate a severe battery failure, it is actually a function of the battery’s inherent performance capability and its efficiency for short, high-rate discharges.

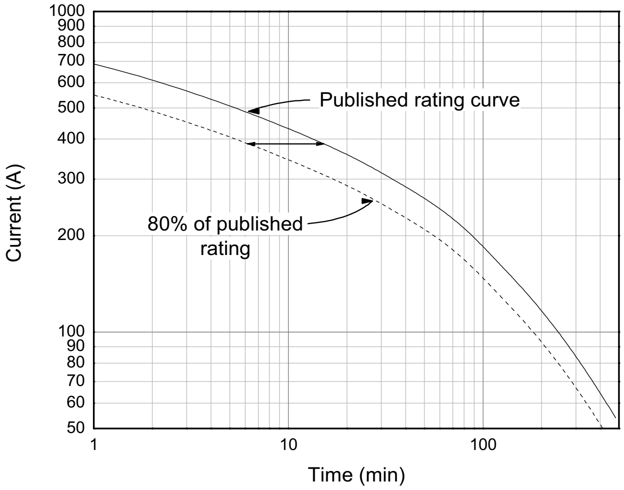


Figure F.3—Comparison of rate- versus time-adjusted end-of-life prediction

F.3.4 Application of rate-adjusted method for other sizing criteria

The preceding examples have assumed that a 1.25 aging factor was used in the sizing calculation (see IEEE Std 1115). The rate-adjusted method can be equally applied for other aging factors used.

Example 1. If an aging factor of 1.11 was used for sizing a battery for a 15-minute duty, the rate used for the rate-adjusted test is 90% of the published 15-minute rate. The battery should be replaced when it 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, and the rate used for the rate-adjusted method is 100% of rating. The battery should be replaced when it can no longer provide this rate for the full published time.

Annex G

(informative)

IEC 60623 test method

As discussed in 8.2.2, factory acceptance tests are performed in accordance with IEC 60623 [B1]. The test procedure in this standard may vary slightly from issue to issue, but it consists essentially of the following elements:

a) A constant-current discharge at $0.2C_5$ (20 A per 100 Ah of rated capacity) to 1.0 V/cell

b) A constant-current charge at $0.2C_5$ for 7 or 8 hours

c) A constant-current discharge at $0.2C_5$ to 1.0 V/cell

These steps are performed at a nominal temperature of 20 °C, and the discharged capacity in step c) forms the basis for the rated capacity of the cell.

Annex H

(informative)

Bibliography

[B1] IEC 60623 (September 2001), Secondary Cells and Batteries Containing Alkaline or Other Non-Acid Electrolytes-Vented Nickel-Cadmium Prismatic Rechargeable Single Cells.[8]

[B2] IEEE 100, *The Authoritative Dictionary of IEEE Standards Terms*, Seventh Edition.[9, 10]

[B3] IEEE Std 450™-2002, IEEE Recommended Practice for Maintenance, Testing, and Replacement of Vented Lead-Acid Batteries for Stationary Applications.

[B4] IEEE Std 693™ -1997, IEEE Recommended Practice for Seismic Design of Substations.

[B5] Illuminating Engineering Society of North America, *Lighting Handbook*, Eighth Edition.

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[8] IEC publications are available from the Sales Department of the International Electrotechnical Commission, Case Postale 131, 3, rue de Varembé, CH-1211, Genève 20, Switzerland/Suisse (http://www.iec.ch/). IEC publications are also available in the United States from the Sales Department, American National Standards Institute, 25 West 43rd Street, 4th Floor, New York, NY 10036, USA (http://www.ansi.org/).

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