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IEEE Guide for Batteries for Uninterruptible Power Supply Systems

IEEE Power Engineering Society

Sponsored by the
Stationary Battery Committee

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Abstract: Various battery systems are discussed so that the user can make informed decisions on selection, installation design, installation, maintenance, and testing of stationary standby batteries used in uninterruptible power supply (UPS) systems. This guide describes how the UPS battery charging and converter components can relate to the selection of the battery systems. Design requirements of the UPS components are beyond the scope of this document. Battery back-up systems for dc-output rectifiers are also beyond the scope of this document. .
Keywords: battery system, Ni-Cd batteries (Ni-Cd), uninterruptible power supply, UPS, valve-regulated leadacid (VRLA), vented lead-acid batteries (VLA)

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Introduction

This introduction is not part of IEEE Std 1184-2006, IEEE Guide for Batteries for Uninterruptible Power Supply Systems.

Our society's increasing dependence on computerized information has resulted in the expanded use of uninterruptible power systems (UPS) to ensure the integrity of essential power systems. These systems require that stored energy be available to maintain operation. Although rotating inertia has at times been used to store this energy, batteries remain the preferred method of energy storage for this purpose. An array of battery designs and extensive technologies are available to the user.

This guide is intended to inform the user of the various battery technologies available and some of the design points to be considered when selecting a battery for UPS applications. Some of the battery design options that result in volumetric efficiency may also result in reduced life. This guide can help the user to become aware of which designs and operating procedures can result in optimum battery life. This guide is intended to be used along with IEEE Std 485™, IEEE Recommended Practice for Sizing Lead-Acid Batteries for Stationary Applications; IEEE Std 484™, IEEE Recommended Practice for Installation Design and Installation of Vented Lead-Acid Batteries for Stationary Applications; IEEE Std 450™, IEEE Recommended Practice for Maintenance, Testing, and Replacement of Vented Lead-Acid Batteries for Stationary Applications; and IEEE Std 1106™, IEEE Recommended Practice for Installation, Maintenance, Testing, and Replacement of Vented Nickel-Cadmium Batteries for Stationary Applications.

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IEEE Guide for Batteries for Uninterruptible Power Supply Systems

1. Overview

1.1 Scope

This guide discusses various battery systems so that the user can make informed decisions on selection, installation design, installation, maintenance, and testing of stationary standby batteries used in uninterruptible power supply (UPS) systems. This guide describes how the UPS battery charging and converter components can relate to the selection of the battery systems. Design requirements of the UPS components are beyond the scope of this document. Battery back-up systems for dc-output rectifiers are also beyond the scope of this document. While this document applies to all UPS systems, it may be impractical to implement some of its guidance and recommendations with small, self-contained systems, such as products intended to back up individual personal computers.

This guide divides the available technologies into the following three main categories:

- Vented lead-acid batteries (VLA)
- Valve-regulated lead acid (VRLA)
- Ni-Cd batteries (Ni-Cd)

For each category, the technology and the design of the battery are described in order to facilitate user selection. The specific advantages for particular applications are also listed.

1.2 Purpose

This guide is intended to assist those involved with battery systems for uninterruptible power supply systems. Proper design, installation, and maintenance will enable the user to manage the battery system for optimum operation and results.

2. Normative references

The following referenced documents are indispensable for the application of this document. 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 450™, IEEE Recommended Practice for Maintenance, Testing, and Replacement of Vented Lead-Acid Batteries for Stationary Applications.[1, 2]

IEEE Std 484™, IEEE Recommended Practice for Installation Design and Installation of Vented Lead-Acid Batteries for Stationary Applications.

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

IEEE Std 1106™, IEEE Recommended Practice for Installation, Maintenance, Testing, and Replacement of Vented Nickel-Cadmium Batteries for Stationary Applications.

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

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

IEEE Std 1188™, IEEE Recommended Practice for Maintenance, Testing, and Replacement of Valve Regulated Lead-Acid (VRLA) Batteries for Stationary Applications.

3. Definitions

For the purposes of this guide, the following terms and definitions apply. *The Authoritative Dictionary of IEEE Standards Terms, Seventh Edition* [B2][3], should be referenced for terms not defined in this clause.

3.1 commissioning: A process that assures that a component, subsystem, or system will meet the intent of the designer and the user.

3.2 cycle: A battery discharge followed by a complete recharge. A deep discharge cycle is described as the removal and replacement of 80% or more of the cell's design capacity.

3.3 cycling: Repeated charging and discharging of a storage battery. Some batteries are rated by their ability to withstand repeated, deep discharge cycles.

3.4 depth of discharge: The ampere-hours removed from a fully charged battery, expressed as a percentage of its rated capacity at the applicable discharge rate.

3.5 equalizing voltage: A voltage, higher than the float voltage, used to correct inequalities of voltage, specific gravity, or state of charge that may have developed between the cells during service.

3.6 float service: Operation of a standby battery at a continuous charging voltage selected to maintain a full state of charge and optimize battery life.

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[1] IEEE publications are available from the Institute of Electrical and Electronics Engineers, 445 Hoes Lane, P.O. Box 1331, Piscataway, NJ 08855-1331, USA (http://standards.ieee.org/)

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

[3] The numbers in brackets correspond to those of the bibliography in Annex A.

3.7 ohmic value: A value derived from the measurement of a cell's internal resistance, conductance, or impedance; used as one element of determining a battery's state of health.

3.8 rated capacity: The ampere-hour capacity assigned to a storage cell by its manufacturer for a given discharge rate and time, at a specified electrolyte temperature and specific gravity, to a given end-of-discharge voltage.

3.9 temperature-compensated charging: A charging technique in which battery temperature is measured and the charging voltage is adjusted in proportion to changes in temperature.

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

3.11 vented lead-acid (VLA) cell: A cell in which the products of electrolysis and evaporation are allowed to escape to the atmosphere as they are generated. These batteries are commonly referred to as flooded.

3.12 uninterruptible power supply (UPS): A device or system that provides quality and continuity of an ac power source through the use of a stored energy device as the backup power source.

4. Battery types

4.1 General

The smallest unit of a battery is the cell, which has the following basic components:

— Container
— Positive plates
— Separators/retainers
— Negative plates
— Electrolyte
— Cover
— Flame arrestor with vent or valve
— Plate straps, terminal posts, and other current-carrying components

These components may be designed and implemented in various ways to optimize performance for specific applications. (See Annex C and Annex D).

4.2 Performance considerations

Battery designs are available for the following standby applications:

a) Long duration (i.e., telecommunications or low discharge rate) batteries are designed for applications in which the standby loads are relatively constant and the battery is required to supply these loads for a minimum of 3 h. Long duration batteries are characterized by thicker plates.

b) General-purpose (i.e., switchgear and control) batteries are similar to the long duration battery, but have additional design features to improve conductivity. In UPS applications, this design is best suited for discharge times of 1 h to 3 h.

c) Short duration (i.e., UPS or high discharge rate) batteries are designed to supply large amounts of power for a relatively short period of time. Thinner plates typically characterize short duration batteries. These batteries are best suited for applications requiring reserve times of 1 h or less.

In addition to these designs, which typically serve stationary standby or float service applications, there are batteries available for a variety of other applications. Such batteries are rarely used for UPS applications.

4.3 Vented lead-acid (VLA) batteries

4.3.1 General

VLA cells are constructed with the liquid electrolyte completely covering (flooding) the closely spaced plates. The electrolyte maintains uniform contact with the plates. Depending on plate thickness (among other factors) cells of this design can provide a very high, short-duration current due to their low internal resistance. (See Annex C.)

4.3.2 Voltage

The fully-charged lead-acid cell has an open circuit voltage of approximately 2.10 V, which varies as a function of cell-specific gravity and temperature. Open circuit voltage increases with specific gravity and decreases with temperature, and typically ranges from 2.06 V/cell to 2.10 V/cell. The float voltages range from 2.15 V/cell to 2.30 V/cell, depending on individual cell design, temperature, and manufacturer recommendations.

4.3.3 Construction

Lead-acid batteries are described by their plate construction and the alloying elements (if any) that are used to strengthen the plate structure. Several designs have been created to improve performance characteristics, including cycling and life expectancy. Each design, however, places its own constraints on cell operation. (See C.2 for plate construction.)

4.4 Valve-regulated lead-acid (VRLA) batteries

4.4.1 General

VRLA cells are sealed with the exception of a valve that opens as required to relieve excessive internal pressure. These cells provide a means for recombination of gases to limit water consumption. This is accomplished by allowing oxygen evolved from the positive plate to pass across to the negative, where the recombination reaction occurs. The valve regulates the internal pressure to optimize recombination efficiency; hence, the term “valve regulated.”

VRLA cells are more sensitive to elevated operating temperatures and abusive conditions. In extreme cases this can lead to thermal runaway (see 5.4.2; Annex C for construction).

4.4.2 Voltage

The fully-charged VRLA cell has an open circuit voltage of approximately 2.15 V, which varies as a function of cell-specific gravity and temperature. Open circuit voltage increases with specific gravity and decreases with temperature, and may range from 2.06 V/cell to 2.17 V/cell. The float voltage ranges from 2.20 V/cell to 2.35 V/cell, depending on individual cell design, temperature, and manufacturer recommendations.

4.4.3 Electrolyte immobilization

One of the requirements for effective recombination is that the electrolyte be immobilized. There are two means by which this can be accomplished, known as absorbed electrolyte and gelled electrolyte.

4.4.3.1 Absorbed electrolyte systems

VRLA cells of this design are constructed with a controlled volume of liquid electrolyte contained in a highly absorbent blotter-like separator, positioned between closely spaced plates. This non-woven separator distributes the electrolyte uniformly and maintains it in contact with the plate active material, while permitting the passage of oxygen evolved during charging. Cells with absorbed electrolyte technology have inherently low internal resistance and can be designed to provide a very high-rate, short-duration current. Cells with absorbed electrolyte are also known as “absorbed glass mat” (AGM) types.

4.4.3.2 Gelled electrolyte systems

VRLA cells of this design are similar to vented designs, except that the electrolyte has been gelled to immobilize it. They can provide a high-rate, short-duration current, but because of the higher internal resistance they are not as effective as the absorbed electrolyte design. However, the higher thermal conductivity in gelled designs makes them better suited for elevated temperature applications than equivalent absorbed electrolyte cells. A gelled electrolyte cell is typically heavier and larger than an absorbed electrolyte cell for a given capacity.

4.4.4 Valves and flame arrestors

Whichever electrolyte immobilization technique is selected, this cell design will employ a pressure relief valve. This valve is designed to:

a) Limit the maximum pressure within the cell.
b) Prevent the oxygen of the atmosphere from entering the cell and discharging the negative plates.

If this valve or other seals should fail, the cell would start to perform as a vented cell, release gases, and eventually dry out.

There are conditions of cell operation where explosive mixtures of hydrogen and oxygen may be present; therefore, flame arrestors should be provided.

4.4.5 Ventilation

Valve-regulated cells should be placed in a controlled environment that is well ventilated, and should not be placed in the heat flow of electronic equipment within the same enclosure. Proper cell ventilation around the cell casing is recommended to reduce the possibility of thermal runaway.

Under normal recombination operation, valve-regulated cells periodically vent small amounts of hydrogen, and some hydrogen may also diffuse through the plastic case. Larger amounts of gas are emitted when the battery is overcharged. Users should consult the manufacturers' specifications to determine whether additional ventilation is required for a particular application.

Charging above the recommended manufacturer's voltage values or operating at elevated temperatures without reducing the float voltage to compensate for the elevated temperature may result in venting of hydrogen and oxygen from the cell.

4.5 Vented Ni-Cd batteries

4.5.1 General

Ni-Cd batteries use an alkaline electrolyte (potassium hydroxide). The active materials are nickel oxyhydroxide (NiOOH) in the positive plate, and cadmium metal (Cd) in the negative plate.

The electrolyte in the Ni-Cd battery does not take part in the overall cell reaction, so the specific gravity does not change during charge and discharge. The electrolyte retains its ability to transfer ions between the cell plates, irrespective of the charge level, and also acts as a preservative of steel components in the cell mechanical structure.

The batteries are resistant to mechanical and electrical stresses, operate well over a wide temperature range, and can tolerate frequent shallow or deep discharging.

4.5.2 Characteristics

The Ni-Cd cell has an open circuit voltage of approximately 1.30 V and a nominal discharge voltage of 1.20 V. The manufacturers' recommendations indicate a range of float voltages of 1.40 V/cell to 1.47 V/cell and high-rate voltages of 1.45 V/cell to 1.65 V/cell, depending on their individual designs and the requirements of the application. Ni-Cd cells can tolerate very high charge rates without damage. Some designs may be stored for years with no life loss.

The cell can tolerate complete discharge with almost no permanent deterioration of capacity or life. Depending on the number of cells used, the typical end-of-discharge voltage in this application may vary from 1.00 V/cell to 1.10 V/cell. It is advisable to use the lowest end-of-discharge voltage and the largest possible number of cells that will satisfy the manufacturer's charging recommendations, since this will result in the most economic battery for the application.

4.5.3 Construction

Several designs of vented Ni-Cd batteries are available, depending on plate construction. The most commonly used designs are the pocket plate, the fiber plate, the sintered plate, and the plastic bonded plate. The construction of Ni-Cd batteries is detailed in Annex D.

Ni-Cd cells are designed with varying plate thickness. For long-duration, low-discharge rates, thick plates (3 mm to 4 mm) are used. Medium rate cells, often used in applications where a combination of high and low discharge currents is required, have thinner plates (2 mm to 3 mm). For short-duration, high-rate performance, which depends more on the active plate surface available rather than the total amount of active material, thin plates (0.8 mm to 1.5 mm) are used.

4.6 Sealed Ni-Cd batteries

Sealed Ni-Cd cells are normally used in electronics and consumer equipment, such as cordless power tools. They are limited in capacity and are therefore used mainly in small UPS applications.

The cells are typically constructed from sintered or pasted electrodes that are wound together with a separator to form a cylindrical plate group. The cell container is completely sealed and no gas is released under normal operating conditions. Recombinant designs are also available for larger capacities. In construction they resemble vented cells, but also incorporate a special separator, which allows charge gases to recombine.

5. Selection considerations

5.1 Design considerations

5.1.1 Lead-acid cells

There are special designs for long duration, general purpose, and short duration applications, typically characterized by their plate thickness (see 4.2). The thinner-plate designs are optimized for high-rate, short-duration discharges.

a) **Vented cells:** The plates of a VLA cell are immersed in a liquid electrolyte and housed in a clear container. The clear container allows for visual inspection of the plates and internal components. Normal charging results in gassing and water consumption. While this will necessitate electrolyte maintenance, the ability to replenish lost water makes vented cells more tolerant than VRLA cells to overcharging and operation at elevated temperature.

b) **VRLA cells:** AGM cells are generally more suitable for high-rate, short-duration discharges, whereas gelled electrolyte types are more suited to longer discharges (see 4.4.2). However, the higher energy density of AGM designs often favors them where space is limited, regardless of discharge duration.

5.1.2 Ni-Cd

Ni-Cd cells are designed for long duration, general purpose, and short duration. These designs are primarily based on plate thickness. The life expectancy, however, is not directly related to the thickness of the plate. The active material ages gradually and there is no degradation of the plate structure, so there is no sudden fall-off in cell capability.

5.1.3 Reliability

In most cases, the reliability of a VLA is better than VRLA cells given similar environments. VLA batteries are also more robust to environmental conditions such as temperature and ripple current (see 6.2.2).

Ni-Cd cells have similar reliability to VLA batteries. Ni-Cd cells may perform better than VLA in applications with temperature extremes.

5.2 Battery footprint and floor loading

Vented batteries (VLA and Ni-Cd) require that they be oriented with the cell vent facing upward. Some VRLA batteries can be oriented in the horizontal position allowing for a smaller footprint than a similar sized vented battery. In general, VRLA batteries have higher volumetric energy densities than VLA and, therefore, can have a smaller footprint. Floor loading should always be considered in system design.

5.3 Battery life

5.3.1 Operating temperature

The location and arrangement of cells should result in no greater than a 3 ºC temperature differential between cells at a given time. Avoid conditions that result in spot heating or cooling, as temperature variations will cause the battery to become electrically unbalanced.

Elevated temperature operation will shorten battery life. A general rule of thumb for lead-acid batteries is that prolonged use at elevated temperatures will reduce the battery life by approximately 50% for every 8 ºC above 25 ºC. Ni-Cd cells are less affected, with a life reduction of about 20% for the same temperature increase.

Rated performance of cells are typically at 25 ºC. A location where this temperature can be maintained will contribute to optimum battery life, performance, and cost of operation. Extreme ambient temperatures should be avoided because low temperatures decrease battery capacity, while prolonged high temperatures shorten battery life and increase maintenance cost. Installation in a location with an ambient below the rated temperature will affect sizing. Refer to IEEE Std 485[4] and IEEE Std 1115.

5.3.1.1 VLA

Vented cells are more tolerant to environmental and system abuses than VRLA.

5.3.1.2 VRLA

For VRLA batteries, optimal gas recombination is a function of operating temperature and float voltage. The additional issues of possible dry-out and thermal runaway with VRLA batteries should be carefully assessed for elevated temperature operation. Consideration should also be given to current limiting chargers for elevated temperature applications. In addition, the use of temperature-compensated chargers is recommended for those applications where temperature variations can be expected.

5.3.1.3 Ni-Cd

A Ni-Cd battery will not be damaged by low temperatures or freezing. With a normal electrolyte, the battery will operate at temperatures as low as –20 ºC; with a higher specific gravity electrolyte, it will operate at even lower temperatures. The available capacity is reduced at low temperatures, but at –40 ºC, a Ni-Cd battery can deliver 60% or more of rated capacity.

[4] Information on references can be found in Clause 2.

5.3.2 Frequency and depth of discharge

The life of a battery is related to the frequency and depth of discharges. A battery can provide more short-duration, shallow cycles than long-duration, deep discharge cycles. Even momentary fluctuations in the ac power to the UPS may result in battery discharges of several seconds or more. Frequent cycling of the UPS battery, even for short durations, shortens battery life.

5.3.2.1 VLA

A VLA battery can be designed for extended cycle life either by placing retaining mats against the positive plates or by enveloping the positives in a perforated sleeve. This partial electrical isolation increases internal resistance, and may limit the rate at which power is withdrawn from the battery. (See Annex C.6.)

5.3.2.2 VRLA

Many AGM designs can provide superior cycle service to vented cells with the same grid alloy, since the plate element is under compression and the glass fiber mat acts as a retainer. Manufacturers of gel designs may incorporate additives into the electrolyte that provide extended cycle service.

5.3.2.3 Ni-Cd

Ni-Cd cells can provide long-term cycle service for deep discharge applications. To enhance cycle life and to reduce the adverse effect of high temperatures, various amounts of lithium hydroxide may be added to the potassium hydroxide electrolyte. The manufacturers specify the exact amount added during manufacturing.

5.4 Ventilation

As a cell approaches full charge, the charging process becomes more inefficient and an increasing amount of the current input goes into electrolysis. In this process water is broken down, with oxygen being evolved at the positive plates and hydrogen at the negative plates. Once a cell has reached a full state of charge, almost all of the current goes into the electrolysis process. In a vented cell, the oxygen and hydrogen gases are allowed to escape into the atmosphere, resulting in loss of water.

In VRLA cells, the oxygen recombination cycle suppresses hydrogen evolution and limits water loss, but results in the production of heat. Ventilation systems should, therefore, be designed for both hydrogen removal and thermal management.

5.4.1 Hydrogen removal

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 air in the battery area, or as required by local codes for the specific installation. The location should be free of areas that might collect pockets of hydrogen. The maximum hydrogen evolution rate is shown in Equation (1).

$$1.27 \times 10^{-7}\ \text{m}^3\text{/s per charging ampere per cell at 25 °C and 101.325 kPa.} \tag{1}$$

The worst-case condition exists when forcing maximum current into a fully charged battery. The maximum charging current exists when the battery is charged at the highest voltage and maximum temperature and can be obtained from the manufacturer.

Although the normal recombination process suppresses hydrogen evolution in VRLA cells, small amounts of hydrogen are periodically released as a result of the grid corrosion process. Larger amounts of hydrogen are released, along with some oxygen, when the battery is overcharged. The system designer should use the above formula to calculate maximum hydrogen evolution.

5.4.2 Thermal management

Maintaining the operating temperature of the battery at 20 °C to 25 °C will maximize its service life and efficiency.

Normal charging of a vented cell results in very little heat evolution. The small amount of heat produced is readily dissipated through the bulk of the liquid electrolyte or with evolved gas. Although heat may be evolved under fault conditions (e.g., overcharging with low electrolyte levels), the primary concern under such conditions is normally hydrogen removal rather than thermal management.

When a VRLA cell is operating at float or overcharge in a fully recombinant mode, there is virtually no net chemical reaction and almost all of the overcharge energy results in heat generation. If the design of the system and its environment are such that the heat produced can be dissipated and thermal equilibrium can be reached, then the potential for thermal runaway is diminished. However, if the recombination reaction rises to the point where the rate of heat generation exceeds the rate of heat dissipation, the battery temperature will rise and more current will be required to maintain the float voltage. The additional current results in still more recombination and heat generation, which further raises battery temperature. This process is known as thermal runaway, and if left unchecked can result in catastrophic battery failure. This potential problem is further aggravated by elevated ambient temperature, shorted cells, or charging system malfunctions.

Conditions that can lead to thermal runaway include the following:

- High operating ambient without compensation of float voltage
- Improper float voltage adjustment
- Inadequate current limitation in battery charging circuit
- Shorted cell(s) within a battery string
- High ac ripple in dc circuit
- Charger malfunction
- Malfunctions of HVAC systems

An uncorrected thermal runaway condition results in excessive hydrogen evolution, venting, eventual dry-out, and failure. When charging current is at maximum levels, the battery temperature can cause meltdown, leading to a fire or explosion.

Ideally, VRLA cells should be placed in a controlled environment. Proper ventilation around the cell casing is recommended to reduce the possibility of thermal runaway. The risk of thermal runaway can be further reduced by limiting the charging current and by temperature compensation of the charging voltage. Some types of cell construction are better suited for the dissipation of heat than others. Contact the manufacturer for additional information.

6. Application considerations

The following subclauses provide an overview of the techniques and application considerations used to determine a battery system design. IEEE Std 484, IEEE Std 1187, and IEEE Std 1106 provide more detailed information and procedures on installation design and installation.

6.1 Installation design

System application and local environmental conditions have a great effect on the design of the installation, which can have a significant effect on battery performance and life. Consideration should be given to the applicable subclauses.

6.1.1 Ventilation

Ventilation conditions must be appropriate for the battery type selected. (See 5.4.)

6.1.2 Parallel strings

Parallel strings of batteries can be utilized for increased capacity and/or redundancy. Ideally, the strings should be as similar as possible. At a minimum, float voltage requirements must be compatible. Redundancy is achieved by using more strings than required to meet the minimum system requirements.

Parallel strings may be used for flexibility in maintenance, for example, one string of a 500 kW battery versus two strings of 250 kW each, for a total backup time of 15 min in both cases. In this example, utilizing two strings with individual battery disconnects allows for the removal of one string for maintenance purposes, while keeping the other string on line at a reduced back-up time (see below in this subclause). Redundancy could be achieved to this system by adding a third string of 250 kW.

There are limitations that should be considered when utilizing parallel strings. The installation is often larger and more complicated. Maintenance will increase with the additional strings. Consideration should be given to charger sizing and to load testing requirements. Individual battery disconnects should be incorporated into the system design.

The advantages of using parallel strings often outweigh their limitations. Using redundant strings increases system reliability and improves access to off-line maintenance using individual battery string disconnects. Cable sizing between the battery and load should reflect the increased load that will be present with parallel string(s) disconnected.

Care must be taken when sizing battery systems with parallel strings. The one-minute rate and the coup de fouet (the initial voltage drop under load) must be considered for each string.

In the example above, using two strings of 250 kW for a 500 kW load would be of little advantage if one string alone could not support the connected load through the coup de fouet. Even if a single string will support the load through the coup de fouet, the run time will be severely reduced and, depending on cell design, could be as little as 2 min.

6.1.3 Racks and cabinets

The battery string(s) will be installed on battery racks or in cabinets. Seismic rating of the installation site must be considered in the choice of racks or cabinets. Refer to local building codes for applicable seismic design requirement. High seismic areas will require more substantial rack construction and cell retention. The open racks can be step or tier design and are found typically in vented and large VRLA cell installations. Open racks offer better ventilation and access for maintenance.

Battery cabinets are found predominantly on UPS systems of 300 kVA and below and contain VRLA cells. Top-connected battery cells/units require sufficient vertical clearance to safely perform the recommended maintenance. The ventilation and thermal considerations are often secondary concerns in the cabinet design but should not be overlooked.

All rack and cabinet layouts need to allow adequate space for proper and safe maintenance and testing. Local codes may mandate minimum spacing.

6.1.4 Battery disconnects

A battery disconnect provides a means to take the battery off line and isolate it from the UPS system and should always be rated for full load. This can be an advantage during installation and maintenance. The disconnect provides an additional safety aspect to the system. Battery disconnects are often used with parallel strings to allow for the isolation of each string. Battery disconnects should be used when the battery is located in another room from the UPS system. For UPS systems requiring a battery string to be installed on multiple racks, or for strings whose dc bus voltage exceeds 250 V, a multipole battery disconnect should be utilized to “split” the string into sections, thereby minimizing the overall voltage on a rack and increasing personnel safety during maintenance. Battery disconnects should always be able to be activated (opened) from within the battery area and should have lock-out/tag-out capability within the battery room.

6.1.5 Spill containment

Battery electrolyte could pose a hazard if this material is released. Spills can occur due to handling errors, cracked and/or leaking jars because of improper installation, plate growth, thermal runaway, fires, mechanical failures, and the use of cleaning solvents on the jar. Spill neutralization and containment measures that are appropriate for the selected battery should be considered, both for normal operation, during handling (installation and removal) and temporary storage. Applicable regulations and codes shall be followed. (IEEE P1578 [B6] provides additional information on battery electrolyte spill containment.)

6.1.6 Cable selection, sizing, and connections

The layout of the battery system should take into consideration the routing, length, type of cabling and temperature. Cable voltage drop due to undersized cable can be a major factor in shorter than expected run times (see 7.5.2 for an example of sizing). A safety issue arises when cable losses result in overheating. Multistranded, flexible, insulated-type cable is recommended for the battery post connections wherever cable connections are used. The battery post seals can be damaged by an improper cable connection. This cable should not put undue stress on battery cell posts. Multiple cable connections on the battery posts should be installed utilizing terminal plates and cable management systems where possible.

6.1.7 Provisions for maintenance and testing

The battery installation should allow adequate safe access and servicing headroom for maintenance, testing, and replacement. Some cabinet systems may not allow safe and easy access to the battery and should not be used. Access to cell/module terminals should be adequate for probes/clamps related to all maintenance and testing measurements in accordance with IEEE Std 450, IEEE Std 1188, and IEEE Std 1106. Aisle space for multitier rack installations should allow for ladder access and cell lifting equipment. The type of cabinets and racks will influence access to the battery, thus encouraging or limiting proper maintenance and testing.

6.1.8 Monitoring

The inclusion of a monitoring system may help in the performance of the recommended maintenance and testing activities. The monitor selected may include the ability to record discharges, cell voltage, temperature, connection resistance, internal ohmic, or other measurements. Some monitors may be able to provide real-time test data during a load test. Consideration for an appropriate interface for a monitoring system will reduce the potential logistic impact if monitoring is to be added in the future.

6.2 UPS operating consideration

The UPS maintains a constant ac output voltage to the load. During a battery discharge the battery supplies constant power to the inverter of the UPS. The dc input voltage to the inverter decreases during the discharge. To maintain a constant power output, the battery discharge current increases accordingly.

6.2.1 UPS charging limitations

When calculating the relation of battery size to the rectifier and inverter subsystems of the UPS, the user should consider the battery charging capability of the rectifier and the charge acceptance of the battery. The UPS system should minimize the discharge cycles imposed on the battery caused by load changes exceeding the rectifier output or response capability.

In addition, the rectifier should be sized to meet the full system load, system loss, and transient requirements, while providing battery recharge current, to minimize the period during which the load is not protected by a fully charged battery. Battery recharge is a function of charge acceptance, which is related to the battery technology and temperature. It is important that the load be fully protected following restoration of the normal ac supply to the rectifier.

CAUTION

Caution should be exercised to ensure the charger is of appropriate size for parallel string operation.

6.2.2 AC ripple current

AC ripple currents can cause overheating in VRLA batteries and may also have detrimental effects on VLA and, to a lesser extent, Ni-Cd batteries. UPS applications can place unusual conditions on a battery. Typically, UPS battery design seeks excellent short-term, high-rate current characteristics, which, in turn require the lowest possible internal cell resistance. This low resistance allows a lower impedance path for the ripple current coming out of the rectifier stage of the UPS, than the filter capacitors in the output of the rectifier.

In addition, the inverter stage of the UPS requires large transient currents as it builds ac power from the parallel rectifier/battery combination.

With a (high-impedance) ac power source, short-term, instantaneous load current changes will be drawn from the lower impedance battery. These factors may result in a relatively high ac component in the battery. At present, manufacturers place no warranty penalties on VLA cells operating in a high ripple current environment, but some manufacturers do publish maximum allowable ripple for VRLA. Ripple is an important consideration in affecting design life and it is advisable to maintain the rectifier filters as prescribed by the manufacturer.

6.2.3 Equalizing charge

An equalizing or freshening charge is given at a voltage higher than the float voltage for a selected length of time necessary to correct deviations from the manufacturer's specified voltage or electrolyte specific gravity, or if one or more cells fall below the minimum voltage defined by the manufacturer (corrected for temperature). The equalizing charge should not exceed the voltage limits of the connected equipment (UPS) and should not exceed the battery manufacturer's specifications. The equalizing charge can be applied to the entire battery or to an individual cell. Since excessive equalizing charge will have an adverse effect on battery life, equalizing should be minimized.

Given this consideration, the user will want to evaluate the use of any equipment that automatically equalizes after a discharge, particularly if that equipment automatically equalizes for a long period after short discharges or equalizes on a preset time base. Recharging will occur at normal float voltages; however, recharging can be expedited using an equalizing charge.

VRLA cells should not be equalized except when recommended by the battery manufacturer.

6.3 Warranty considerations

Since the warranties vary widely among manufacturers, the warranty deserves careful consideration when selecting a battery.

6.3.1 Acceptance criteria

The warranty offered should address the application and use of the battery. Some manufacturers offer warranties based on cycle service (number of cycles) and/or temperature, and may require use of a monitor for validation. Warranties can be based on full float service and design life. It is important to consider how the manufacturer defines a UPS application and how this might affect the warranty. It is important to understand what type of record keeping may be required to validate the warranty.

6.3.2 Full warranty replacement

If the battery or a cell becomes defective within the initial interval of service life (typically one year), it will usually be replaced by the manufacturer under the full warranty. This normally does not include the labor to change out the battery or cell and/or the shipping charges.

6.3.3 Pro-rated adjustment

If the battery or a cell fails prematurely after the full warranty replacement interval, the cost of the replacement battery is usually pro-rated based on the months of in-service use and the stated warranty period. This credit is typically applied to the current price of the battery. This normally does not include the labor to change out the new battery or cell, the freight to ship the new battery or cell, or the cost of disposal of the failed battery or cell.

6.3.4 Miscellaneous charges

Shipping and installation of the new battery may not be covered as a part of the warranty adjustment. Disposal of the defective battery frequently is not covered as part of the warranty.

6.3.5 Warranty evaluation

In evaluating a warranty the following items should be considered:

- Full replacement period
- Pro-rated adjustment period
- Shipping charges
- Installation costs
- Use conditions
- Temperature
- Cycling
- Charging
- Maintenance practices/records
- Warranty start date
- Defective battery disposal
- Claim
- Verification costs
- Installation testing requirements and restrictions

7. Battery sizing

The following subclauses provide an overview of the techniques and application considerations used to determine a battery size. IEEE Std 485 and IEEE Std 1115 offer more detailed information and procedures on the methods used for sizing batteries.

7.1 Voltage window design

The UPS voltage window determines the voltage range over which the battery is allowed to operate. The number of cells in the battery should be chosen so that the battery may be adequately charged, while allowing an end-of-discharge voltage that results in efficient utilization of the battery's capacity (see 7.4.3). The maximum operational dc voltage of the UPS is the maximum voltage that may be applied to the battery. The minimum operational inverter dc voltage determines the final voltage to which the battery may be discharged. In general, it is more economical to select the number of cells in the battery that gives the lowest possible end-of-discharge voltage provided that:

a) The battery may be charged in accordance with the manufacturer's recommendations within the maximum voltage limit for the system.

b) The end-of-discharge voltage is not below the manufacturer's minimum discharge value for the specified discharge time.

7.2 Temperature

The battery operating temperature affects the battery's life and performance.

7.2.1 Lead-acid

Battery performance decreases at temperatures below 25 °C. Note that temperature correction factors (see Table 1 and IEEE Std 485) apply to the discharge rate and not the discharge time. For example, a temperature correction factor of 1.11 for a certain cell type at 15.6 °C indicates that battery performance is approximately 10% less than at 25 °C. If this battery can supply, say, 100 kW for 15 min at 25 °C, it will be capable of delivering 90 kW for 15 min at 15.6 °C. The extent of this effect varies with cell construction.

Table 1— Temperature correction sizing factors for lead-acid cells based on nominal 1.215 specific gravity electrolyte

Initial Temperature (°C)	Temperature Correction Factor *K*	Initial Temperature (°C)	Temperature Correction Factor *K*
– 4	1.523	25	1.000
–2	1.459	26	0.988
0	1.399	28	0.970
2	1.344	30	0.956
4	1.307	32	0.941
6	1.271	34	0.934
8	1.233	36	0.923
10	1.190	38	0.909
12	1.161	40	0.894
14	1.133	42	0.885
16	1.106	44	0.878
18	1.083	46	0.870
20	1.056	48	0.863
22	1.031	50	0.856
24	1.010	52	0.849

Table 1 is based on VLA cells with nominal 1.215 specific gravity electrolyte. For information on a specific VLA or VRLA battery, contact the manufacturer.

7.2.2 Ni-Cd

While most UPS batteries operate in climate-controlled environments, it is not unusual for Ni-Cd UPS batteries to be subjected to a wider range of temperatures. If the lowest expected electrolyte temperature is below the standard temperature used to establish performance ratings (normally 25 °C), then the battery size should be increased. The value of the temperature correction factor is dependent upon battery design, discharge time, and electrolyte temperature at the beginning of the discharge. The application of the de-rating factor is similar to lead-acid cells (see 7.2.1). There is generally no noticeable increase in the available capacity at temperatures above 25 °C. Consult the battery manufacturer for temperature de-rating factors for various discharge times and temperatures.

7.3 Design and aging considerations

Although it is possible to size a battery for a smaller connected load, the UPS battery is generally sized to accommodate the full-load rated capacity of the UPS. The installed battery capacity should be selected so that the battery is capable of supporting the full UPS load at the end of the battery life.

A lead-acid battery has reached the end of its life when the available capacity drops to 80% of rated capacity. Therefore, to ensure that the battery will support the fully loaded UPS for the entire life interval, the calculated battery size should be increased by a 25% margin.

For Ni-Cd batteries there is no defined end-of-life point. Generally, a 1.25 aging factor is used. However, factors may vary from 1.10 to 1.40 depending on cell design, the expected operating conditions, and the planned life of the UPS system. Consult the battery manufacturer for additional information on aging factors.

Aging effects may be taken into account by the use of a separate factor, or, more commonly, by inclusion in the system design margins.

7.4 Battery sizing calculations

7.4.1 UPS efficiency and power factor

UPS power ratings are quoted in volt-amperes (VA) and/or watts. The rating in watts is equal to the rating in volts/amperes multiplied by the power factor [see Equation (1)]. The battery load for sizing purposes is the UPS output rating in watts divided by the efficiency of the inverter [see Equation (2)]. The efficiency should be based on rated UPS output.

$$\text{UPS output power rating in watts} = \text{UPS output in volts-amperes} \times \text{power factor} \tag{2}$$

$$\text{Nominal battery load} = \text{UPS output power} / \text{inverter efficiency} \tag{3}$$

7.4.2 Adjusted battery load calculation

The nominal battery load should be adjusted for aging and operating temperature conditions.

$$\text{Adjusted battery load} = \text{nominal battery load} \times \text{aging margin} \times \text{temperature correction factor} \tag{4}$$

7.4.3 Voltage window and number of cells

The UPS inverter has an input dc voltage range. The voltage range plus the voltage drop in the cable between the battery and the UPS needs to be considered. Cell voltage required for charging may be either the float or equalizing voltage as recommended by the manufacturer.

To take full advantage of the battery's usable capacity, the lowest possible end-of-discharge cell voltage should be used. This is subject to the limits imposed by the minimum allowable system voltage and the battery manufacturer's stated minimum cell voltage for the discharge time in question.

More important, the battery must first be capable of being charged in accordance with the manufacturer's recommendations and within the maximum system voltage limit.

These principles are illustrated in Equations (4) through Equation (7).

Error! Objects cannot be created from editing field codes. (5)

Minimum battery voltage = minimum UPS voltage (cutoff voltage) + voltage drop in cable at rated conditions. (6)

$$\frac{\text{Minimum battery terminal voltage}}{\text{Number of Cells}} = \text{minimum cell voltage} \qquad (7)$$

Based on the voltage range of the UPS and the minimum discharge voltage and charging voltage of the cell, the number of cells can be determined. Usually there are options for the number of cells, and an iterative approach may be followed to optimize the selection to reflect operating voltage recommendations and available cell sizes. For example, if the calculated minimum cell voltage is below the manufacturer's minimum recommendation for the specified discharge time, the calculation should be repeated so that the minimum cell voltage is equal to the value specified by the manufacturer. (This process is detailed in the sample calculations in 7.5.3 and 7.5.4.)

7.4.4 Cell selection

The manufacturers provide performance data in watts (or kilowatts) per cell, so the battery power required (from 7.4.2) must be divided by the number of cells (see 7.4.3). A cell is then selected that can provide at least this power for the specified time to the specified end of discharge voltage.

7.5 Sample application: three-phase UPS

System size: 500 kva at 0.80 power factor = 400 kW [see Equation (2)]
System ac output voltage: 3 phase, 120/208 V (not required for calculation)
Inverter efficiency: 0.92 efficiency at full load (dc input to ac output)
The inverter input power is therefore:

$$\frac{400\,\text{kW}}{0.92\,\text{eff}} = 435\,\text{kW} \quad \text{[see Equation (3)]}$$

NOTE—In practice, the battery load is frequently designated as "kW_b" to avoid confusion with the output power rating of the inverter.[5]

5 Notes in text, tables, and figures are given for information only, and do not contain requirements needed to implement the standard.

7.5.1 Operating conditions

UPS dc operating range and conditions:

- 432 V maximum rectifier equalizing voltage
- 405 to 430 V normal float voltage range
- 290 V minimum inverter low voltage cutoff
- Reserve time: 30 min
- Battery temperature range: 15 °C minimum to 40 °C maximum

NOTE—These values apply to this example only; other applications will have different values.

7.5.2 Voltage drop/cable sizing

In this example, the heavy batteries must be located in the basement of a relatively "light load design" commercial office building. The UPS must be located 50 cable meters away (100 cable meters total) in available space on the second floor.

Calculate maximum discharge current as follows:

435 kW / 290 V = 1500 A

Calculate cable size:

See: National Electrical Code® (NEC®) [B11] Article 310, Table 310.16.

Assume 75 °C temperature rating of copper conductors:

Calculation of cable ampacity and voltage drop is an iterative process. For this example, we assume the designer chooses to use four conductors per terminal in two separate raceways: one for positive conductors and one for negative conductors.

De-rate 20% per NEC [B11] Table 310.15(B.2.a) for more than four conductors in a raceway:

1500 / 0.80 = 1875 A

1875 A / 4 conductors = 469 A per conductor

Per NEC [B11] Table 310.16, a 750 kcmil (380 mm^2) conductor is rated for up to 475 A × 4 conductors = 1900 A

Therefore, minimum cable requirement = (4) 750 kcmil (380 mm^2) conductors per battery terminal. The designer should ensure that battery terminal plates are provided that can accommodate the number and size of the conductors.

Calculate voltage drop

See: NEC [B11] Chapter 9, Table 8.

Per the table, resistance for 1000 m (1 km) = 0.0563 ohms

Calculating for 100 m of cable = 0.0563 × 100/1000 = 0.00563 ohms

Use Ohm's Law to calculate voltage drop

$E = IR$

$E = 1500/4 \times .00563 = 2.1\ \text{V}$

The battery terminal voltage then needs to be 2.1 V greater than the minimum load voltage. A minimum calculated battery voltage of 292 V is practical.

A similar calculation should be performed for cabling from the battery terminals to the battery disconnect, including the center tap, if applicable, and the minimum battery voltage should be adjusted accordingly.

7.5.3 Lead-acid calculations

7.5.3.1 Initial assumptions and limiting factors

Battery discharge voltage range: 1.67 V/cell to 2.10 V/cell
Battery equalizing charge range: 2.30 V/cell to 2.50 V/cell

Sample calculation: Since the battery capacity does not remain at its nameplate rating throughout its life, a 25% margin will be included as an aging factor.

Also, since it is expected that the operating temperature will drop to a low of 15.6 °C (60 °F), the battery capacity should be increased by a factor of 1.11 (see 7.2.1,**Error! Reference source not found.**) to ensure that it will provide rated load at reduced temperature.

The adjusted battery load (see 7.4.1) is then as follows:

$$435 \times 1.25 \times 1.11 = 604\ \text{kW [see Equation (4)]}$$

7.5.3.2 Selection of number of cells and end voltage

For this example, it is assumed that the manufacturer recommends an equalizing voltage of 2.40 V/cell. The maximum number of cells is therefore as follows:

$$\frac{432\ \text{V}}{2.4\ \text{V/cell}} = 180\ \text{cells [see Equation (5)]}$$

In this case, no adjustment is made for the voltage losses in the cables and cell connectors. In the final stages of battery recharge the current drops to a point where the voltage drops are insignificant, allowing for the planned 2 V loss in the cables, the minimum battery voltage of 292 V is then used to calculate the final voltage per cell:

$$\frac{\text{Minimum UPS voltage}}{\text{Number of cells}} = \frac{292}{180} = 1.62\ \text{V/cell [see Equation (7)]}$$

In most cases, the calculated number of cells and minimum voltage per cell would be used directly in the remainder of the battery sizing exercise. However, in this example, it is assumed that the battery manufacturer states a minimum discharge voltage of 1.67 V/cell for a 30-min discharge. Since the calculated minimum voltage is 1.62 V/cell and the manufacturer's minimum voltage is 1.67 V/cell, it is necessary to adjust the number of cells to reflect the higher value of the minimum discharge voltage.

$$\frac{292\ \text{V}}{1.67\ \text{V/cell}} = 174.8\ \text{cells}$$

Use 175 cells, or round up to the next standard size if using multicell units.

7.5.3.3 Cell selection

The required cell performance can now be calculated as follows:

$$\frac{604\ \text{kW}}{175\ \text{cells}} = 3.45\ \text{kW/cell}$$

Now there is complete information with which to consult the manufacturer's performance charts and select the proper cell for the application (30 min, 1.67 V/cell, and at least 3.45 kW/cell). It may be beneficial to repeat the calculation to optimize the number of cells for a particular cell type. For example, if there is a cell that can provide 3.40 kW/cell, it would probably be more economical to increase the number of cells rather than using 175 of the next larger cell size. In this case, the new number of cells would be as follows:

$$\frac{604\ \text{kW}}{3.40\ \text{kW/cell}} = 178\ \text{cells}$$

Note that changing the number of cells will affect both the equalizing and the end-of-discharge voltages. Increasing the number of cells allows a lower end-of-discharge voltage per cell (more usable capacity) within the lower system limit, but may result in a required equalizing voltage that is higher than the upper system limit. Decreasing the number of cells will not impose any constraints on the maximum voltage limit, but will result in a higher end-of-discharge voltage per cell (less available capacity). In this particular example, it is already known that 180 cells can be accommodated within the upper system voltage limit.

At the lower voltage limit, the use of 178 cells would allow discharging to 1.64 V/cell, but would fail to meet the battery manufacturer's stated minimum of 1.67 V/cell.

Battery selection, then, is a process of finding the best fit between the maximum charge voltage and the minimum operating point of the UPS that will allow the maximum use of the available battery capacity.

7.5.4 Ni-Cd calculations

7.5.4.1 Initial assumptions and limiting factors

- Battery equalizing voltage 1.47 V/cell
- Battery discharge voltage 1.00 V/cell to 1.10 V/cell

Sample calculation: Since the design life (assumed to be 15 years) is well within the life expectancy of vented Ni-Cd batteries, a 10% margin will be included as an aging factor.

In this example, it is assumed that the temperature correction factor for the 15.6 °C minimum temperature is 1.03 (the manufacturer should be contacted for specific data).

The adjusted battery load can then be calculated as follows:

$$435 \times 1.10 \times 1.03 = 493 \text{ kW [see Equation (4)]}$$

For such a small temperature correction factor, another approach is to incorporate it into the overall battery sizing margins (see 7.2.2) to give a combined figure for both aging and low temperature operation.

7.5.4.2 Selection of number of cells (cell type) and end voltage point

The most economical battery choice results from using the lowest end-of-discharge voltage and the largest possible number of cells that will satisfy the manufacturer's recommendations. The first step in the battery calculation is to ensure that the battery can be properly charged.

For this example, it is assumed that the manufacturer recommends a minimum equalizing voltage of 1.47 V/cell. The maximum number of cells is therefore:

$$\frac{432 \text{ V}}{1.47 \text{ V/cell}} = 294 \text{ cells [see Equation (5)]}$$

NOTE—In this case no adjustment is made for voltage losses in the battery cables and cell connectors. In the final stages of battery recharge the current drops to a point where the voltage drops are insignificant on the large cables that have been sized for the final discharge currents.

Allowing for the planned 2 V loss in the cables, the minimum battery voltage of 292 V is then used to calculate the final voltage per cell:

$$\frac{\text{Minimum UPS voltage}}{\text{Number of cells}} = \frac{292}{294} = 0.99 \text{ V/cell [see Equation (7)]}$$

The calculated minimum voltage per cell is below the acceptable value of 1.00 V/cell to 1.10 V/cell. The number of cells would therefore be reduced to 292 for a minimum voltage per cell of 1.00 V.

7.5.4.3 Cell selection

At this point it has been determined that the battery required is one with 292 cells that can deliver 493 kW for 30 min and not drop below 1.00 V/cell. The required cell performance is therefore as follows:

$$\frac{493 \text{ kW}}{292 \text{ cells}} = 1.69 \text{ kW/cell}$$

Now there is complete information with which to consult the manufacturer's performance charts and select the proper cell for the application. When using tabular data, it may be necessary to interpolate between published values. In the example, the cell type required is one that will supply 1.69 kW/cell for 30 min to a final voltage of 1.00 V/cell. Since most manufacturers offer high, medium, and low rate cell ranges, it may be advisable to determine cell sizes for two or more of the ranges. The most economical option meeting the above parameters can then be chosen. Battery selection then, is a process of finding the best fit between the maximum charge voltage and the minimum operating point of the UPS that will allow the maximum use of the available battery capacity.

8. Commissioning

Commissioning is a process of verifying that components, subsystems, and systems as a whole perform according to the design intent. This process starts in the design phase by documenting design intent and continues through construction and acceptance ending with the verification of performance and system interactions. Commissioning incorporates the separate functions of system documentation, equipment startup, and performance testing and training. This process not only assures that components and subsystems are performing to the designer's intent, but that systems and system interactions meet design requirements.

Commissioning can be applied to any level appropriate to a job. When applied to batteries, commissioning could incorporate: documentation of the design intent and the basis of design; verification of the installation of racks, wiring, circuit protection devices, and monitoring system; validation of battery performance; and training of the operation and maintenance staff. Commissioning of the battery system might be a subset of commissioning the UPS system, which in turn, could be a subset of the commissioning of the electrical distribution system.

8.1 Design adherence

The party selected for commissioning will document the design intent and basis of design with the assistance of the design professionals. The designers also assist in clarifying the operation and control of UPS and batteries. Specific tests are developed to measure adherence to design specifications and performance requirements.

8.2 Installation adherence

The party selected for commissioning, verifies that all equipment is installed according to the manufacturer's published installation practices by use of forms and site inspections. Systems that are in effect "built up," require customized inspection procedures that assure conformance to industry and professional standards and design specifications.

8.3 Performance adherence

A defined acceptance pass/fail criterion prior to testing is necessary. Verify that the battery is fully charged and stabilized for at least 48 h prior to testing to ensure accurate measurements. A battery system acceptance test, as defined by one of the following IEEE recommended practices: IEEE Std 450, IEEE Std 1106, or IEEE Std 1188 is the appropriate test to verify performance versus design requirements. (See Annex F.)

9. Maintenance and testing

9.1 General

Proper maintenance and testing procedures will help optimize the life of a battery and will aid in ensuring that it is capable of satisfying its design requirements. This subclause presents minimum guidelines for the performance of maintenance and testing. However, the reader should consult the manufacturer's written instructions and IEEE Std 450, IEEE Std 1188, or IEEE Std 1106 as applicable. All inspections and measurements should be performed under normal float conditions where possible.

9.2 Safety

All procedures should be performed in a safe and professional manner by knowledgeable personnel in UPS systems and trained in the safety precautions involved. It is good practice to perform all inspection and maintenance activities in teams of at least two persons.

WARNING

The potential for lethal voltages, both dc and ac, may exist at the battery terminals and/or between the battery and ground.

9.2.1 Protective equipment

Protective equipment shall be provided and used whenever performing maintenance on a battery. The following is an abbreviated list of protective equipment that shall be available to personnel who perform battery maintenance work:

a) Safety glasses with side shields, or goggles, or face shield, as appropriate
b) Protective gloves
c) Protective aprons
d) Portable or stationary water facilities in the battery vicinity for rinsing eyes and skin in case of contact with electrolyte
e) Class C fire extinguisher (use of a class C, CO_2, fire extinguisher is not recommended by some battery manufacturers due to the potential for container damage from thermal shock)
f) Appropriate neutralizing agent (in accordance with battery manufacturer's recommendations) to neutralize electrolyte spillage (the removal and/or neutralization of an electrolyte spill may result in production of hazardous waste; the user should comply with appropriate governmental regulations)
g) Electrically insulated tools

9.2.2 Warnings

9.2.2.1 Opening battery string while under load

Never open a battery string circuit while it is under a load other than by an appropriate interrupting means. The entire string voltage will appear across any two open points within a battery circuit when the string is connected to a load. Additionally, arcing may occur when the circuit is opened or closed. For example, if the terminals are opened at the individual cell level while the string is connected to a load, lethal voltages may be present across the open circuit that is created by removing one side of the connection.

9.2.2.2 Hazardous voltage path to ground

Battery terminals may have lethal voltages with respect to ground. It cannot be assumed that the battery is ungrounded. Check the voltage to ground (ac and dc) before working around the battery. If the voltage is other than anticipated, or is considered to be in an unsafe range, do not work on the battery until the situation is understood and/or corrected. Wear protective equipment suitable for the voltage. A path to ground can be created through the UPS when the rectifier is connected to a transformer with a grounded winding.

9.2.2.3 Hazardous voltages within the system

Lethal voltages may exist between components within the system (e.g., between tiers, across aisles, across open switches). Take appropriate precautions.

9.2.2.4 Battery isolation from input power

When the battery is not isolated from UPS ac input, hazardous voltage may exist at battery terminals and ground. (See 9.2.3 for precautions.)

9.2.3 Precautions

Written protective procedures shall be adhered to as part of the inspection and maintenance activities. A safe working environment will help ensure personnel protection and accident avoidance.
The following are typical precautions used during inspection and maintenance activities:

a) Use caution when working on batteries since the potential for lethal voltages, both dc and ac, may exist at the battery terminals and/or between the battery and ground

b) Prohibit smoking and open flames and avoid arcing in the immediate vicinity of the battery; only properly insulated tools should be used when working on the battery

c) Ensure that all test leads are clean, in good condition, and connected with sufficient length of wire or cable to work safely

d) Provide over current protection for test equipment connections

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

f) Ensure unobstructed egress from the battery area

g) Do not wear metallic objects such as jewelry

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

i) Ensure that all alarm/monitoring systems are operable

9.3 Maintenance of lead-acid batteries

The key to ensuring the reliable operation of your battery plant is to establish a comprehensive predictive maintenance and testing program. The following are guidelines that can help establish or reinforce the maintenance program.

Proper maintenance will prolong the life of a battery and will aid in ensuring that it is capable of satisfying its design requirements. A good battery maintenance program will serve as a valuable aid in maximizing battery life, preventing avoidable failures, and reducing premature replacement. Battery maintenance should be performed by personnel knowledgeable of batteries and the safety precautions involved.

VRLA battery maintenance is similar in many respects to that required for vented batteries. However, VRLA maintenance practices do not include internal cell inspections, specific gravity readings, or water additions. Therefore, procedures such as internal ohmic measurements are recommended. (See IEEE Std 450 for maintenance requirements for VLA batteries and IEEE Std 1188 for VRLA.)

9.3.1 Inspections

Regular inspections should be performed on both vented and VRLA battery installations. A battery cabinet or other type of enclosure should not restrict access for periodic inspections or testing.

Regular inspections should include: visual checks for signs of cracks in the cell/unit or electrolyte leakage, unusual jar or cover distortion, signs of corrosion at terminal connections, and the condition of racks/cabinets and ventilation equipment. The inspection should also include a review of the general appearance and cleanliness of the battery installation and accessibility to protective equipment.

Establishment of a pilot cell program will aid in quantifying the overall condition of the battery without the need to perform a detailed inspection of individual cells on a frequent basis. The pilot cells provide a quick overview on the physical and electrical conditions of the battery and should be reviewed during scheduled inspections (see Annex G). Selection of pilot cell/unit should include cells that have been identified for special attention during previous inspection.

The following is an abbreviated list of the most common items that should be included in the inspection procedure. A detailed list of all the conditions that might be noted as part of the physical inspection is beyond the scope of this guideline. An inspection of a VRLA battery is limited to the exterior of the battery since the jar material is opaque and does not permit internal inspection. Subclauses 9.3.1.3 through 9.3.1.6 are specific to VLA batteries. Refer to the manufacturer for information on specific observations that are not addressed below.

9.3.1.1 Post seals

Integrity of the post seals is important for reliable operation. Undue stress on the post seal can result in failure of the seal. External stress on the seal may occur through improper handling or unsupported cables attached to the post. Internal stress on the seal may be a result of corrosion of the cell plates.

In a lead-acid battery, corrosion problems occur predominantly at the positive post due to the tendency of acid to migrate up the positive post. Nodular (or crevice) corrosion can lead to post seal failure. Nodular corrosion is generally hidden within the seal area and eventually results in cracking of the cell cover. Creep corrosion is characterized by blackening of the post above the seal area and can cause connection problems (see 9.3.1.2).

In VLA cells, severe nodular corrosion may require cell replacement. Creep corrosion can often be managed, but it should not be allowed to affect the connection.

In VRLA cells the post seal must be “gas tight.” Any sign of seal failure should be investigated for possible cell replacement.

9.3.1.2 Connections

Corrosion on the connecting surfaces will cause an increase in connection resistance. An increase in resistance will cause heating and voltage drop at the connection during discharge. This condition can damage terminals, containers, or cause a fire.

Corrosion at the cell connections can occur if:

- Cleaning during installation was improperly performed
- Electrolyte has migrated up the post (see 9.3.1.1)
- Electrolyte was deposited on the cover, post, or connector during maintenance
- Electrolyte has overflowed from cell due to overfilling or due to a high electrolyte level at the time of equalize charging

Visually inspect all cell connections for signs of corrosion. If corrosion is observed, the resistance of the connection should be measured (see 9.3.2.5). If the resistance is acceptable and maintenance is performed at regular intervals, it may be acceptable not to disassemble the connection and only neutralize and clean the external surfaces. Inspect the connection during the next scheduled maintenance. If the resistance is unacceptable, disassemble, neutralize, clean, remake the connection and measure connection resistance.

9.3.1.3 Sulfation and plate contamination

The term *sulfation* normally refers to the accumulation of lead sulfate on the plates of the cell due to undercharging. Undercharging occurs whenever the current passing through the cell is insufficient to offset self-discharge. For batteries in float service, this corresponds to low float voltage.

For VLA cells in transparent jars, sulfate crystals may be observed by shining a flashlight on the plate edges. The crystals will reflect the light and will appear to sparkle. Sulfation may occur on either plate polarity.

On cells with copper inserts in the post, copper contamination may occur due to improper casting of the post or excessive corrosion. The edges of the plate will develop a red or copper color.

9.3.1.4 Sediment

It is natural to see sediment in a VLA cell. On a new cell this sediment is normally no more than a fine dusting across the bottom. Sediment will increase as the cell ages, and all cells should have approximately the same amount of sediment. Large flakes of material can indicate accelerated grid corrosion or other problems. Mounds of sediment in only a few cells in a string are also indicative of a problem. The primary causes of excessive sediment accumulation are undercharging, overcharging, cycling, and high cell temperatures. Sediment can also be the result of a problem during manufacture, such as improper curing or formation.

The battery manufacturer designed the cell to allow space at the bottom of the jar for the accumulation of material. If the sediment accumulation becomes so high that the sediment space is entirely filled, then the sediment may reach a point where it touches the bottoms of the plates in the cell and causes a cell short.

Examine the cell for excessive sediment accumulation, large pieces of plate material, and shorted plates.

9.3.1.5 Plate growth

Positive plate growth is a normal process occurring during the service life of the cell. The rate of positive plate growth can be accelerated by excessive cycling, overcharging, undercharging, or high temperature operation.

Examine the positive plates for signs of excessive growth, warping, or other abnormalities, and consider replacement as necessary.

9.3.1.6 Electrolyte level

The visual inspection of a vented battery should include a record of the electrolyte level of each cell. In the case of lead-antimony cells, this should be monitored frequently. The electrolyte should always be maintained between the maximum and minimum level lines. The electrolyte level should never be allowed to drop to a point that can expose the plate material to air. Only water that meets manufacturer specifications (e.g., de-ionized or distilled) should be added to the electrolyte.

9.3.1.7 VRLA

An inspection of a VRLA battery should include the cell/unit, post seals, and connections for signs of corrosion or electrolyte leakage. The containers should be examined for signs of excessive bulging, leaking, or cracking.

9.3.2 Measurements

In addition to regular visual inspections, other measurements of the battery should be recorded. Recorded measurements should include: individual cell and battery voltages, cell and ambient temperatures, and the resistance of all connections. A procedure that should be included in a maintenance program for VRLA is the recording of internal cell ohmic values. Measurements of ohmic values may also be useful in VLA cells used for short-duration, high-rate discharges. All measurements should be recorded and trended over the service life of the battery. (See Annex G for recommended measurement intervals.)

Following is a summary of the items to be included in battery maintenance.

9.3.2.1 Float voltage

The float voltage of the battery is specified by the manufacturer to maintain the battery at a full state of charge and maximize service life. The float voltage is dependent on the type of battery, its specific gravity, and operating temperature. Deviations from the average float voltage per cell may indicate a problem with the cell. Deviations in the battery float voltage from the recommended value may indicate a problem with the charger.

9.3.2.2 Float current

Float current is an indicator of battery state of charge or cell internal changes. Changes in float current may be associated with temperature and temperature variations, aging, state of charge, or cell internal changes. A typical normal charge current requirement at 25 °C on a fully charged VLA cell is less than 0.5 A per 1000 Ah of the battery's eight-hour rating, or 2 A per 1000 Ah for VRLA. Values that are more than twice this value in a fully charged battery should be investigated and the cause of the excessive current determined and corrected.

9.3.2.3 Ripple voltage and current

Many UPS designs use power-switching electronics. The switching of the current causes current harmonics and associated voltage ripple. Periodic measurements of voltage ripple should be taken. High levels of ripple current will cause excessive heating in VRLA cells, elevated water consumption in VLA cells, and accelerated aging in both. Ni-Cd cells will experience elevated water consumption. A common recommendation by the battery manufacturers for maximum ripple voltage, as a percentage of the applied battery float voltage, is 5% peak-to-peak (3.5% of the rms voltage). The maximum ripple current is often expressed as 5% of the eight-hour rated capacity.

9.3.2.4 Specific gravity

Specific gravity measurements in VLA cells can be used as an indicator of the state of charge of a cell. A specific gravity measurement that is lower than the manufacturer's nominal value may indicate a low state of charge; however, it may also be as a result of high temperature, recent discharge, or recent water addition. High specific gravity readings may be observed at low temperature or when water consumption has lowered the electrolyte level. Specific gravity readings can be useful under certain circumstances, but the variability discussed above often limits its value. Specific gravity readings require temperature correction to be accurate.

9.3.2.5 Connection resistance

Post or connector corrosion may cause an increase in connection resistance. An increase in resistance will cause abnormal heating and voltage drop at the connection during discharge. This condition can damage terminals, containers, or cause a fire.

The resistance of all connections should be measured immediately after installation and periodically throughout the battery's service life. For an individual connection, a deviation of more than 20% from its baseline value, or from the manufacturer's typical value, indicates that corrective action should be taken.

9.3.2.6 Internal ohmic values

Measurements of internal ohmic values on VRLA batteries can provide useful information on the condition of the battery. Measurements should be performed on a stable battery. Recent discharges, recharges, or rectifier/charger anomalies can influence readings.

Internal ohmic values can be taken using test sets that employ proprietary technology and express the readings as impedance, conductance or resistance. While these measurement techniques are related, there is no direct conversion between values measured by different devices or generations of devices. For this reason, baseline values should be established and further measurements should be made using the same device. For VRLA batteries in high-rate, short-duration UPS applications, an increase of 50% in impedance or resistance, or a decrease of 30% in conductance, is generally considered significant and indicates a need for discharge testing or possible cell/unit replacement.

While internal ohmic measurements provide useful information about the condition of VLA batteries in high-rate, short-duration UPS service, at this time there is no consensus regarding the deviations at which corrective actions should be taken.

9.3.2.7 Temperature

The impact of operating temperature is discussed in 5.3.1. Temperature measurements permit assessment of the temperature differential between cells/units within the battery and the differentials between ambient and electrolyte temperatures. Because of their greater sensitivity to elevated temperature, the measurement frequency for VRLA batteries should be greater than for VLA types. VRLA temperatures should be measured at the negative terminal post of each cell/unit, while VLA temperatures can be measured directly from the electrolyte of a sampling of cells (typically 10%).

Corrective action should be taken if the temperature differential between cells/units is greater than 3 ºC. Battery temperatures that are consistently above ambient may indicate high ripple (see 9.3.2.3), overcharging, or internal cell shorting and should be investigated.

9.4 Maintenance requirements – Ni-Cd

Inspection of the battery should be performed on a regularly scheduled basis. The interval should be selected depending upon site conditions, charging equipment, and monitoring devices providing remote indications of abnormal operations.

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 Ni-Cd batteries and the safety precautions involved.

9.4.1 Inspections

Regular inspections should be performed on battery installations. A battery cabinet or other type of enclosure should not restrict access for periodic inspections or testing.

Regular inspections should include: visual checks for signs of cracks in the cell/unit or electrolyte leakage, unusual jar or cover distortion, signs of corrosion at terminal connections, and the condition of racks/cabinets and ventilation equipment. The inspection should also include a review of the general appearance and cleanliness of the battery installation and accessibility to protective equipment.

Establishment of a pilot cell program will aid in quantifying the overall condition of the battery without the need to perform a detailed inspection of individual cells on a frequent basis. The pilot cells provide a quick overview on the physical and electrical conditions of the battery and should be reviewed during scheduled inspections. Selection of pilot cell/unit should include cells that have been identified for special attention during previous inspection.

The following is an abbreviated list of the most common items that should be included in the inspection procedure. A detailed list of all the conditions that might be noted as part of the physical inspection is beyond the scope of this guideline. Consult the manufacturer for information on specific observations that are not addressed in 9.4.1.1 through 9.4.1.4.

9.4.1.1 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 upon 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

9.4.1.2 Semiannually

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

9.4.1.3 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

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.

9.4.1.4 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 9.4.1.1 and 9.4.1.2.

9.4.2 Corrective actions

9.4.2.1 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.

9.4.2.2 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.

9.4.2.3 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 D to determine the state of charge and take corrective action.

9.4.2.4 Connections

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.

When a bolted connection is found loose, disassemble, clean, reassemble, and re-torque the connection. The re-assembly should be made using corrosion inhibitor, following the instructions of the manufacturer.

9.5 Testing

9.5.1 Load testing

The most accurate way to determine the condition of a battery is through load testing. Load testing is the most widely accepted method to evaluate the system response to a loss of normal power and should be performed as per Annex G. This will aid in the identification of battery degradation and provide information on the expected operation of the battery and related components.

Load testing is the accepted way to determine where the battery is on the capacity versus life curve for the particular battery, cell, or unit. It is the most accurate way to determine the capacity of the battery. Load testing may also provide data on the performance of the associated system (e.g., UPS inverter) as well as the conduction path of the interconnected system. Load testing should be performed at the rate that most closely resembles its duty cycle. Battery voltage measurement must be taken at the battery terminals. Verify that the battery is fully charged and stabilized for at least 48 h prior to testing to ensure accurate measurements.

The true measure of the condition of a battery is how it performs under load. IEEE Std 450, IEEE Std 1188, and IEEE Std 1106 provides criteria for battery replacement. For example, it is recommended that a lead-acid battery be replaced when it reaches 80% of its rated capacity. The best method of performing a battery load test is to monitor each individual cell or unit during the discharge. Weak or bad cells can be identified and scheduled for replacement a determination can be made whether to replace individual cells or the complete string. Thermographic scanning of bolted connections should be considered during the discharge to aid in the identification of conduction problems.

It is desirable to trend-load test results to allow prediction of battery end of life. This requires that the discharge be continued to a voltage at or close to the system end voltage.

9.5.2 Test load

The test may include using actual or real loads; however, using real loads may present a potential exposure to an interruption in power should the battery suffer a gross failure during the test procedure. An alternative to using real load is to connect a resistive load bank to the system. Extreme caution must be used when selecting and connecting a load bank to ensure proper voltage and current compatibility with the system being tested.

CAUTION

Load-bank testing must always include a proper means to safely disconnect maximum possible current.

An ac load bank is used when connecting to the output of UPS. This would require either a shutdown of the real load or establishing an alternate source for the continued operation of equipment. A review of the system design should be performed to verify that such a configuration is available and that the source can support the critical load and the addition of a load bank. Considerations should include source, conductor and switchgear capacity. Installation of new UPS systems should include consideration for establishing a maintenance bypass that would facilitate these activities.

Alternatively a dc load bank may be used to test the battery. DC load banks must not be used for ac loads and ac load banks must not be used for dc loads.

Test loads may be selected based on full load capacity of the UPS, the actual loading of the UPS or the rated capacity of the battery. Results from testing at partial loads are not indicative of performance at full load. The battery should be tested to the dc system design end voltage.

9.5.3 Test duration

The test duration is dependent on the selected rate.

9.5.4 Test equipment

The test equipment used during the performance of the load test should, at a minimum, be capable of monitoring the overall system voltage, current, and duration of the test. The test equipment should be of a sufficient sampling rate as to provide real-time data for test personnel. In addition to the above basic parameters, test equipment is available that can also provide information on individual cell or unit voltage and intercell connection performance. Monitoring the performance of individual cells or units during load testing can identify problems that could not be identified without this capability.

In addition to the monitoring of the above electrical characteristics, thermographic monitoring of the battery plant can identify unwanted heating problems not only of the cell/unit but also of the related connections. Testing performed on a UPS where the load is connected at the output of the inverter can provide thermographic data on the entire conduction path including the battery, the UPS, and the interconnection between both.

9.6 Data analysis

Data analysis should quantify the average load, either in amperes or kilowatts, and the time duration of the load test. The capacity of the battery may be calculated using this information and by referencing manufacturer's published discharge data for the specific cell/unit. The formula used for calculating the percent capacity of the UPS battery is shown in Equation (8).

9.6.1 Capacity calculations

$$\text{Percent capacity} = [W_a/W_t] \times 100 \tag{8}$$

where

W_a is the actual power after temperature compensation has been factored
W_t is the rated power based on manufacturers published data for the actual test duration, t.

The process used for calculating battery capacity using test data requires that a discharge curve be constructed for the cell under test. The curve is constructed by using the manufacturer's published power in watts versus time data tables for a predetermined end voltage. The curve is created from the plotted points.

The remainder of this subclause provides an example of a battery capacity calculation.

Discharge Curve data for cell model XYZ from published power data to 1.63 V are shown in Table 2.

Table 2—Discharge power for cell XYZ to 1.63 V/cell at 25 °C

Discharge power (kW/cell)	Discharge power (W/cell)	Time (s)
3.335	3335	60
2.970	2970	300
2.573	2573	600
2.452	2452	720
2.340	2340	840
2.279	2279	900
2.227	2227	960
2.123	2123	1080
2.030	2030	1200
1.663	1663	1800
1.025	1025	3600
0.452	452	10800

The step-by-step calculation process is as follows:

a) Calculate the average load power in watts applied to the battery over the duration of the load test. The average power in watts is the arithmetic mean of the measured battery terminal voltage multiplied by the current over the test duration

Table 3 shows example test data for a 180-cell string:

Table 3—Example text data for 180-cell string

Time (s)	Discharge power (W)	Avg. power (W/Cell)
30	517890.7	2877.17
60	524123.6	2911.8
90	523705.4	2909.47
120	523394.9	2907.75
150	523528.2	2908.49
180	523108.2	2906.16
210	523518.7	2908.44
240	523147.2	2906.37
270	522905.8	2905.03
300	522620.4	2903.45

b) Calculate the average power (W_{avg}) in watts per cell (or unit) by dividing the average power in watts measured at the battery terminal by the number of cells in the string. The average power (W_{avg}) over the duration of the test is therefore 2904 W/cell.

c) Adjust the average power (W_{avg}) for the initial battery temperature by multiplying the temperature-correction factor (see 7.2.1, **Error! Reference source not found.**) to adjust the discharge power rate in the capacity calculation. The temperature-corrected average power is called adjusted power (W_a). In the example, the battery was tested at 25 °C. The correction factor is 1.0. Therefore, W_a for this example is 1.0 × 2904 = 2904

d) The adjusted discharge rate W_a is used for the capacity calculation using the discharge curve prepared for the cell

e) Draw a vertical line at the actual test time until it intersects the curve constructed below

f) Read the corresponding power (W_t) on the *y* axis

g) The calculated percent capacity is the power (W_a) identified with the actual run time divided by the power (W_t) derived from the discharge curve multiplied by 100.

% Capacity = $[W_a/W_t] \times 100$, where temperature compensation has been factored into W_a.

Figure 1 is a portion of the entire log curve for this example.

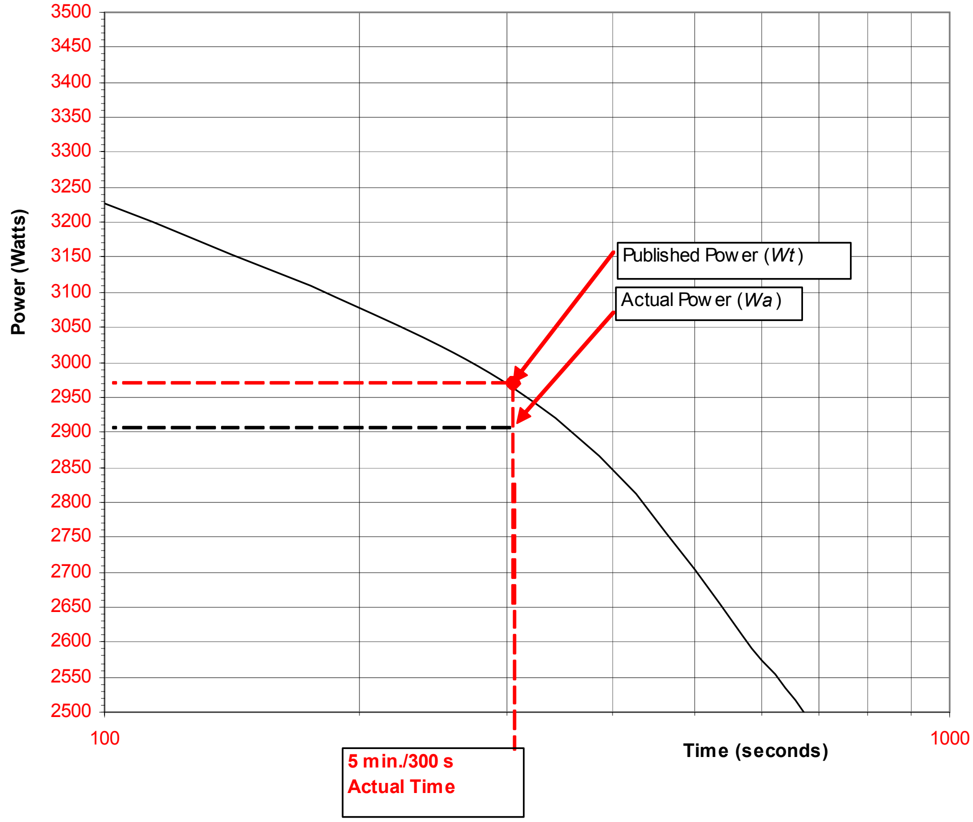

Figure 1—Graph of discharge date for XYZ cell

The result for the above example is: $W_a/W_t = (2904/2970) \times 100 = 97.7\%$

This calculation can also be performed using a spreadsheet. Figure 2 shows a spreadsheet that is designed to perform interpolations on published data.

B16 fx =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:	**UPS #1**				
4	Mfr/cell type:	**XYZ**				
5	Test date:	**6/29/2005**				
6	Initial temperature:	**25**	°C			
7						
8						
9		**Rate**		**Time**		
10	Published data point 1	2970	W/cell	5	min	
11	Published data point 2	2573	W/cell	10	min	
12						
13	Test results	2904	W/cell	5	min	
14	Temperature factor	1.00				
15						
16	**Calculated capacity**	**97.8%**				
17						
18	Enter two published data points that bracket the actual time of the test,					
19	plus the results of the test itself. (See next sheet for example.)					
20	The temperature factor is the factor applicable for the electrolyte					
21	temperature at the start of the test, and should be a number greater					
22	than or equal to 1.00. (Note that the actual current used for the test					
23	should be reduced in accordance with the same factor.)					
24						

Figure 2—Spreadsheet for capacity calculation

9.6.2 Benchmark data

It is important that benchmark data be established for the battery at the time of commissioning. Later, this data can be compared with information collected during each of the subsequent maintenance and/or test schedules.

9.7 Record retention

All data should be maintained for review and to track the performance of the battery over time.

Annex A

(informative)

Bibliography

[B1] Brecht, W.B., “Strategies for Overcoming the Adverse Effects of Imbalances in the Second Order Reactions in Valve-Regulated Lead-Acid Cells,” Proceedings of Intelec ’98, paper 19-1, pp. 436-442.

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

[B3] IEEE Std 1189™-1996, IEEE Guide for Selection of Valve-Regulated Lead-Acid (VRLA) Batteries for Stationary Applications.

[B4] IEEE Std 1375™-1998 (R2003), IEEE Guide for the Protection of Stationary Battery Systems.

[B5] IEEE Std 1491™-2005, IEEE Guide for Selection and Use of Battery Monitoring Equipment in Stationary Applications.

[B6] IEEE P1578/D10, IEEE Draft Recommended Practice for Stationary Battery Electrolyte Spill Containment and Management.[6]

[B7] International Code Council (ICC), International Fire Code, 2006 ed.

[B8] International Code Council (ICC), International Building Code, 2006 ed.

[B9] International Code Council (ICC), International Mechanical Code, 2006 ed.

[B10] National Fire Protection Association (NFPA), NFPA 1 Uniform Fire Code, 2003 ed.

[B11] NFPA 70-2005, National Electrical Code® (NEC®).[7]

[B12] NFPA 70B-2002, Recommended Practice for Electrical Equipment Maintenance.

[B13] NFPA 70E-2004, Standard for Electrical Safety Requirements for Employee Workplaces.

[B14] NFPA 75-2003, Standard for the Protection of Electronic Computer/Data Processing Equipment.

[B15] NFPA 76-2005, Standard for the Fire Protection of Telecommunications Facilities.

[B16] NFPA 110-2005, Standard for Emergency and Standby Power Systems.

[B17] NFPA 111-2005, Standard on Stored Electrical Energy Emergency and Standby Power Systems.

[B18] NFPA 5000-2005, Building Construction and Safety Code.

[B19] PECI, Portland Energy Conservation, Inc.

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[6] This IEEE standards project was not approved by the IEEE-SA Standards Board at the time this publication went to press. For information about obtaining a draft, contact the IEEE.

[7] The NEC is published by the National Fire Protection Association, Batterymarch Park, Quincy, MA 02269, USA (http://www.nfpa.org/). Copies are also available from the Institute of Electrical and Electronics Engineers, 445 Hoes Lane, Piscataway, NJ 08855-1331, USA (http://standards.ieee.org/).

[B20] Underwriters Laboratories, Inc., UL 94, Tests for Flammability of Plastic Materials for Parts in Devices and Appliances.

[B21] Underwriters Laboratories, Inc., UL 924, Emergency Lighting and Power Equipment.

[B22] Underwriters Laboratories, Inc., UL 1778, Uninterruptible Power Systems.

[B23] Underwriters Laboratories, Inc., UL 60950-1, Information Technology Equipment – Safety.

Annex B

(normative)

Seismic requirements

The UPS battery user/integrator/specifier should first identify what seismic risk exists at the site where a battery will be installed. This information is available from a number of sources, the most common being Building Codes. Local building code enforcement officials should be contacted for details. For example, in the USA:

— International Building Code [B8]

— Building Construction and Safety Code [B18]

The next step is to verify with the battery manufacturer that the battery is designed to survive a seismic event. As it is not practical to manufacture multiple lines of products, most battery manufacturers will design for the worst case seismic rating. The user wants reasonable assurance that, during an earthquake or other seismic event, the battery:

— Will not rupture, crack, or otherwise breach the integrity of the enclosure, including jar and post seals

— Will not leak or discharge electrolyte

— Will not damage posts or connections

— Will not damage internal plates or cause plate-to-plate short circuits

For rack-mounted batteries, the industry has standardized on a battery rack rating system that was originally based on building code designations. (Other designations may be applicable, such as nuclear or telecommunications applications, but the following are the most common commercial designations.)

Zone 0–1: Negligible seismic activity
Zone 2: Infrequent and minor seismic activity
Zone 3: Significant seismic activity
Zone 4: Areas of intense seismic activity

Annex C

(normative)

Lead-acid battery technology

The lead-acid battery is one of the oldest rechargeable (secondary) battery technologies in existence. A number of designs have evolved to meet specific design objectives and applications.

C.1 Components

The active plate materials are lead dioxide (PbO_2) for the positive electrode and sponge lead (Pb) for the negative. The active materials for both the positive and negative electrodes are incorporated in a plate structure composed of lead or a lead alloy.

The electrolyte, an aqueous solution of sulfuric acid (H_2SO_4), is an active component in the overall cell reaction. Its concentration depends on the battery design. On discharge, lead sulfate ($PbSO_4$) is formed at both the positive and the negative plates, and the concentration of sulfuric acid in the electrolyte is reduced as sulfate ions are consumed and water is generated.

During recharge, the lead sulfate is converted back into lead dioxide at the positive plate and sponge lead at the negative. Towards the end of recharge and during float operations, oxygen and hydrogen are generated at the positive and negative plates, respectively.

C.2 Plate constructions

C.2.1 Pasted plate

The pasted plate (see Figure C.1) is the most common design for float applications. Cycling capabilities can be improved by the addition of active material retention devices (C.8). The active material is formulated into a paste mixture, which is applied to a lead alloy grid. This grid structure provides many interconnecting current paths to the plate terminal. The plates are installed vertically in the cell. Pasted flat plates are manufactured with grids of varying thickness (C.6).

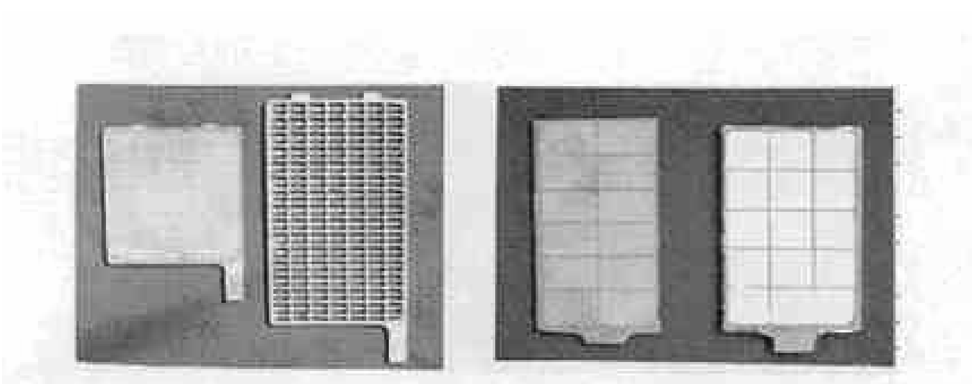

Figure C.1—Examples of pasted flat plates

C.2.2 Planté plate

The Planté positive plate (see Figure C.2) uses a thick, pure lead casting that is attached to an antimony alloy lead connecting strap. The surface of the plate becomes the active material, and both sides of the plate are configured to increase the surface area.

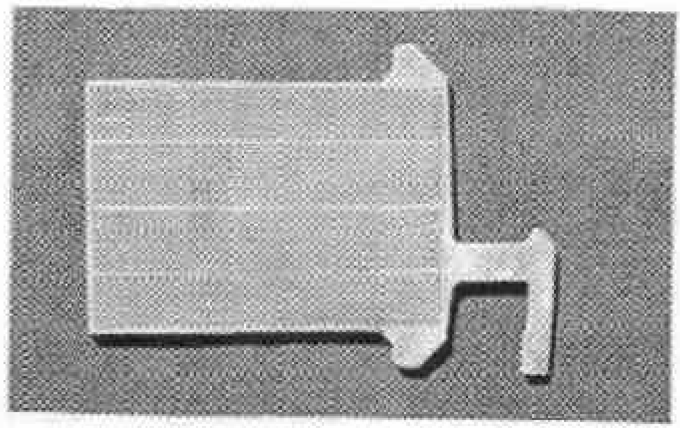

Figure C.2—Planté plate

C.2.3 Modified Planté plate

The modified Planté positive plate design (see Figure C.3) uses a thick antimony alloyed lead grid with cast holes into which coiled, corrugated pure lead strips have been pressed. Like the Planté design, the surfaces of the lead strips become the active material.

Both Planté designs provide a very long float service life and are capable of many charge/discharge cycles. They can be used for high-rate, short-discharge applications, but may require more floor space than other designs.

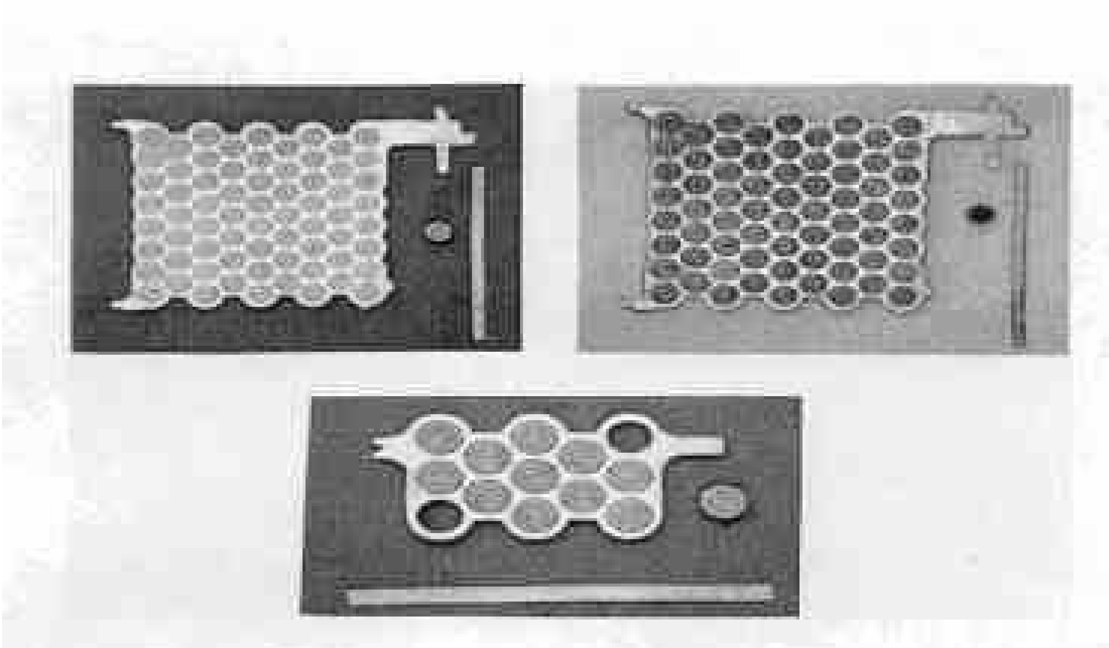

Figure C.3—Examples of modified Planté plates

C.2.4 Round plate

Round plate construction (see Figure C.4) is a variation of the pasted flat plate design. In the round plate design, the active material paste is applied to a pure lead grid structure that is horizontal, round, and slightly conical. The round plate is designed for very long life in float operation. However, its high-rate, short-duration discharge performance is less than that of most flat plate designs, and it is not well-suited for applications where frequent deep discharges could be expected.

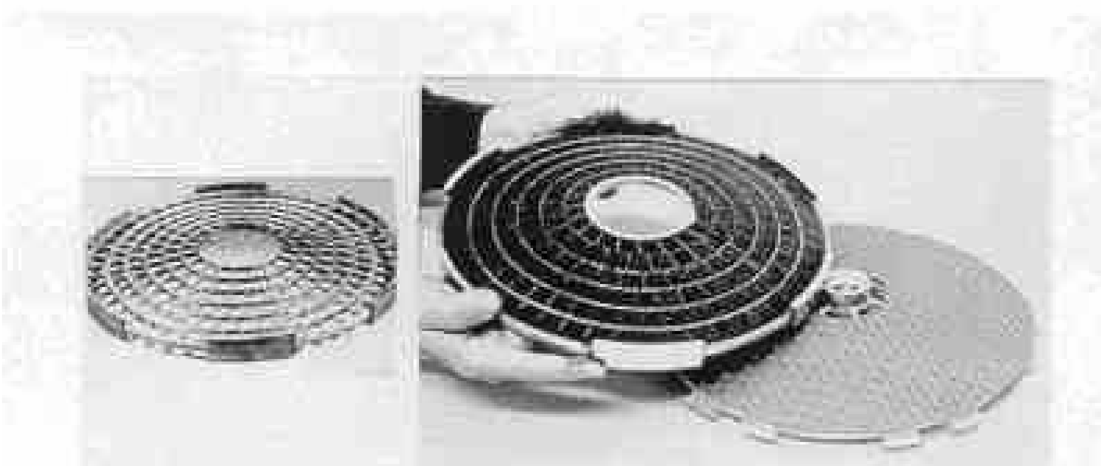

Figure C.4—Examples of round plates

C.2.5 Tubular plate

The Tubular plate design (see Figure C.5) involves a positive plate arrangement that places the active material in nonconductive porous tubes. An alloyed lead rod is positioned in the center of each tube to act as a current conductor.

Due to the material retention properties of the tube, this design is capable of many charge/discharge cycles. Vented cells with tubular positive plates can be used for high-rate, short-discharge applications, but their rather poor high-rate performance will require a larger capacity to be used.

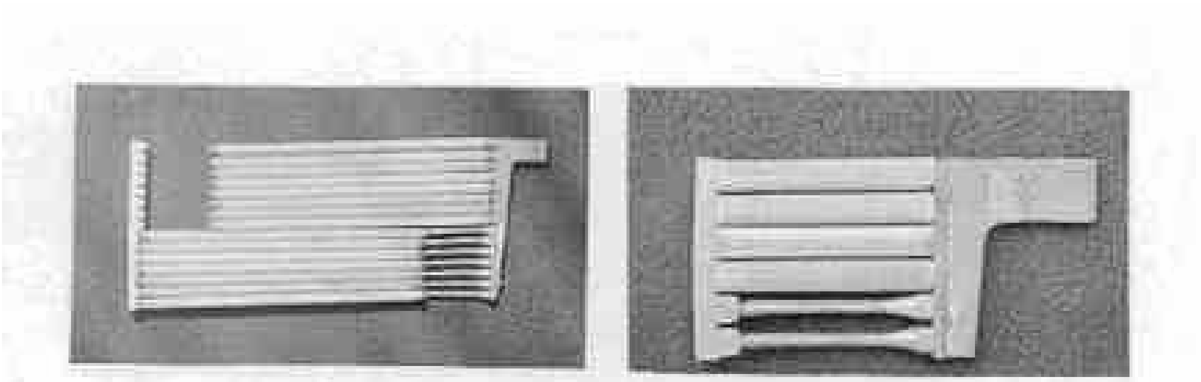

Figure C.5—Examples of tubular plates

C.3 Negative plate construction

With the exception of the round plate, VLA batteries (using the positive plate designs described previously) use a negative electrode that is a pasted flat plate. Batteries with round positive plates employ pasted round negative plates.

C.4 Plate thickness

As a lead-acid battery discharges, the active material on both the positive and negative plates is converted to lead sulfate. In pasted plate designs, this conversion process occurs slowly, first converting the active material on both flat surfaces of the plate, and then converting the material behind those surfaces, gradually reaching the interior of the plate from both sides. Batteries designed for low-rate discharges usually have thick plates, since the slow discharge allows full advantage to be taken of the active material near the center of the plate.

To meet the UPS demand for high-rate, short-term energy, the battery manufacturers expose the maximum plate surface area to the electrolyte by providing many thinner plates per cell. The disadvantage of the thinner plate construction is that the positive plates tend to fail from positive plate corrosion sooner than the heavier thick plates. See 4.2 for a discussion of battery designs for different discharge durations.

C.5 Grid types

Lead is the primary component of battery grids. However, since lead is a soft metal, the grids are generally alloyed with a hardening metal so that they can support the plate element in the cell jar. The most common grid alloys are

a) Lead calcium grids

b) Lead antimony grids

c) Selenium/cadmium grids
d) Pure lead grids
e) Hybrid grids

C.5.1 Lead calcium grids

Cells with calcium alloy grids require very low float currents to keep them at full charge, which results in very low gassing rates and water consumption. These cells usually require a higher float voltage than those with other grid designs.

Calcium cells function well under float conditions, but might be less suitable when frequent deep discharge service is required. When used in UPS service, excessive testing of the system (resulting in frequent battery discharges) should be avoided.

C.5.2 Lead antimony grids

Grids alloyed with antimony are used in applications where frequent cycling and/or deep discharge service is required. Antimony content is typically in the range of 4% to 6%.

Float charge current, gas evolution, and watering frequency are proportional to the antimony content of the grids. Furthermore, as antimony grid cells age, releasing increasing amounts of antimony to the electrolyte, float current, water consumption, and hydrogen evolution increase due to interaction of the dissolved antimony with the negative plate.

C.5.3 Selenium/cadmium grids

Lead grids alloyed with selenium or cadmium and a very low level of antimony (about 1% to 2%) yield a grid that has good cycling service, but reduces the antimony migration (see C.5.2).

C.5.4 Pure lead grids

Positive grids made from pure lead can avoid some of the life-degradation properties associated with hardening agents in other alloy systems. Float, cycling, and water additions are comparable to calcium systems. Pasted plate cells with pure lead grids should not be confused with Planté type cells (seeC.2.2 and C.2.3). Pure lead grids are easily damaged during handling and transportation.

C.5.5 Hybrid grid designs

Generally, battery cells employ positive and negative grids of the same alloy (except for the Planté cell, which normally uses lead antimony negative plates). In so-called “hybrid” designs, the positive and negative grids are fabricated from different alloys. Antimony-based alloys are generally used for the positive grids and calcium-based alloys are generally used for the negative grids.

C.6 Separators and retainers

A separator is a porous nonconductive inert material designed to prevent the positive and negative plates from physically coming into contact with each other. The separator also prevents conductive bridges (dendrites) of active material from forming between the plates and short-circuiting the battery.

A retainer is a porous mat of inert material (typically fiberglass) that is either pressed between the plates or wrapped around the positive plate, depending on the anticipated use of the battery. A retainer helps to minimize the tendency of the positive active material to shed or slough off the plate during discharge and recharge.

C.7 Electrolyte

Electrolyte is a mixture of sulfuric acid and water having a specific gravity in the range of 1.210 to 1.300. The acid reacts with the active materials of the plates during discharge, forming lead sulfate ($PbSO_4$) and producing power.

With VRLA cells the electrolyte is immobilized by absorbed glass separators or by a gelling agent that is added.

C.8 Plate element support

The method used to support the plate element is an important aspect of cell design. Because the positive plates in the lead-acid system tend to physically grow larger during their service life, their support must be designed to preclude either undue internal stress or excessive pressure on the container itself, which would result in mechanical failure. Often this is accomplished by allowing the positive plate to grow by using such methods as a collapsible bridge, hanging the positive plate, or incorporating a sliding post bushing.

The plate element should also be constrained to prevent undue stress on the container caused by external movement during shipment or if the battery is to be applied in an area of seismic activity (see Annex B).

C.9 Jars and covers

The battery components are enclosed in a jar that provides a durable, leak-proof container for the electrolyte. A cover is bonded or welded to the jar, completing the enclosure.

Although covers are normally opaque, jars are often transparent to allow visual inspection of the cell element. Transparent jar materials include polystyrene (PS), styrene Acrylonitrile (SAN), polypropylene, polycarbonate (PC), and polyvinyl chloride (PVC). However, not all VLA designs utilize transparent jars. Some designs employ translucent polypropylene, and other designs use materials that are completely opaque (e.g., ABS plastic).

Whatever material is used, the primary requirement for vented cells is that the design enables the user to examine the internal condition of the cell and visually to determine its electrolyte level. Valve-regulated cells do not normally use transparent containers, since the electrolyte level is not variable and the internal cell components (e.g., the plates) are not visible for inspection. Otherwise, the jars and covers are similar to those used for vented cells.

As an additional precaution, many jars and covers are also manufactured using flame-retardant materials, such as PC and PVC.

C.10 Jar-to-cover and post seals

Post seals are one of the most critical aspects of cell design. The integrity of the post seal has a direct bearing on the float life and performance of the UPS battery, and its construction should be carefully considered in relation to its intended application. Poor seals can cause a number of serious problems, such as electrical faults that may result in fires or electrical shocks.

If the seals allow acid to creep up the post, oxidation will occur, which can lead to increased resistance at the connection or corrosion of the post. This degraded conductivity will cause a drop in available capacity or, in severe cases, may lead to post meltdown. Violation of either the jar-to-cover or post seals may also result in venting cell gases without the precaution of the flame arrestor. In valve-regulated cells, this will lead to cell dry-out and premature failure (see 9.3.1.1).

C.11 Cell terminal posts

Typically, the positive and negative terminals of VLA and VRLA cells/modules are designed for bolted connections. They are generally constructed of alloyed lead and may incorporate a copper or brass reinforcement which improves conductivity and optimizes high-rate performance. Sometimes smaller VRLA cell/units are equipped with quick-connect terminals.

C.12 Flame arrestor vents

Flame arrestor vents must be provided and installed for all VLA cells. As VLA batteries reach full charge, an explosive mixture of hydrogen and oxygen is emitted through the vent. If the vent is not functioning as designed, a spark could explode the concentration of gas within the cell (see 5.4.1).

Flame arrestor vents should be designed into all VRLA cells and is typically an integral part of the valve. As VRLA batteries reach full charge, especially if they are subjected to elevated temperature or excessive charging voltage or current, the internal pressure will increase and an explosive mixture of hydrogen and oxygen can be emitted through the vent. If the vent is not functioning as designed, a spark could explode the concentration of gas within the cell (see 5.4.1).

C.13 Recombination in VRLA cells

Valve-regulated lead-acid cells are sealed with the exception of a valve that opens as required to maintain internal pressure. These cells provide a means for recombination of gases to limit water consumption. This is accomplished by allowing oxygen evolved from the positive plate to pass across to the negative, where the recombination reaction occurs. The valve regulates the internal pressure to optimize recombination efficiency, hence the term “valve regulated.”

In a vented electrolyte system, excess charging energy causes water to be broken down into hydrogen and oxygen, which are vented out of the cell; this lost water must eventually be replaced. In a valve-regulated system, hydrogen evolution is suppressed in normal operation. Charging above recommended manufacturer’s ratings or at elevated temperatures will result in venting of hydrogen and oxygen from the cell; prolonged overcharging will result in premature failure.

C.14 Catalyst in VRLA cells

Under certain operating conditions it is possible for some VRLA batteries to experience a progressive self-discharge of the negative electrode, leading in turn to a progressive increase in float current. This effect is due to an imbalance in the second-order reactions in these cells and one method of overcoming this imbalance is to incorporate a catalyst in the head space of the cell (see Brecht [B1]). The catalyst restores the balance between the second-order reactions and inhibits premature failure due to negative self discharge. The use of a catalyst can provide additional benefits by reducing float current, grid corrosion and water loss, but such benefits should be considered relative to other (non-catalyst) designs.

Annex D

(normative)

Ni-Cd battery technology

Applications of Ni-Cd batteries typically follow three standby applications, as described in 4.2.

D.1 Plate construction

Ni-Cd battery types are normally characterized by their plate constructions. Differences between the various types can be seen in high-rate performance, cycling capability, and physical size and weight (see 4.5 and 4.6).

D.1.1 Pocket plate

Pocket plates consist of interlocking pockets of perforated, nickel-plated steel strips, which are pressed around the active materials to provide a current path and to reduce shedding. The plate is sealed in a steel frame and welded or bolted to the current collectors and terminal posts. All mechanical parts and connections in the cell are made of steel.

To improve the battery's performance, additives are combined with the active materials. Graphite is added to the positive plate for improved conductivity, while an expander (typically iron oxide) is added to the negative plate to stabilize capacity and enhance cycle life.

The separators are constructed of plastic in the form of either rods or grids, or of perforated corrugated sheets.

D.1.2 Fiber plate

Fiber plates are formed from a mat of nickel-plated fibers impregnated with the active materials. The plated fibers are welded to nickel-plated steel tabs connected to the steel terminal posts. The separators are usually made of micro-porous plastic.

In the fiber plate cell, no graphite or iron oxide is added to the active materials, which is an advantage if the battery is operated at very high temperatures and with repeated deep discharge cycles. Fiber plate cells may also offer advantages of reduced size and weight for a given capacity.

D.1.3 Sintered plate

In the sintered plate, carbonyl nickel powder is sintered at high temperature to a current collector of pure nickel or nickel-plated steel. The resultant porous structure is then impregnated with the active materials. The plate pieces are welded to tabs, and connected to the steel terminal posts.

The sintered plate has excellent conductivity and high-power density. Sintered plate designs are often used in small sealed cells, usually for portable consumer electronics, and in specialized batteries for aircraft applications. Sintered plates are also used in hybrid designs for industrial uses—including UPS (see D.1.5).

D.1.4 Plastic bonded plate

In a plastic bonded plate, the active materials are combined with a plastic powder and a solvent to form a thick paste, which is extruded onto a strip of pure nickel or nickel-plated steel. The plate pieces are welded to tabs and connected to the steel terminal posts.

Positive plates with this construction have added graphite to improve conductivity, but unlike other designs, the plate element must be clamped to inhibit expansion of the positive plate during the charge/discharge cycle. Consequently, this design is used only for negative plates in hybrid cells (see D.1.5). Plastic bonded negatives do not use iron oxide in the active material.

D.1.5 Hybrid designs

A combination of different plate types is sometimes used to optimize cell design, performance, and life for a particular application. One example uses a sintered positive plate with a plastic bonded negative to give good high temperature and cycling characteristics and low weight and volume.

D.2 Cell construction

As with other battery types, Ni-Cd batteries consist of a number of individual cells connected together in a series (and sometimes parallel). For most UPS applications, cell capacities range from as little as 5 Ah to over 1500 Ah. In addition to consisting of individual cells, Ni-Cd batteries are often available using multicell units with 2 to 10 or more cells per container.

Although most Ni-Cd batteries for the UPS application are vented, sealed cells and other special designs are also available. The type of cell chosen depends on the application load current, voltage window, and discharge time required.

D.2.1 Electrolyte

The alkaline electrolyte is a solution of potassium hydroxide in water, generally with addition lithium hydroxide. The specific gravity of the alkaline electrolyte ranges from 1.160 to 1.250. Lower specific gravities are used in cells with large electrolyte reserves, while higher specific gravities are used for low-temperature applications. Special electrolyte with higher level of lithium hydroxide is used for cycling application.

D.2.2 Separators and retainers

Separators in Ni-Cd cells provide physical and electrical isolation of the positive and negative plates. In many cases, the separators have an open construction, using plastic rods or grids, or corrugated plastic sheets with large perforations. Some newer plate designs, in which the active material is on the exposed plate surface, use micro-porous plastic separators to prevent conductive crystal bridges (dendrites) from forming between the plates.

Because the active materials in Ni-Cd cells are not normally prone to shedding, retainer mats are not normally used. Some cell designs, however, use a fiber mat separator to provide for partial gas recombination in a flooded cell.

D.2.3 Jars and covers

Ni-Cd cells generally have jars and covers made of plastic. For especially harsh conditions, cells with stainless steel cases are also available. Most containers are made of translucent polypropylene, which allows the user to monitor electrolyte levels. The cover is welded to the jar, ensuring an impermeable, secure joint.

For installations where low flammability is required, flame-retardant plastic materials or stainless steel are available.

D.2.4 Cell covers and post seals

Terminal posts are usually sealed with a gasket and an O-ring. It is essential to have an effective seal, particularly for the negative terminal; otherwise, potassium carbonate, a gray-white powder, tends to form around the terminal.

Excessive buildup of potassium carbonate around the posts may cause grounding problems. Although post seal leakage does not cause terminal post corrosion or degradation of electrical connections, it is important to keep the post exterior clean.

D.2.5 Cell connections

The intercell connectors are made of nickel-plated copper. The nickel plating on the copper should be impermeable. Nickel-plated or stainless steel nuts or bolts are generally used for the connections.

D.2.6 Vents and flame arrestors

Cells are frequently equipped with flip-top vents to facilitate water addition. Flame arrestor vents are provided for all vented Ni-Cd cells. Some manufacturers offer catalytic recombination vent caps to reduce maintenance. These should be correctly sized for the individual application and cell type.

Annex E

(normative)

Service life considerations

E.1 Factors affecting battery life

E.1.1 Lead-acid cells

Lead-acid cells are the predominant energy storage choice for UPS applications. Clause 6 alerts the user to the several factors that may affect the service life of lead-acid cells. As indicated below, many of these factors may be controlled through proper application, installation, maintenance, operation, and environmental control.

E.1.1.1 Temperature

The battery-charging current and corrosion rate of the positive grid advances exponentially with increased electrolyte temperature. Prolonged operation at elevated temperatures will shorten the life of the battery. Colder temperatures ensure longevity, but the slowed electrochemical reaction will reduce the available capacity.

For maximum efficiency, the battery should be maintained at its optimum temperature. Battery life and electrical performance are rated at a standard temperature of 25 °C. During operation, the maximum spread of individual cell temperatures should not exceed 3 °C. When charging at a fixed float voltage, the float current will increase with increasing temperature and decrease with decreasing temperature.

VRLA cells are affected to a greater extent by temperature extremes than are vented cells. To minimize the temperature effects and possible thermal runaway, the float charging voltage should be adjusted according to the temperature of operation. At elevated temperature, a typical recommendation is to decrease the float charging voltage from that recommended at 25 °C by 0.005 V/cell per degree Celsius above 25 °C. At reduced temperature, the float charging voltage may be increased 0.005 V/cell per degree Celsius below 25 °C from the voltage recommended at 25 °C. Consult the manufacturer for the recommended adjustment and applicable limits.

E.1.1.2 Cycle service

A stationary lead-acid battery can survive more short-duration, shallow cycles than long-duration, deep discharge cycles. The user should understand that the very high, short-term discharge rates in the UPS application may result in discharge cycles of significant depth, and regulate maintenance testing schedules accordingly.

Various grid alloys and paste formulations affect the sensitivity of the cell to cycled service. Consider that short, nearly undetectable power dropouts, can, depending on UPS design, cause the UPS to frequently discharge the battery.

E.1.1.3 Elevated float voltages

Float voltages in excess of that required to overcome the self-discharge rate of the cell will cause higher float currents and higher corrosion rates at the positive plates. The best float voltage is the value at which the battery remains in a fully charged state and that causes the least amount of corrosion and gassing.

Manufacturers generally recommend a 2.20 to 2.30 V/cell float for UPS applications, depending mainly on electrolyte specific gravity. Prolonged charging at higher voltages than recommended by the manufacturer accelerates positive grid corrosion and shortens life. It also results in increase gassing and maintenance requirements for vented cells.

E.1.1.4 Equalize charge

Equalize charging can be used for rapid recharge, to correct imbalances in cell float voltages, or to promote mixing of electrolyte after water additions. Consult the manufacturer for specific instructions regarding equalization.

Most UPS systems have the capability to equalize the battery automatically after a discharge. Assure that this feature is used in accordance with the battery manufacturer's recommendations.

While limited equalize charging can optimize the operating capabilities of a lead-acid battery, excessive equalizing will shorten battery life by accelerating grid corrosion. Equalize charging is generally discouraged by manufacturers of VRLA batteries as it accelerates dry cell. For this reason, this practice should be restricted to specific circumstances, and routine equalizing should be avoided.

E.1.1.5 Ripple currents

UPS applications can place unusual load conditions on a battery such as ripple currents. Ripple current is an important consideration affecting battery life and it is advisable to maintain the UPS as prescribed by the manufacturer.

E.1.2 Ni-Cd cells

In Ni-Cd cells, there is no deterioration of the mechanical structure of the plates. Consequently, there is no sudden loss of battery capacity or performance. Instead, cell aging relates to changes in the active materials, and capacity loss is gradual over time.

E.1.2.1 Cycle life

To enhance cycle life and to reduce the adverse effect of high temperatures, various amounts of lithium hydroxide may be added to the potassium hydroxide electrolyte. The manufacturers specify the exact amount added during manufacturing.

E.1.2.2 Float charge

Float voltages recommended for Ni-Cd cells are generally in the range of 1.40 V/cell to 1.47 V/cell. The manufacturer's recommended voltage will maintain a cell in a fully charged condition and minimize water consumption. Higher float voltages will result in increased water loss.

After extended float charging of a Ni-Cd battery, it is normal to see a lowering of the average discharge voltage compared with that of a battery that has been fully charged at constant current. This may affect the available capacity to a specified end-of-discharge voltage.

The data used in Ni-Cd battery sizing calculations should be based on prolonged constant potential charging.

E.1.2.3 Equalizing charge

Recommended equalizing voltages range from 1.45 V/cell to 1.65 V/cell. To achieve reasonable end-of-discharge voltages, the equalizing voltage attainable in a specific application is normally restricted by system voltage limitations to about 1.55 V/cell.

Generally, equalizing is used for a fast recharge after a discharge. Depending on the float voltage, frequency, and depth of discharge, routine periodic equalizing may be necessary. Consult the manufacturer for specific instructions.

E.1.2.4 Carbonation

Potassium carbonate is formed in alkaline electrolyte when it is exposed to air and because of the oxidation of graphite in pocket plate cells. Potassium carbonate buildup is rarely a problem in float service applications, unless the battery is operated at extremely high temperatures, or is deeply discharged on a frequent basis.

The amount of carbonate in pocket plate cells should not be allowed to increase over the limits specified by the manufacturers. Carbonation may have an adverse effect on cell life and high-rate performance, particularly at low temperatures. A standard test method exists for determining the carbonate content of the electrolyte.

E.1.2.5 Memory effect

The memory effect occurs mainly in cells with sintered negative plates. These cells are rarely found in UPS applications.

The memory effect results from repeated shallow cycling to approximately the same depth of discharge. A premature voltage drop may occur if the discharge is continued past this shallow depth of discharge. The memory effect is caused by the reversible formation of intermetallic compounds of cadmium and nickel, and may also involve a loss of surface area of the negative active material due to the growth of large crystals.

A cell may have its memory erased by a complete discharge, followed by a full charge with constant current.

E.2 Replacement criteria

When the battery reaches its end of life, or when individual cells become defective, they will require replacement. IEEE Std 450, IEEE Std 1188, and IEEE Std 1106 provide criteria for determining end of battery life. For example, a lead-acid battery is considered to be at the end of its life when it has reached 80% of its rated capacity. Other factors such as damage or low voltage will also necessitate replacement.

The age of the battery system should be taken into consideration when making a decision to replace individual units. Consideration should be given to permanently removing and/or bypassing individual cells from a string providing that sufficient capacity is available and the reduced battery voltage is within the operating voltage window of the UPS. However, this requires an adjustment of the float/equalizing voltage for the remaining number of cells in the string. This may not be an appropriate technique for parallel strings.

E.2.1 Selecting replacements (individual cells/units)

When replacing cells or units within an existing battery string, the replacement units should be compatible with the existing cells.

E.2.2 Selecting replacements (entire system)

Refer to Clause 7 of this document to determine the proper replacement battery.

E.2.3 Handling and storage

Cells/units removed from service should be secured to pallets with their terminals protected against accidental shorting. Cells/units should be stored in low traffic areas to prevent physical damage while waiting for disposal.

E.3 Disposal

Transportation, storage, and disposal means should be determined prior to removing the batteries from the UPS. The longer batteries are stored the greater the risk of accidental damage. All batteries should be recycled. Seek advice from the battery manufacturer or distributor on how to proceed with battery recycling. Follow all applicable governmental regulations for storage, transportation and disposal. It should be noted that only a small number of recycling plants will process batteries containing cadmium.

Annex F

(normative)

Commissioning

F.1 General

Commissioning is a systematic process of ensuring that all components and systems perform interactively according to the design intent. The process is completed by documenting the design intent and basis. This process continues through construction and acceptance and ends with the verification of performance and training. The commissioning process integrates the normally separate functions of system documentation, equipment startup, system calibration, testing and balancing, performance testing, and training.

After the design intent and basis of design are documented, the commissioning process during construction is intended to achieve the following objectives:

1) Verify that applicable equipment and systems are installed according to the manufacturer's guidelines and industry accepted standards and that they receive adequate startup services by the manufacturer and/or contractor
2) Verify and document proper performance of equipment and systems
3) Verify that Operations and Maintenance (O&M) documentation is complete and transmitted to the owner
4) Verify that the operating personnel are trained

The commissioning process does not take away from or reduce the responsibility of the system designers or installing contractors to provide a finished and fully functioning product.

F.1.1 Abbreviations

The following are common abbreviations used in the *Specifications* and in the *Commissioning Plan*:

A/E-	Architect and design engineers	FT-	Functional performance test
CA-	Commissioning authority	GC-	General contractor (prime)
CC	Controls contractor	MC-	Mechanical contractor
CM-	Construction Manager (the owner's representative)	PC-	Pre-functional checklist
Cx-	Commissioning	PM-	Project manager (of the Owner)
Cx Plan-	Commissioning Plan document	Subs-	Subcontractors to General
EC-	Electrical contractor	TAB-	Test and balance contractor

F.2 Coordination

F.2.1 Commissioning team

The members of the commissioning team consist of the Commissioning Authority (CA), the Project Manager (PM), the designated representative of the owner's Construction Management firm (CM), the General Contractor (GC or Contractor), the architect and design engineers, the Mechanical Contractor (MC), the Electrical Contractor (EC), the TAB representative, the Controls Contractor (CC), and any other installing subcontractors or suppliers of equipment. The owner's building or plant Operator/Engineer is also a member of the commissioning team.

F.2.2 Management

The owner hires the CA directly. The CA directs and coordinates the commissioning activities and is part of the CM team. All members work together to fulfill their contracted responsibilities and meet the objectives of the contract documents. The CA's responsibilities are the same regardless of who hired the CA.

F.2.3 Scheduling

The CA will work with the CM and GC according to established protocols to schedule the commissioning activities. The CA will provide sufficient notice to the CM and GC for scheduling commissioning activities. The GC will integrate all commissioning activities into the master schedule. All parties will address scheduling problems and make necessary notifications in a timely manner in order to expedite the commissioning process.

The CA will provide the initial schedule of primary commissioning events at the commissioning scoping meeting. The *Commissioning Plan—Construction Phase* provides a format for this schedule. As construction progresses more detailed the CA develops schedules. The Commissioning Plan also provides a format for detailed schedules.

F.3 Commissioning process

F.3.1 Commissioning plan

The commissioning plan provides guidance in the execution of the commissioning process. Just after the initial commissioning scoping meeting the CA will update the plan which is then considered the "final" plan, though it will continue to evolve and expand as the project progresses. The *Specifications* will take precedence over the *Commissioning Plan*.

F.3.2 Commissioning process

The following narrative provides a brief overview of the typical commissioning tasks during construction and the general order in which they occur:

1) Commissioning during construction begins with a scoping meeting conducted by the CA, where the commissioning process is reviewed with the commissioning team members.
2) Additional meetings will be required throughout construction, scheduled by the CA with necessary parties attending, to plan, scope, coordinate, schedule future activities, and resolve problems.
3) Equipment documentation is submitted to the CA during normal submittals, including detailed startup procedures.

4) The CA works with the Subs in developing startup plans and startup documentation formats, including providing the Subs with pre-functional checklists to be completed during the startup process.

5) In general, the checkout and performance verification proceeds from simple to complex, and from component level to equipment to systems and intersystem levels, with pre-functional checklists being completed before functional testing.

6) The Subs, under their own direction, execute and document the pre-functional checklists and perform startup and initial checkout. The CA documents that the checklists and startup were completed according to the approved plans. This may include the CA witnessing startup of selected equipment.

7) The CA develops specific equipment and system functional performance test procedures. The Subs review the procedures.

8) The procedures are executed by the Subs, under the direction of, and documented by the CA.

9) Items of noncompliance in material, installation, or setup are corrected at the Sub’s expense and the system retested.

10) The CA reviews the O&M documentation for completeness.

11) Commissioning is completed before Substantial Completion.

12) The CA reviews, pre-approves, and coordinates the training provided by the Subs, and verifies that it was completed.

13) Deferred testing is conducted, as specified or required.

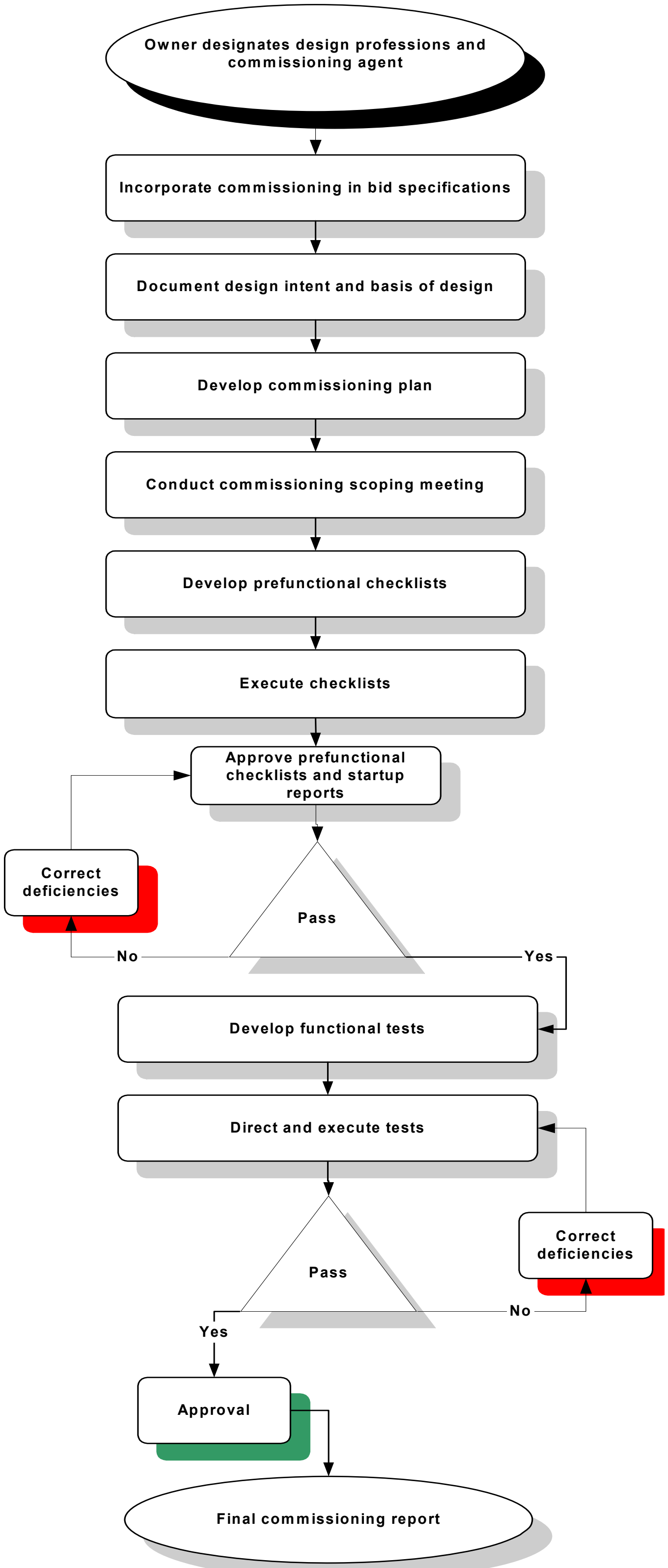

Figure F.1—Sample—Battery system commissioning checklist

Project ___________________________________

Associated checklists: UPS, Emergency Generator

1. Submittal/Approvals

Submittal: The above equipment and systems integral to them are complete and ready for testing. The checklist items are complete and have been checked off only by parties having direct knowledge of the event, as marked below, respective to each responsible contractor. This checklist is submitted for approval, subject to an attached list of outstanding items yet to be completed. A Statement of Correction will be submitted upon completion of any outstanding areas. None of the outstanding items preclude safe and reliable functional tests being performed.

___ List attached.

Mechanical Contractor	Date	Controls Contractor	Date
Electrical Contractor	Date	Sheet Metal Contractor	Date
TAB Contractor	Date	General Contractor	Date

Pre-functional checklist items are to be completed as part of startup and initial checkout, preparatory to functional testing.

- This checklist does not take the place of the manufacturer's recommended checkout and startup procedures or report
- Items that do not apply shall be noted with the reasons on this form (N/A = not applicable, BO = by others)
- If this form is not used for documenting, one of similar rigor shall be used
- Contractors' assigned responsibility for sections of the checklist shall be responsible to see that checklist items by their subcontractors are completed and checked off
- "Contr." column or abbreviations in brackets to the right of an item refer to the contractor responsible to verify completion of this item. A/E = architect/engineer, All = all contractors, CA = commissioning agent, CC = controls contractor, EC = electrical contractor, GC = general contractor, MC = mechanical contractor, SC = sheet metal contractor, TAB = test and balance contractor

Approvals: This filled-out checklist has been reviewed. Its completion is approved with the exceptions noted below.

Commissioning Agent	Date	Owner's Representative	Date

2. Documentation submitted and approved: [All]

__ manufacturer's cut sheets data
__ installation and checkout manual and plan
__ full written sequences and list of all control strategies
__ written copy of all control parameters, settings
__ full descriptive points list
__ O&M manual
__ performance
__ operating manual
__ completed control drawings
__ design criteria and set points

Documentation complete as per contract documents ___ YES ___ NO

3. Model verification [Initial = ________]

	As Specified	As Submitted	As Installed
Manufacturer			
Model No.			
Serial No.			

The equipment installed matches the specifications for given trade ___ YES ___ NO

4. Initial setup and checkout

4.1. Battery system installation

Check if OK. Enter comment or note number if deficient.

Check	Y / N	Initial
General appearance good, no apparent damage and/or leakage		
Equipment labels affixed and battery numbers installed		
Layout and location of emergency shower and eye wash station per drawings		
Battery room ventilation meets design air flow requirements		
Pull tests of rack anchors complete per specifications		
Battery disconnect means labeled/tagged		
Monitoring system connections made to labeled terminal(s) as shown on drawings		
All battery connection resistances measured and within manufacturer's specifications		
Initial charge complete per manufacturer's specifications		
Battery temperature at 25 °C (If <>25 °C correct test results as required)		
Spill containment installed per specifications		

The above setup and checkout was successfully completed for given trade ___ YES ___ NO

5. Battery discharge test

—SAMPLE FORM—

BATTERY DISCHARGE TEST RESULTS

PRIMARY UPS MODULE 1

TIME	UPS FRONT PANEL		TEST INSTRUMENTS	
(min/s)	Battery voltage (V)	Battery current (A)	Battery voltage (V)	Shunt voltage drop (mV)
00:00				
00:15				
00:30				
00:45				
01:00				
01:15				
01:30				
01:45				
02:00				
03:00				
04:00				
05:00				
06:00				
07:00				
08:00				
09:00				
10:00				
11:00				
12:00				
13:00				
14:00				
15:00				

The above test was successfully completed for given trade__ YES ___ NO

6. Thermographic survey

6.1 Visual and mechanical inspection

1) Inspect physical, electrical, and mechanical condition
2) Remove all necessary covers prior to thermographic inspection

6.2 Equipment to be inspected shall include all current-carrying devices

6.3 Provide report including the following:

1) Discrepancies
2) Temperature difference between the area of concern and the reference area
3) Cause of temperature difference
4) Areas inspected. Identify inaccessible and/or unobservable areas and/or equipment
5) Identify load conditions at time of inspection
6) Provide photographs and/or thermograms of the deficient area*

6.4 Test Parameters

1) Inspect battery systems with imaging equipment capable of detecting a minimum temperature difference of 1 °C at 30 °C
2) Equipment shall detect emitted radiation and convert detected radiation to visual signal
3) Thermographic surveys should be performed during periods of maximum possible loading but not less than 40% of rated load of the electrical equipment being inspected. (Refer to NFPA 70B, Section 18-16—Infrared Inspection.)

6.5 Test Results

1) Temperature differences of 1 °C to 3 °C indicate possible deficiency and warrant investigation
2) Temperature differences of 4 °C to 15 °C indicate deficiency; repair as time permits
3) Temperature differences of 16 °C and above indicate major deficiency; repair

*optional

The above test was successfully completed for given trade ___ YES ___ NO

The initial setup and checkout has been successfully completed as described in Sections 4, 5, and 6 and documented on attached forms ___ YES ___ NO

Annex G

(normative)

Maintenance and testing intervals

The maintenance and testing programs described in this annex represent "the best program for UPS installations" based on the information available at the time this document was developed. The user should evaluate these practices against their operating experience, operating conditions, manufacturer's recommendations, resources, and needs in developing a maintenance program for a given application. These maintenance and testing recommendations were developed without consideration of economics, availability of testing equipment and personnel, or relative importance of the application. Development of a maintenance and testing program for a specific application requires consideration of all issues, not just the technical issues considered in this document.
Tables G.1 through G.3 represent recommendations for the frequency of maintenance procedures to be performed on VLA, VRLA, and Ni-Cd batteries

Table G.1—VLA maintenance

VLA battery	Monthly	Quarterly	Annually
Visual inspection of battery	X	X	X
Environmental inspection	X	X	X
Ambient temperature	X	X	X
Detailed inspection of battery		X	X
String float voltage	X	X	X
String float current	X	X	X
Pilot cell float voltage	X	X	X
Pilot cell electrolyte temperature	X	X	X
Individual cell float voltage		X	X
Cell electrolyte temperature (10%)			X
AC ripple current and voltage		X	X
Specific gravity			X
Intercell connection resistance			X
Internal ohmic measurement [a]			X
System load testing [b]			X

[a] For very large VLA cells, some ohmic test sets may lack sufficient resolution for trending purposes. Consult the battery and equipment manufacturer for suitability.

[b] Although IEEE Std 450 recommends testing VLA batteries with a frequency of 5 years or 25% of expected life, whichever is shorter, load testing of the UPS and associated equipment is generally recommended on an annual basis.

Table G.2—VRLA maintenance

VRLA Battery	Monthly	Quarterly	Annually
Visual inspection of battery	X	X	X
Environmental inspection	X	X	X
Ambient temperature	X	X	X
String float voltage	X	X	X
String float current	X	X	X
Pilot cell/unit float voltage	X	X	X
Individual cell/unit float voltage		X	X
Individual cell/unit temperature		X	X
Intercell connection resistance			X
Internal ohmic measurement		X	X
AC ripple current and voltage	X	X	X
System load testing			X

Table G.3—Ni-Cd maintenance

Ni-Cd	Quarterly	Semiannually	Annually
Visual inspection of battery	X	X	X
Environmental inspection	X	X	X
Ambient temperature	X	X	X
Detailed inspection of battery		X	X
String float voltage	X	X	X
String float current	X	X	X
Pilot cell float voltage	X	X	X
Pilot cell electrolyte temperature	X	X	X
Individual cell float voltage		X	X
Cell electrolyte temperature (10%)			X
AC ripple current and voltage		X	X
Connection torque			X
System load testing			X