

IEEE Guide for the Selection and Sizing of Batteries for Uninterruptible Power Systems

Sponsor

**Energy Development and Power Generation Committee
of the
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Abstract: The characteristics of the various battery energy systems available are described so that users can select the system best suited to their requirements. This guide also describes how the rectifier and the inverter components of the uninterruptible power system (UPS) can relate to the selection of the battery system.

Keywords: flooded cell, hydrogen evolution, lead-acid battery, nickel-cadmium battery, Planté plate, uninterruptible power system (UPS), valve-regulated lead-acid (VRLA) cell, vented cell

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Introduction

(This introduction is not a part of IEEE Std 1184-1994, IEEE Guide for the Selection and Sizing of Batteries for Uninterruptible Power 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 485-1983, IEEE Recommended Practice for Sizing Large Lead Storage Batteries for Generating Stations and Substations; IEEE Std 484-1987, IEEE Recommended Practice for Installation Design and Installation of Large Lead Storage Batteries for Generating Stations and Substations; IEEE Std 450-1995, IEEE Recommended Practice for Maintenance, Testing, and Replacement of Vented Lead-Acid Batteries for Stationary Applications; and IEEE Std 1106-1987, IEEE Recommended Practice for Maintenance, Testing, and Replacement of Nickel-Cadmium Storage Batteries for Generating Stations and Substations.

This guide was prepared by the Task Force on Battery/UPS Interface, a sub-organization of the Station Batteries Working Group, Station Design Subcommittee of the Energy Development and Power Generation Committee of the IEEE Power Engineering Society. At the time this guide was approved, the Task Force had the following membership:

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Victor W. Sokolski
Edward C. Stallings
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Frank L. Tarantino
Graham Walker
Walter A. Wylie

The liaison representatives were:

Bradford M. Radimer and Robert R. Beavers, Station Batteries Working Group
C. R. Pope, Station Design Subcommittee
R. E. Cotta, Energy Development and Power Generation Committee

The following persons were on the balloting committee:

L. D. Boydston
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R. S. Coleman
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D. Diamant
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IEEE Guide for the Selection and Sizing of Batteries for Uninterruptible Power Systems

1. Scope

This guide is intended to assist users who select battery systems for uninterruptible power systems (UPS). The guide informs users of the characteristics of the various battery energy systems available so they can select the system best suited to their requirements. This guide does not place any restrictions on the rectifier or inverter components of the UPS. It does, however, describe how those components can relate to the selection of the battery system.

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

- a) Lead-acid batteries, which include both vented (flooded) and valve-regulated (sealed) constructions
- b) Nickel-cadmium batteries

For each category, both 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.

Several battery designs are available to the UPS user. Each design has advantages and disadvantages, all of which should be considered when selecting a battery.

2. References

This guide shall be used in conjunction with the following standards. When the following standards are superseded by an approved revision, the revision shall apply.

ANSI/NFPA 70-1993, National Electrical Code® (NEC®).¹

IEEE Std 100-1992, The New IEEE Standard Dictionary of Electrical and Electronics Terms (ANSI).²

IEEE Std 450-1995, IEEE Recommended Practice for Maintenance, Testing, and Replacement of Vented Lead-Acid Batteries for Stationary Applications.

¹NFPA publications are available from Publications Sales, National Fire Protection Association, 1 Batterymarch Park, P.O. Box 9101, Quincy, MA 02269-9101, USA.

²IEEE publications are available from the Institute of Electrical and Electronics Engineers, 445 Hoes Lane, P.O. Box 1331, Piscataway, NJ 08855-1331, USA.

IEEE Std 484-1987, IEEE Recommended Practice for Installation Design and Installation of Large Lead Storage Batteries for Generating Stations and Substations (ANSI).

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

IEEE Std 1106-1987, IEEE Recommended Practice for Maintenance, Testing, and Replacement of Nickel-Cadmium Storage Batteries for Generating Stations and Substations (ANSI).

IEEE Std 1115-1992, IEEE Recommended Practice for Sizing Nickel-Cadmium Batteries for Stationary Applications (ANSI).

UL 94-1991, Tests for Flammability of Plastic Materials for Parts in Devices and Appliances.³

UL 924-1990, Emergency Lighting and Power Equipment.

UL 1778-1992, Uninterruptible Power Supply Equipment.

Uniform Building Code™, 1991 ed., International Conference of Building Officials (ICBO).⁴

3. Definitions

The following definitions apply specifically to the subject matter of this guide. For other definitions, refer to the standards listed in clause 2.

3.1 crazing: The small internal cracking around a point of mechanical stress that sometimes occurs in plastics.

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

3.3 cycling: The repeated charge/discharge cycle of a storage battery. Some batteries are rated by their ability to withstand repeated, deep discharge cycles.

3.4 float service applications: Storage batteries applied for reserve use and maintained at a continuous "float" voltage point selected to just exceed the batteries' internal (self-discharge) losses.

3.5 flooded cell: A liquid electrolyte filled vented cell.

3.6 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.

3.7 thermal runaway: A condition that is caused by a battery charging current that produces more internal heat than the battery can dissipate. This condition ultimately causes cell venting and premature failure.

3.8 valve-regulated lead-acid (VRLA) cell: A lead-acid cell that is sealed with the exception of a valve that opens to the atmosphere when the internal gas pressure in the cell exceeds the atmospheric pressure by a pre-

³UL publications are available from Underwriters Laboratories, Inc., 333 Pfingsten Road, Northbrook, IL 60062-2096, USA.

⁴ICBO publications are available from the International Conference of Building Officials, 5360 S. Workman Mill Road, Whittier, CA 90601, USA.

selected amount. VRLA cells, sometimes called recombinant cells, provide a means of recombination of internally generated oxygen and suppression of hydrogen gas evolution to limit water consumption.

3.9 vented cell: A cell in which the gaseous products of electrolysis and evaporation are allowed to escape into the atmosphere as they are generated.

4. 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.

- a) *Components.* Lead-acid batteries have an acidic electrolyte solution of sulfuric acid (H_2SO_4). 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, a solution of sulfuric acid and water, 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.

- b) *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 may range from 2.06 to 2.15 V/cell. Float voltages range from 2.15 to 2.40 V/cell, depending on their individual cell designs, temperature, and manufacturer recommendations.
- c) *Design.* Lead-acid battery designs are available for the following three standby applications:
 - 1) Long duration (i.e., telecommunications or low rate) batteries are designed for applications in which the standby loads are relatively small and the battery is required to supply these loads for a minimum of 3 h. Long duration batteries are characterized by thicker plates and lower specific gravity electrolytes. The typical discharge duration is 8 h.
 - 2) 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 1–3 h.
 - 3) Short duration (i.e., UPS or high rate) batteries are designed to supply large amounts of power for a relatively short period of time. Short duration batteries are typically characterized by thinner plates and higher specific gravity electrolytes. These batteries are best suited for applications requiring reserve times of 1 h or less. The typical discharge time is 15 min.

In addition to these designs that typically serve standby or float service applications, there are batteries available for a variety of other applications. For example, motive power batteries (used in fork lifts, golf carts, etc.) have a unique construction designed to withstand the physical abuse of constant movement and vibration, and to withstand hundreds if not thousands of discharge/recharge cycles. Motive power batteries are rarely used for UPS applications.

Another design is the starting-lighting-ignition (SLI) battery for automotive application. There are also designs that have been adapted to special applications [e.g., those that must be performed under extreme

temperatures, those that require a specific charge/discharge capability, or those involving a limited space with seismic requirements (see annex C)].

Note—All batteries should be recycled.

4.1 Cell construction

The smallest unit of a lead-acid battery is the cell. In its simplest form, a cell consists of a physically separated positive and negative plate assembled in a container with a sulfuric-acid electrolyte.

The lead-acid cell has the following five basic components:

- a) Container
- b) Positive plate(s) of lead dioxide
- c) Separator/retainer
- d) Negative plate(s) of sponge lead
- e) Electrolyte of sulfuric acid

These components may be designed and implemented in various ways to optimize performance for specific applications.

The performance of a cell is typically optimized through variations in grid alloy and geometry, separator material type and thickness, retainer existence and design, terminal design, and electrolyte specific gravity.

4.1.1 Plate constructions

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

4.1.1.1 Flat plate

Of the lead-acid designs, the pasted flat plate (see figure 1) is the most common. 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.

The typical pasted flat plate is mostly used in full float applications. Cycling can be improved by the addition of plate material retention devices (see 4.1.3).

Pasted flat plates are manufactured with grids of varying thickness (see 4.1.1.7).

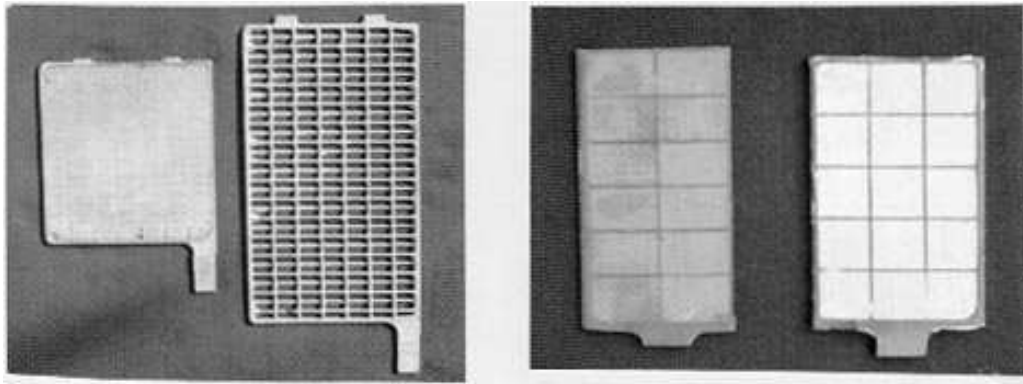


Figure 1—Examples of pasted flat plates

4.1.1.2 Planté plate

The Planté positive plate (see figure 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.

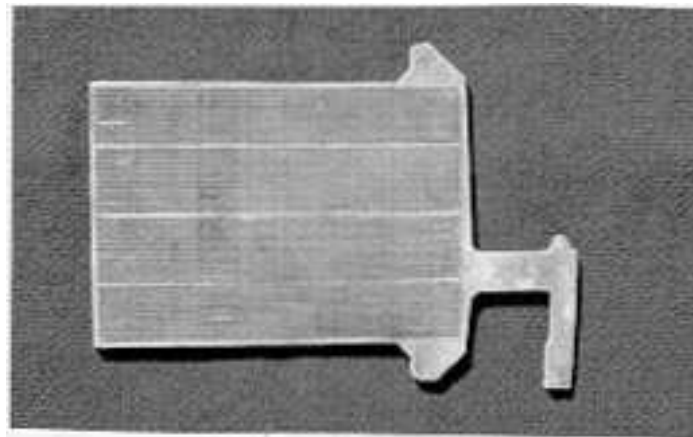


Figure 2—Planté plate

4.1.1.3 Modified Planté plate

The modified Planté positive plate design (see figure 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.