XL Risk Consulting

Property Risk Consulting Guidelines

A Publication of AXA XL Risk Consulting

PRC.5.7.4

STATIONARY BATTERIES

INTRODUCTION

Utility stations, substations, industrial complexes and commercial facilities require dc electric power to run various processes and power special equipment. Applications include electric power generation and distribution, communications, process control and data processing. Specifically, dc power is often used to actuate medium and high voltage electrical switchgear, to operate emergency equipment and to provide uninterrupted or standby power supplies (UPS/SPS) for critical processes and computer systems. Rectification of ac power is one method of obtaining dc power. Typically, however, electric batteries provide a reliable power source, one that is independent of the ac system.

An electric battery is a device in which an electro-chemical reaction converts chemical energy to electrical energy. It is also called a storage battery or simply, a battery. The construction and electrical characteristics of a battery are defined by its function. The three major types common to industrial facilities are stationary, automotive and motive batteries.

Automotive and motive batteries are used on mobile equipment. In an engine-driven car or truck, a lead-acid automotive battery provides electric power. A motive battery is typically a lead-acid battery designed to propel an industrial truck, such as an electric lift truck. Automotive, motive and stationary batteries differ in construction features and electrical characteristics.

A stationary battery is designed for use in a permanent location. It is a source of reliable, short term, high power density, high discharge rate, emergency, dc power. It has a long stand life, which means that keeping it in storage for weeks or months before use will not cause significant deterioration. It can be recharged. Most stationary batteries are wet cell, flooded, vented lead-acid batteries. These and nickel-cadmium (Ni-Cad) batteries are the most common types of stationary stored-energy power sources.

This Property Risk Consulting Guideline is intended for use where the reliability of stationary batteries is important to a loss control program. It supplements information in PRC.5.6.1 and applies to typical battery arrangements and uses. It does not apply to on-line battery storage for load leveling in electric utility power systems or “ac battery systems” which are modules containing special dc batteries and inverters.

POSITION

General

Select only stationary batteries with flame-retardant enclosures. For flooded cell units, select units having either flame arresting or catalytic gas recombining type vent caps.

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For electrical coordination studies, determine the maximum short-circuit available current at the battery terminals at 77°F (25°C). The battery manufacturer can provide this information.

Because of the pH of battery electrolytes and their potential to liberate hydrogen, allow only qualified individuals trained in proper procedures using proper tools and protective equipment to install and maintain batteries. Follow the precautions identified in NFPA 70E.

Follow manufacturers' guidelines for battery installation and preventive maintenance (PM). Document, date and maintain acceptance and subsequent test results. Look for trends. Consult other recommended practices and standards, such as IEEE Std 484, IEEE Std 450, IEEE Std 1106 and NFPA 70B, when establishing and updating battery PM programs.

Maximize the reliability of dc control power for electrical switchgear by following the guidance in this Property Risk Consulting Guideline and in PRC.5.6.1. The servicing frequencies identified in this guide are a starting point in setting up a PM program. Site conditions, monitoring devices and battery use may permit modifications.

Design stationary battery areas to meet the conditions identified in this Property Risk Consulting Guideline and in other appropriate codes and standards. The NFPA 70 (NEC), NFPA 850, NFPA 851 and IEEE 484 may be consulted. In general:

- Avoid use of areas:
    - Containing structural pockets in which hydrogen can accumulate.
    - Having inadequate ventilation.
    - Subjecting the installation to vibration from nearby machinery.
    - Where the arrangement will result in electrical unbalance caused by excessive thermal variations between connected cells. For lead-acid batteries, limit ambient temperature differences between cells to 5°F (3°C). For Ni-Cad batteries, limit ambient temperature differences between cells to 9°F (5°C).
    - Having insufficient heat to maintain cell temperatures as appropriate for the type of battery. (Heat should be maintained in battery areas as described later.)
    - Subject to flooding, high humidity and other moisture accumulation (areas that cannot be kept dry).
    - Containing combustible storage or other significant fire exposure unless appropriately separated from such exposure by fire barriers rated for a minimum of 2 h fire resistance.
- Provide complete automatic sprinkler protection for the room or area. These are normally Ordinary Hazard Group 2 occupancies. Refer to NFPA 13 and PRC.12.1.1.0.
- Vent all battery and battery charging rooms and areas to prevent hydrogen from accumulating. Prevent concentrations of hydrogen exceeding 1% by volume. A hydrogen generation rate of 2.69×10^{-4} cfm (7.614 cm^3/min) per charging ampere per cell at 77°F (25°C) and one atmosphere, may be used in the design. Natural ventilation is usually sufficient when the highest elevation through a roof or a wall over the area has a ventilation opening.
- Prohibit ordinary electrical equipment and other sources of ignition from being located in any hydrogen venting path. The area directly above the batteries and the area at and above the elevation of the vent are likely to be in a venting path. Other nearby areas within adequately ventilated rooms are not normally considered hazardous (classified) locations as defined by the NEC because hydrogen rises and diffuses rapidly.
- Design the area to support the weight and loading forces of the complete battery and rack installation.
- Provide and maintain sufficient clear space for PM activities, including cleaning, removing and replacing stationary batteries.
- Integrate those construction features that will satisfy any reasonable expectations for future expansion. This includes extended floor space and added structural bracing.

- Where battery installations are subject to seismic activity:
    - Limit racks to a height of two tiers where possible, and not more than three tiers where access to each battery and temperature uniformity can be assured.
    - Provide anchors, spacers and restraining rails designed to secure the battery against earthquake shocks and shaking.
- For battery installations in facilities located in areas of moderate or severe earthquake potential, incorporate state-of-the-art seismic construction features. In the U.S., a site is subject to this potential: in ATC Zones 4, 5, 6 and 7 and in any area where building codes or local building practices require seismic resistance. As a minimum, comply with all features required by local codes.

Locate any battery that powers any critical system in a separate, ventilated battery room having no other occupancy.

Prohibit hazardous activities and enforce a “No Smoking” policy around storage battery areas. Activities that can be hazardous include smoking, localized heating, and all actions that produce sparks, arcs, flames, static charges (both accumulating and discharging) and movement that can result in mechanical injury.

Maintain an adequate supply of distilled water for refilling batteries. Store this water in inert, nonmetallic containers. Assure the quality of water being added to a cell meets specifications set by the battery manufacturer. Maintain a record of the amount of water added to each cell and the date it was added.

Do not use ammonia or hydrocarbon type cleaning agents (solvents, detergents, oils) to clean contaminants from stationary battery jars.

Use instruments that must contact electrolytes only in batteries of the same type to avoid contamination.

Electrically ground any electrically conductive, e.g., steel, racks used to support stationary batteries. Provide an electrically nonconductive barrier that resists damage from leaks and spills, e.g., plastic props, between the batteries and conductive rack structure to prevent a fault path from developing through the rack.

For each stationary battery power circuit, monitor high voltage, low voltage and the grounding of normally ungrounded circuits. Transmit alarms to a constantly attended location.

Provide overcurrent protection in each stationary battery power circuit.

Batteries contain hazardous materials and are therefore themselves considered hazardous. Document safe storage and disposal practices in operating, maintenance and other management programs. Follow established governmental regulations when handling, storing and disposing these materials.

Lead-Acid Stationary Batteries

Maintain ambient temperature in storage battery areas at approximately 77°F (25°C) for optimum battery life and performance. Avoid direct sunlight and localized heating sources, like radiant heaters and steam pipes.

Maintain the appropriate electrolyte level and specific gravity in all cells. Specific gravity measurements taken within 72 h of adding water to a cell or terminating an equalizing charge may not be accurate. Since the specific gravity of a cell changes with its temperature, record the electrolyte temperature in the pilot cell when testing the specific gravity. Immediately repair or replace damaged cells and batteries.

Provide an adequate supply of a sodium bicarbonate and water mixture and of clean water for handling acid spills. Wash spilled electrolyte with the sodium bicarbonate and water solution until foaming ceases. Then flush the area with clean water.

Ni-Cad Stationary Batteries

Although Ni-Cad batteries operate satisfactorily over a wide range of temperatures, for optimum battery life and performance, maintain the ambient temperature between 68°F and 77°F (20°C and 25°C) unless the unit is specifically designed to operate at other temperatures or its capacity has been appropriately derated.

Store an adequate supply of boric acid solution or some other neutralizing agent, as recommended by the manufacturer, and an adequate supply of clean water to handle electrolyte spills.

Inspections and Tests

Upon taking delivery of any stationary battery, perform an acceptance test. Document that the battery performance meets manufacturer's specifications. Maintain the acceptance profile for later use with the PM program.

Perform weekly inspection and tests of stationary batteries, battery chargers and associated dc circuits to verify, as applicable:

- The battery charger is operating correctly, with appropriate voltage and current outputs. Cables are not worn.
- Batteries are holding proper charge.
- Cell plates are not swelling, buckling, warping or cracking, and are an appropriate color. (Positive lead-acid plates will be light brown; negative lead-acid plates will be gray.)
- Electrolyte levels are correct. Electrolyte and cells are clear with minimal deposits, gassing or rings. There is only minor sediment below the plates.
- Cell connectors, other conductors, connections and racks are clean, free of corrosion and not discolored.
- Cells are not cracked and are not leaking. Covers and seals are not cracked or damaged.
- Ambient temperature and ventilation are appropriate.
- Vent caps are clean. When necessary, they should be cleaned by rinsing in clean water, and air dried before being returned to the battery.
- Batteries are secure and protected against exposures.
- The pilot cell electrolyte is at the proper temperature.
- The pilot cell electrolyte in a lead-acid battery has the proper specific gravity.

Perform quarterly inspections and tests of stationary batteries, battery chargers and associated dc circuits to include the following servicing, as applicable:

- Measure and document the voltage, specific gravity (for flooded, lead-acid types only) and fluid level of each cell. Compare the measured values with manufacturer specified tolerances.
- Verify system connections using an up-to-date single-line diagram.
- Check the integrity, appearance and cleanliness of the battery rack.
- Verify that connections are tight. When infrared scanning equipment is available, battery terminals and cell connectors can be scanned during battery discharge. For meaningful results, the temperature rise on the straps should be at least 18°F (10°C). A lesser rise indicates the current flow is too low to allow detecting poor connections. When this temperature criteria is met, poor strap connections will show as hot spots during scanning. All connections should be approximately the same temperature.

Semiannually, conduct and record an impedance test on each stationary battery by testing each cell and cell connector. Intercell and terminal resistance tests and conductivity tests may be considered acceptable where impedance tests cannot be performed. Clean, repair and retest poor connections; if conditions cannot be corrected, replace the damaged parts. Consult battery and test equipment manufacturers when a test result at a cell deviates by more than 20% from the installation or average impedance value.

Perform acceptance tests on new batteries to verify compliance with manufacturers' specifications and to develop acceptance profiles.

Deliver an equalizing charge to wet cell lead-acid batteries on a schedule not less than that specified by the manufacturer, and not less than:

- Every 18 months.
- When any test shows a cell voltage below 2.13 V.
- When the specific gravity of any cell, corrected for electrolyte temperature and level, is more than 10 points (0.010) below the average specific gravity of all cells at the time of testing.
- When the average specific gravity of all cells, corrected for electrolyte temperature and level, is more than 10 points (0.010) below the average installation (profile) value.

Deliver a high rate charge to wet cell Ni-Cad batteries as recommended by the battery manufacturer. Typically, float voltage is maintained at 1.37-1.47 V per cell. A high rate charge is recommended upon encountering low battery float voltage, when testing shows a cell having low float voltage and following any major discharge. In general:

- Apply a high rate charge to any individual cell whose float voltage drops to 1.35 V or less.
- Apply a high rate charge to any battery whose total float voltage is found to be less than the manufacturer's recommended minimum.
- Perform a test to determine the state of charge and the need for a high rate charge following any significant discharge. Typically, current and voltage readings in the float charge mode are compared with similar readings in the high rate charge mode to evaluate these issues.

Where the loss of a stationary battery will result in severe consequences or in the loss of a critical power system, perform battery capacity or service tests on the following schedule:

- With acceptance or proof testing.
- In the second year of operation.
- On a 5-year frequency from the second year of operation.
- Yearly, when a battery has reached 85% of its service life.
- Yearly, when any consecutive capacity tests show an average yearly loss of more than 1.5% of the battery rating.

DISCUSSION

Stationary batteries are often grouped on a rack. They are interconnected in series or parallel to meet the voltage and capacity requirements of the electrical system. They are often located in a battery room, separated from the equipment they serve.

Establishing reliability of stationary batteries is an important loss control activity. Damage to other types of batteries and loss of their use are normally minor incidents. But stationary batteries require a high level of reliability to prevent small loss-incidents from growing. If switchgear fails to open when a fault occurs, if power is interrupted while a computer is operating, or if a backup dc-drive motor fails to start, then what starts out as a minor incident can become a major incident that leads to significant financial loss. Preventive Maintenance (PM) can improve the reliability of these power sources.

Basics and Definitions

The basic integral component of a battery is a storage cell. It is an enclosure containing an electrolyte. The enclosure is commonly described as a jar with a cover, or a battery case. Two electrodes, one negative (anode) and one positive (cathode), extend into it. The electrodes are in the form of plates to provide a wide surface area. The wide surface area for the electro-chemical process allows high discharge rates and minimizes losses during the generation of cell voltage.

Technically, a battery consists of “two or more storage cells, electrically connected by one or more cell connectors (straps) to produce electric energy.” The single dry cell used in a flashlight or in some other low voltage device does not meet this definition of a battery.

A pilot cell is defined as any selected cell that represents the condition of the whole battery. Pilot cell selections are normally changed on a quarterly basis to limit electrolyte loss and cell contamination from testing.

A multiple compartment container enclosing two or more cells also may be called a jar or a battery case. The electrodes from each cell extend vertically through the top of the case where cell connectors complete the circuit. These cell connectors are exposed above the battery case to ease maintenance. The case is typically a flame retardant transparent plastic. Sometimes clear PVC is used. However, some cases are constructed of hard rubber or metal.

Battery cells are connected electrically in series, in parallel or in series/parallel combinations based on the desired battery output voltage and capacity. Where all cell cathodes are electrically connected, the parallel electrical arrangement of these cells provides increased battery capacity (current) at the single cell voltage. Cathode to anode electrode connections form series circuits, providing voltages that are multiples of the single cell voltage.

TABLE 1

Examples Of Characteristics For A Nominal 100 Ah Capacity 1.2 V Cell

Discharge Current - A -	Hours Duration - h -	Final Cell Voltage - V -	Actual Capacity – Ah -
12.5	8	1.14	100
12.6	8	1.10	100.8
13	8	1.00	104
46	2	1.14	92
47	2	1.10	94
50	2	1.00	100
125	0.5	1.14	62.5
143	0.5	1.10	71.5
165	0.5	1.00	82.5

Typically, two battery posts (one positive and one negative terminal rising from separate cells) protrude through the battery case at remote ends. One post rises from the first cell in the internal battery circuit. The other post comes from the last cell. The posts are at the electrical extremes of the battery cell circuit confined within the bounds of the case. These terminals allow connecting the battery to an external circuit or to other batteries.

Common batteries provide 6, 12 or 24 V power, depending on the number of cells in the battery. When individual stationary batteries are connected to provide a higher voltage or capacity, the entire interconnected battery installation is sometimes also called a battery. Thus, 20 series-connected, three-cell, lead-acid batteries may be referred to as a single 120 V battery. Batteries having terminal voltages of 400-500 V are not uncommon.

Selection and Acceptance

Electrical energy is normally expressed in watt-hours. But stored energy in a battery is expressed in Ampere-hours (Ah), since battery voltage is expected to remain within a specified range during discharges up to rated battery current.

Manufacturers publish tables to show the expected performance of their batteries. Table 1 is one example. It shows the expected duration of specified discharge currents. This table assumes a fully charged, new 1.2 V Ni-Cad cell (with other cells in the battery being similar) being used in a resistive circuit. This battery provides 100 Ah of battery energy. With a discharge current of 12.5 A, the battery will operate 8 h with cell voltages gradually dropping to 1.14 V. In another circuit with a discharge current of 50 A, after two hours cell voltages will drop to 1.0 V. The product of current (A) and time (h) yields the capacity rating (Ah) of the battery. Both examples are of full discharges and assume 100% battery capacity.

Battery capacity is the ratio of actual time to rated time to reach the specified final cell or battery voltage when discharging at the specified test rate. Based on Table 1, if a 50 A discharge results in a 20 cell battery droping from 24 to 20 V in 1.5 h, the battery's capacity is 75%.

Battery ratings are sometimes in kilowatt-hours (kWh) and sometimes in kilowatts (kW). Batteries for UPS systems are typically rated as kW/cell. This rating is based on 15 min of discharge.

Effective use of any battery requires battery ratings and specifications be matched with the requirements of the electrical system. Battery voltage, discharge rate, operating temperature, cycle life and Ah capacity are some of the selection considerations. The type and quality of a battery design affects the installation, maintenance and life of the unit. Battery designations "low maintenance" and "maintenance free" do not imply these batteries are of better quality. Nor do the terms suggest these batteries will withstand the same stress and last as long as standard batteries. Rather, these designations simply mean not much can be done to maintain these units. The terms unfortunately mislead the owners and operators of these batteries, and appear to condone neglecting maintenance of important equipment.

Stationary battery specifications in the U.S. differ from those of other countries. For example, electrolytes in lead-acid batteries manufactured outside of the U.S. are generally designed with a higher specific gravity to meet local battery power specifications. Other design criteria differ also. It is difficult to compare units. Substitutions should be avoided to minimize complications from different codes, standards and practices.

Types of Stationary Batteries

Batteries can be wet or dry depending on the characteristics of the electrolyte. A wet cell battery has a free-flowing electrolyte. In a dry cell battery the electrolyte is absorbed within a solid, is gelled or is otherwise immobilized, as in a paste.

The electrolyte in a wet cell lead-acid battery is a solution of sulfuric acid and water. The electrolyte in a wet cell Ni-Cad battery is a solution of potassium hydroxide and water. But both lead-acid and Ni-Cad batteries are also available as dry units.

A flooded battery is another term for a vented wet cell battery. The battery case contains an opening above each cell to permit the free interchange of cell gases with the outside atmosphere. Vent caps are usually screw-type air-filtering devices, but flip-top caps are also used. They are easily removable for servicing, and should be periodically rinsed in clean water to remove contaminants or should be cleaned as recommended by the manufacturer.

Modern vent devices usually include a porous mineral filter. The filter prevents solids in the air from entering the battery and also provides some measure of protection as a spark or flame-arresting device. Vents on some wet cells contain a catalyst that recombines hydrogen and oxygen, returns water to the cell and thereby reduces the amount of hydrogen that escapes.

In a sealed battery there is no provision to add water or electrolyte, or to measure specific gravity. A Ni-Cad battery is commonly a sealed battery, but it can also be a flooded cell. Gelled lead-acid batteries are also being produced as sealed batteries. Sealed batteries vent excess pressures during overcharging and other abnormal conditions. The battery is not sealed to keep hydrogen in but rather to keep maintenance out.

A valve regulated battery controls gas venting by a pressure sensitive valve that recloses when pressure is relieved. The battery requires the same ventilation and space requirements as flooded cells.

Valve regulated batteries are also called maintenance free, starved electrolyte batteries. They generally contain less than 1.8 in.^{3} (29 mL) of electrolyte, whereas a flooded cell has more than 231 in.^{3} (3.8 L) of fluid. Regardless, the overall battery dimensions of valve regulated batteries are similar to those of flooded cell batteries. The gelled electrolyte lead-acid battery is typically a valve regulated battery.

There is some concern over whether valve regulated batteries are sufficiently reliable for utility station use. Some utilities will not use them because of unsatisfactory experience with early models. Wet cell, flooded lead-acid batteries are reliable, have a proven service record and are generally preferred.

Additional information regarding these batteries is in the NEC.

Lead-Acid Flooded Wet Cell Batteries

The electrolyte in a lead-acid battery is a solution of water and sulfuric acid. The positive plate can be formed to a special shape or constructed of special alloys. This type of battery is sometimes specified by its plate construction features. Planté, pasted plate, lead antimony, lead calcium, lead selenium and tubular or gauntlet plate batteries are all lead-acid batteries.

Lead dioxide or lead peroxide is reduced to lead sulfate at the cathode. Lead sulfate is oxidized at the anode. Water is a normal by-product. The electro-chemical reaction results in stored energy which can be used (discharged) by connecting the battery to an external circuit. As electrons are transferred to the circuit from the battery terminals, ion transfer takes place in the battery through the electrolyte, completing the circuit.

When the battery case is clear and the contents of the cells are visible, a quick inspection can often provide much information about a battery: discolored or contaminated electrolyte; the amount and location of sediment; the color and form of the plates; and the condition of the electrodes, connecting straps and battery case. Plate poisoning, overcycling, over- or under- charging and other causes of deterioration can be detected.

Lead-acid battery voltages are normally calculated on the basis of 2.0 V per cell, however, actual system voltages are likely to be slightly higher. In essence, three lead-acid cells in series can be expected to provide a battery voltage of 6 V.

Electrical energy in a battery can cause hydrogen and oxygen gases to evolve by the electrolysis or breakdown of water in the cells. This can occur when a battery is charging or discharging. For lead-acid batteries, the maximum rate of hydrogen generation occurs near the end of a charging cycle when charging current is injected into the system and batteries are essentially fully charged. The rate of hydrogen generation can reach 2.69×10^{-4} cfm (7.614 cm^3/min). per charging ampere per cell at 77°F (25°C) and one atmosphere. The process is evidenced by the gassing or bubbling of the electrolyte.

If a fully charged 60 cell battery is being overcharged with a 2 A charging current, hydrogen will develop at a rate of 0.0323 cfm (914 cm^3/min). Without room ventilation, hydrogen evolution will cause a 1000 ft^3 (28 m^3) room to reach a 1% hydrogen accumulation in slightly over 5 h. Structural pockets in the ceiling over the area could reach this concentration more quickly since hydrogen is lighter than air. As long as ventilation sufficiently prevents the hydrogen from accumulating, and no electrical equipment is directly in the venting path, the area is not considered hazardous (classified) by the NEC. Adequate ventilation can usually be attained by three to four room air changes per hour with a high level exhaust, even under the most severe conditions.

Generally, the service life of a battery does not exceed 10-15 yr. However, some manufacturers claim a 20 to 30 yr battery service life with normal battery charging (float) applications.

Ni-Cad Flooded Wet Cell Batteries

The electrolyte in a Ni-Cad battery is an alkali, typically potassium hydroxide solution. Nickel oxide is reduced to nickel hydroxide at the cathode. Cadmium oxidizes to cadmium hydroxide at the anode. In older battery cells, an oil layer was placed over the electrolyte to prevent evaporation and reduce other operating problems.

As with lead-acid batteries, the electro-chemical reaction results in stored energy that can be discharged. However, unlike the lead-acid process, the electrolyte in a Ni-Cad battery does not enter into the electro-chemical reaction. Since it is not chemically changed during charging or discharging, the specific gravity does not change with the state of charge of the cell. Thus, specific gravity measurements are of little value in Ni-Cad batteries.

Battery voltage is normally calculated on the basis of the potential across each individual cell being 1.2 V, however, actual system voltages are likely to be slightly higher. In essence, five Ni-Cad cells are required to produce the same voltage (6 V) as three lead-acid cells.

Vented Ni-Cad cells emit less gas than comparable lead-acid units. They also require fewer additions of electrolyte. Sealed Ni-Cad cells allow relatively little maintenance other than electrical tests and recharging.

Battery Charging

Because stationary batteries are commonly used for standby or emergency purposes, they are rarely fully discharged. They are ready to supply power when an emergency arises. They are usually maintained fully charged by battery chargers.

Battery chargers maintain a float voltage on a battery. This float voltage is higher than the battery voltage, sufficient to supply any normal dc load but not high enough to overcharge the cells. The battery, load and charger are connected in parallel. The battery takes over as a power source when the load exceeds the charger output.

Each type of battery has its own charging requirements. Battery chargers often have a “float” and an “equalize” or “high rate” position. In the equalize or high rate position, the charger applies an elevated voltage (higher than the float voltage) to assure that internal battery losses are overcome. For certain batteries, periodic equalizing or high rate charges can restore the life of the active materials in the plate. These charges may be required when water is added or when any cell produces an abnormal voltage.

Battery charging procedures are a very important part of battery maintenance. The proper methods and schedule for battery charging are specified by the manufacturer. For instance, many manufacturers of lead-calcium cells void their warranties if the cells are not equalized within six months of the date stamped on them. These cells are highly time sensitive. Further, overcharging and under-charging batteries can cause irreparable damage. However, some newer batteries are highly voltage and time tolerant. They require no special charging technique and no special precautions.

For a normal float, a constant voltage is applied to the battery to maintain the charge. Alternately, a battery may require constant current charging or a combined step charging procedure. Some batteries require high charging rates; others require low charging rates.

Ni-Cad batteries are “fully charged” upon short-term, constant-current charges. A prolonged float reduces battery capacity. Some battery characteristic tables identify correction factors for constant potential float versus constant current charging.

Normally, an equalizing charge is applied to a wet cell lead-acid battery when test results show values have reached or exceeded specified limits for any of the following measurements:

- Specific gravity of a cell.
- Average specific gravity of all cells.
- Voltage of a cell.

Either a high rate charge or further testing is performed on wet cell Ni-Cad batteries when the voltage of any cell drops to a specified limit.

If other than the manufacturer’s specified charging method is used, the service life of the battery will be shortened. Further information on battery charging is beyond the scope of this guide.

Corrosion and Contamination

Dust and dirt can accumulate on batteries. Damaged seals and poor housekeeping can lead to corrosion. External corrosion, dirt and other contamination should be removed from a stationary battery as quickly as possible.

The problems that cause corrosion should be corrected to reduce the chance of recurrence. The color and texture of corrosive deposits may signal the need for PM actions:

- A dry coffee-colored (brown) stain on a positive terminal post and intercell connector can be caused by lead dioxide leaking through the positive terminal seal. The seal should be repaired. Upon replacing the connector, a copper corrosion inhibitor should be applied.
- Lead sulfate on a negative terminal appears as a wet, white powder. It can be neutralized with baking soda and water.
- Green colored copper sulfate suggests major damage has already occurred to copper conductors, bus bars, etc. Pockmarks can usually be noted when the equipment is cleaned. Components should be replaced.

Potassium carbonate leaves a grayish/white deposit on the tops of cells. While the deposit may look like corrosion, it forms when vapor from the electrolyte escapes into the air. It is a concern because of its conductivity rather than any subsequent corrosion potential. A buildup of this material can cause an electrical short circuit. The material can be wiped clean with a wet cloth.

Corrosion effects should also be considered with respect to building ventilation. Droplets of acid can be released into the air from lead-acid batteries. An acid mist can corrode electrical and electronic equipment, and other metallic structures. One such incident approached $600,000 in property damage. Furthermore, plastics used in battery construction may be fire retardant, but they break down and burn with a severe fire exposure. And they can emit heavy smoke when overheated. Separate room ventilation is desirable, preferably along an outside wall with direct room air exhaust.

Electrical Protection

As with ac power systems, electrical protection is also needed in dc power systems. Electrical protection may include dc fuses, dc circuit breakers, and monitoring systems to actuate disconnects. Unfortunately, national codes and engineering guidelines provide only limited information on dc circuit protection. Furthermore, protective devices with the most suitable operating characteristics may not always be available. Electrical design engineers are often “on their own” in designing such protection. The need for better guidance is recognized, but specific recommendations are beyond the scope of this guideline.

Seismic Considerations for Battery Racks

Various codes and standards may be used to guide battery rack design and installation. One such code is the International Building Code (IBC). It addresses seismic requirements for battery racks. For various occupancies and seismic zones described in the IBC, construction features and performance tests are described. For example, it specifies the values of tension and shear forces that anchor bolts should withstand.

Seismic construction features will generally include the following:

- The batteries are fitted tightly within restraining rails and cannot slide within the rack.
- Batteries are located as close to the floor as practical.
- Battery cables are clamped to racks to prevent stress on battery terminal posts during seismic events.
- Battery racks are attached to only one plane of the building structure, preferably the building floor. Similarly, conduits or cables connected to a battery should also be secured to the same surface to prevent pulling the cable as seismic forces bend the structure.
- Spill containment room designs, which may include pits, are provided to confine acid spills.

- Rack construction is certified by a registered professional engineer.

Battery Tests

Various tests are useful in battery PM programs. They establish battery profiles or benchmarks, and allow results to be compared as a battery ages.

As stated earlier, one of the basic tests for wet flooded lead-acid batteries is a test of the specific gravity of the electrolyte. This test uses a hydrometer. It is simple and quick. Voltage, current, temperature and other measurements are similarly basic and simple tests.

Test equipment and test sets are available from many different manufacturers. Some common tests are described in this Property Risk Consulting Guideline. Information concerning other tests is available from manufacturers. Test procedures for all tests should be reviewed with manufacturers' representatives.

Battery Impedance Testing

As cell capacity deteriorates, cell impedance increases. As a cell connector corrodes or loosens, its impedance increases. By periodic impedance testing, deterioration of batteries, cells, connections and cabling can be monitored.

BITE,^{TM} a test set manufactured by AVO International, can provide impedance data for lead-acid and Ni-Cad cells by indicating impedances directly in milliohms (m Ω) without having to take the battery off-line. The BITE^{TM} test set requires an ac power source. It causes 10 A of 60 Hz ac current to flow through the battery. Probes measure the current and point-to-point voltages across cells and connectors. The test set calculates and displays the impedance. This unique test set is useful as part of a PM program. It identifies cells and strap connections that have abnormal impedances and require immediate repair, replacement or additional testing.

Impedance testing can measure impedances point to point throughout a battery. By testing the impedance of cell #1 (electrode to electrode), then the connected strap (cell #1 electrode to cell #2 electrode), then cell #2 (electrode to electrode), and so on, a battery of 60 cells can be tested in less than 60 min. (Sealed batteries can also be tested, but fewer test points are available.)

Three ways to analyze batteries are to evaluate historical trends, compare similar cells (or similar connectors or straps) and set baseline values:

- Evaluate historical trends. An historical impedance-age plot can identify when the impedance of a cell begins to increase at increasing rates. An acceleration suggests the cell is reaching the end of its service life.

  Cell connectors should be repaired or replaced whenever impedance values increase. Cleaning and retorquing may be all that is required to bring the impedance of the connector within tolerance.

- Compare similar cells. Often, many cells in the battery are the same age and are supplied by the same manufacturer. They also have similar exposures and history of use. Impedance values will be about the same. Comparison of cell impedances, like comparisons of impedances of similarly-sized cell connectors, can point to the abnormal units and guide repairs or replacements.
- Set baseline values. Battery manufacturers can specify appropriate impedance values for the cells that they design. Also, Biddle Instruments has developed a data base of "as found" impedance values by battery manufacturer and model number. By working with these sources, it may be possible to set baseline values.

Battery Conductance Testing

Cell capacity can also be monitored by periodic conductance testing. This test provides essentially the same kind of information found by battery impedance tests. The major difference is this value is basically a reciprocal of the impedance. Where cell impedance is measured in m Ω, cell conductance is measured in mhos or kmhos.

As with impedance tests, conductance tests can be done on-line. Three types of analyses are used. Conductances can be tracked point to point.

The battery conductance tester does not require an ac power source and has only two test leads. The test equipment is less intricate than an impedance test set.

Battery Resistance Testing

Intercell and terminal connection resistances usually increase with time. Test methods for analyzing these changes include using digital low resistance ohmmeters, or using meters to measure the drop of millivolts (mV) during capacity tests.

Battery Capacity Test

A battery capacity test discharges a battery to its designed terminating voltage and analyzes the results. This discharge test is the only reliable way to determine battery condition. It is performed during shutdowns because stationary battery power is typically unavailable during the test and during the time needed for recharging the battery.

A capacity test is performed:

- As an acceptance test to determine whether the battery meets specifications, ratings, or both. It establishes the benchmarks for future evaluations.
- Periodically to determine whether the battery as found performs within acceptable limits. Normally, the test is performed in the second year of operation, then every 5 yr after that until battery capacity diminishes to warrant annual testing or replacement as described in PRC.5.6.1.
- As needed to determine whether the battery meets the design requirements of the system. This purpose is also satisfied by a Battery Service Test.

Capacity tests are recommended for stationary battery control power applications as described in PRC.5.6.1. They are also desirable where any battery is critical or its loss will result in severe consequences.

Battery Service Test

A battery service test is a special battery capacity test to determine whether the battery will meet the design requirements of the dc system. The test does not fully discharge the battery. Generally, the duration of the test is 150% of the designed service time. For turbine generator use, it should be no less than 1½ times the coastdown time period.

The system designer sets the test procedure and acceptance criteria. This test is not as severe as a battery capacity test, since its sole purpose is to evaluate the ability of a battery to do a specific job.

Electrolyte Carbonization Tests

Potassium carbonate buildup in the electrolyte of a Ni-Cad battery can reduce battery performance. Some manufacturers provide test kits that detect carbonization and indicate when the electrolyte should be replaced.

Continual and Automatic Test Equipment

Battery monitoring equipment is available to accomplish continual monitoring of battery systems. Some are capable of automatically performing scheduled tests on battery systems. These instruments monitor and store operating data from hundreds of individual cells, perform periodic integrity and capacity tests, and alarm when an unsatisfactory condition is found. Some systems can also telephone a remote location via a modem, and print out hard copies of test and maintenance records upon request.

These systems do not replace the need for visual and other maintenance services. They only supplement them.