



IMPLEMENTING PROACTIVE BATTERY MANAGEMENT STRATEGIES TO PROTECT YOUR CRITICAL POWER SYSTEM

Executive Summary

According to the Electric Power Research Institute (EPRI), 98 percent of all power outages last less than 10 seconds. Yet, if the batteries in the uninterruptible power supply (UPS) system supporting your critical network fail during those 10 seconds, the cost to the business can quickly escalate to hundreds of thousands of dollars.

Batteries are the low tech component in today's sophisticated power systems. As such, their importance in protecting your critical IT infrastructure may be overlooked. However, because battery-related failure is the primary cause of UPS system failure, it's imperative to adopt proactive battery management strategies designed to optimize battery performance and reliability without placing your operations in jeopardy due to a potentially failing cell.

Proactive strategies that should be considered by facility managers for all critical operations include:

1. Following battery maintenance best practices including the manufacturer's published recommendations, and following guidelines from the Institute of Electrical and Electronics Engineers (IEEE) such as 450 for vented lead-acid (VLA), 1188 for valve-regulated lead-acid (VRLA), and 1106 for nickel-cadmium (NiCad) batteries.
2. Monitoring batteries. A battery monitor can provide ambient temperature, cell voltages, and internal resistance of the batteries, allowing these conditions to be optimized—utilizing the maximum available life and performance of the battery.
3. Keeping on-site spares. Mixing new with old batteries within an aging string may cause substantial risk of complete string failure. Replacing failing batteries with batteries from an on-site spares cabinet that has been properly set up and maintained eliminates the risk of improper float characteristics.

**string:
multiple cells grouped together serially
to form higher voltages or in parallel to form
higher currents**

Introduction

An increase in the density of the servers and communication devices that populate data centers and computer rooms, as well as the proliferation in the number of these devices, is driving change in the power systems that are critical to business continuity.

Consider how power requirements for IT equipment racks have changed in the last 15 years. In 2001, a fully populated server rack could house 42 servers, which were likely to be dual-corded and operating at 208 volts. By 2006, the total power consumption increased from four kilowatts to almost 20 kilowatts. Now, a standard rack can house six dual-corded blade chassis operating at 208 volts with a power consumption of 24 kilowatts.

Further, the addition of new high density equipment often signals increased criticality as companies heighten their dependence on data center systems and computer rooms. The IT infrastructure in many businesses has evolved into an interdependent business-critical network of data, applications, engineering systems, storage, and servers. A power failure at any point in the network can impact the entire operation with serious consequences for the business. Given the high cost of downtime, the need to pay special attention to protecting the power systems that support critical networks should not be underestimated.

In most cases, the ability to keep critical systems running through power outages is dependent on the UPS and its battery system. Unlike other components, batteries wear down over time, whether they are used or not. That wear is especially accelerated by the battery cycling that is caused by short power disruptions that go unnoticed in the facility. According to EPRI, 98 percent of all outages last less than 10 seconds. In addition, a single bad cell in a string could compromise the entire backup system and leave an organization without protection.

By implementing proactive management strategies, companies can optimize battery performance and protect against IT system instability and downtime. Understanding battery life expectancy and aging is the first step in developing an effective battery management strategy that enhances performance and reliability.

Battery Life Expectancy

Batteries represent a significant part of the cost of the critical power system, but are subject to wear and aging faster than most other components. When a UPS fails, there is a good chance that battery failure is the cause. According to the 2013 Study on Data Center Outages by the Ponemon Institute, battery-related failure is responsible for 55 percent of UPS system failures, as shown in Figure 1. Understanding a battery failure involves understanding battery life expectancy as well as the causes of battery aging.

Batteries have a certain life expectancy, and sooner or later, every battery will reach the end of its life. Misunderstanding battery life expectancy is common and stems from confusing battery design life with battery service life. Battery design life is specified by the manufacturer and takes into account cell design and battery aging under controlled conditions in the manufacturer’s laboratory. Battery service life considers how application, installation design, real-world operating conditions, and maintenance practices impact battery aging—most often lowering life expectancy. Figure 2 shows estimated design life versus service life for different classes of batteries. For example, high discharge rate VLA batteries typically used in large UPS systems have a design life of 20 years, but an average service life of 12-14 years.

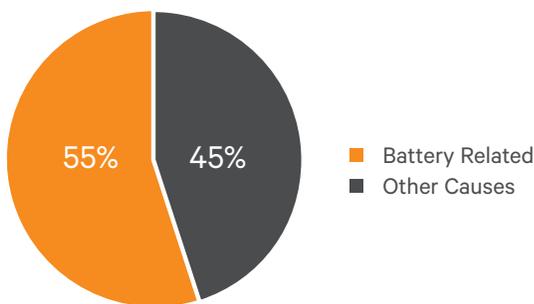


Figure 1: Battery-related failures account for more than half of all UPS system failures.

Factors that Accelerate Aging

Batteries are made by rolling paste onto a grid of positive and negative plates. The positive plates experience mechanical stress due to the discharge and recharge of the battery. This normal battery aging process is illustrated in Figure 3. During discharge, an electrochemical reaction makes the lead paste inside the battery’s grid structure expand. This puts dimensional pressure on the grid structure, thereby changing the physical dimension of the positive plate material and the grid at the molecular level, causing grid corrosion. Grid corrosion causes both horizontal and vertical “growth” of the positive plates and separation of the paste material from the grid structure, allowing the electrolyte to attack the structure over time. This results in corrosion that increases a cell’s internal resistance thus reducing capacity.

Whether the batteries supporting your critical power system will age normally toward their defined life cycle or fail prematurely depends on a variety of factors. How batteries are handled, the environment in which they are housed, the quality of the systems used to maintain the batteries, and other variables affect the aging process.

High ambient temperature and frequent discharge rates are most commonly responsible for reducing useful life across all types of batteries. (Dryout is the most common cause of VRLA battery failure.) Battery aging accelerates dramatically as ambient temperature increases. This is true of batteries in service and in storage. Even under specified temperatures, batteries are designed to provide a limited number of discharge cycles during their expected life. While that number may be adequate in some applications, there are instances where a battery can wear out prematurely.

Other factors that can cause premature battery failure include:

- High or low charge voltage
- Excessive charge current
- Strained battery terminals
- Manufacturing defects
- Improper room temperature
- Overcharging and over cycling
- Loose connections
- Poor and improper maintenance

Nothing can stop the battery aging process. Once a battery is formed, the aging process starts. However, facility managers can optimize battery performance by adopting the following proactive battery management strategies:

1. Whenever possible, follow battery maintenance best practices outlined by IEEE standards and battery manufacturer schedules defining specific battery maintenance checks and how frequently they should be made.
2. Monitor batteries to continually assess the health of your power system's life support without incurring maintenance downtime.
3. Keep on-site spare, maintained and charged like the original string, to avoid catastrophic loss caused by replacing too many of the cells in a string during normal battery lifetime.
4. Perform capacity testing in accordance with IEEE recommended practices to verify battery integrity.

The objective of implementing proactive management strategies is to get the most effective use possible from your batteries without placing your operations in jeopardy due to a failing cell.

Battery Maintenance Best Practices

In a critical power application, the first line of defense in guarding against battery failure presents itself before the batteries are ever placed in service. The batteries need to be fully charged, properly installed—physically, electrically and environmentally—and their condition verified in order to minimize the likelihood of costly retests and equipment

damage. Properly inspecting the batteries before startup and/or load testing will provide valuable information that can be applied immediately and serve as a baseline for any testing conducted throughout the service life of the batteries.

UPS BATTERY TYPE	DESIGN LIFE	SERVICE LIFE
Vented Lead-Acid	20 years	12-14 years
Valve-Regulated Lead-Acid	20 years	8-10 years
Valve-Regulated Lead-Acid	10 years	4-6 years
Nickel-Cadmium	20 years	15 years

Design Life = cell design + manufacturer operating conditions
 Service Life = installation design + operating conditions + maintenance practices
 Warranty Life = manufacturer amortizes the cost of the cell; no relationship to design and service life

Figure 2: The service life of VLA, VRLA and NiCad batteries is typically much shorter than the design life.

If this basic information is not collected, analyzed and understood, there is no guarantee the batteries will perform as needed and trend analysis becomes more difficult. If an abnormality goes undetected, facility managers may experience schedule delays or extra costs to replace or repair damaged components.

Depending on whether the facility is using VLA, VRLA or NiCad batteries, certain maintenance best practices should be followed. These best practices have been documented in IEEE publications (450, 1188 and 1106) and include acceptance testing prior to commissioning, as well as inspections and load testing requirements for all batteries throughout their service life. Figure 4 outlines the requirements per inspection period.

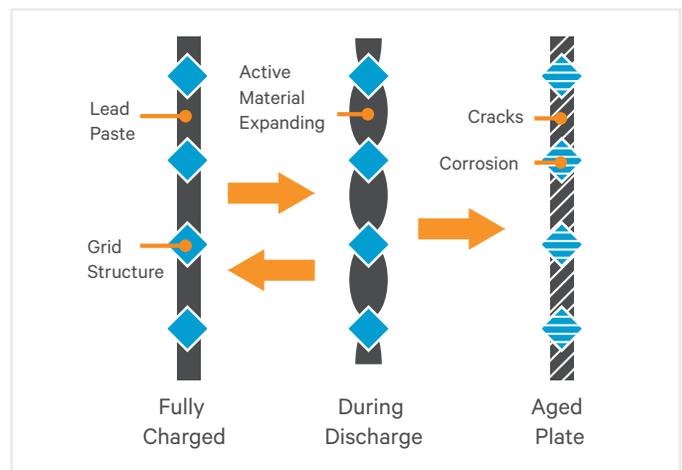


Figure 3: Batteries age when mechanical stress causes grid expansion.

Performing a capacity test, though expensive, is the only true way to determine absolute capacity, and should be conducted at recommended intervals until degradation is evident, then the frequency increases to an annual test.

Normal capacity test intervals (prior to evidence of degradation):

- Vented lead-acid (flooded) – every 6 years
- Valve-regulated (large format) – every 2 years
- Valve-regulated (multi-cell) – every 12-15 months
- Nickel-cadmium – every 5 years

Unfortunately, common practices often replace best practices. Governed by real-world factors, many facility managers are often forced to take into account the cost of performing the recommended IEEE schedule as it relates to the criticality of the application.

While following the IEEE schedules is recommended, when everyday pressures mandate otherwise, facility managers are encouraged to consult manufacturer guidelines for recommended maintenance and potential cost-effective options.

RECOMMENDED TASK	VLA IEEE 450			VRLA IEEE 1188			NICAD IEEE 1106		
	MONTHLY	QUARTERLY	ANNUALLY	MONTHLY	QUARTERLY	ANNUALLY	MONTHLY	QUARTERLY	ANNUALLY
System float voltage	■	■	■	■	■	■		■	■
Float current	■	■	■	■	■	■		■	■
Ambient temperature	■	■	■	■	■	■		■	■
Visual inspection of battery and battery area	■	■	■	■	■	■		■	■
Electrolyte levels	■	■	■					■	■
Pilot cell voltage and specific gravity (if used)	■								
Pilot cell electrolyte temperature (if used)	■							■	
All cells specific gravity		10%							
All cells voltage		■			■	■		■	■
All cells temperature		10%			■	■			■
Cell/unit internal ohmic values					■	■			
Detail internal visual inspection	■	■	■	■	■	■		■	■
AC ripple current and voltage	■	■	■	■	■	■		■	■
Unintentional battery grounds	■	■	■	■	■	■		■	■
Cell-to-cell and terminal connection resistance (if applicable)			■			■			■
Capacity test	Upon installation; within the first 2 years of service; at intervals not to exceed 25% of expected service life			Upon installation; at intervals not to exceed 25% of expected service life or 2 years, whichever is less			Upon installation; within the first 2 years of service; at 5-year intervals until signs of excessive capacity loss		

Figure 4: IEEE standards address best practices for maintaining VLA, VRLA and NiCad batteries.

Battery Monitoring

Once a battery is operating properly, it's important to proactively monitor daily performance trends to help detect battery failure. A continuous battery monitoring system assesses a battery's true state of health. Instead of waiting for an inevitable failure or replacing batteries prematurely to prevent problems, monitors allow organizations to continue to utilize their batteries longer and with confidence by knowing the true condition of all critical battery parameters, such as cell voltage, internal resistance, cycle history, overall string voltage, current, and temperature.

The best way to determine a battery's health without discharging it is to use a monitoring system that measures the internal resistance of all of the cells in the battery string. As the battery ages and loses capacity, the resistance of a battery cell's internal conduction path increases. A substantial increase of the resistance in one cell is considered end of life for a complete battery string.

Figure 5 illustrates how batteries lose capacity as they age. Because 40 percent of the resistance in a battery cell is in effect paralleled with capacitance, DC resistance measurements are more accurate. With AC testing methods, the capacitance tends to mask the increase in resistance. DC resistance-based testing eliminates the capacitance considerations completely.

DC resistance-based testing also eliminates the effect that electrical noise can have on internal ohmic measurements. Stationary batteries are often located in very harsh, electrically noisy environments. A low AC test signal will "disappear" in UPS AC noise.

Typically, resistance data also changes when noise levels change due to load and/or aging capacitors. DC readings are able to completely ignore the AC ripple current and electrical noise produced by the operation of the UPS AC-to-DC battery chargers/rectifiers.

The information gained from battery monitoring should be analyzed and used to optimize battery life. For example, VRLA batteries are sensitive to temperature and float voltage settings. A battery monitor can provide ambient temperature, cell voltage, internal resistance, and data logging of the batteries monitored, allowing these conditions to be optimized, thereby utilizing the maximum available life and performance of the battery.

While there are many battery monitoring services available, the best solution to optimizing battery performance is to utilize an integrated battery monitoring service that combines state-of-the-art battery monitoring technology with proactive maintenance and service response. This type of proactive solution integrates on-site and remote preventive maintenance activities with predictive analysis to identify problems before they occur.

Battery Replacement

If a power outage occurs, even a single bad cell in a string could compromise your entire backup system and leave you without protection. In addition to implementing proper maintenance practices and monitoring batteries, safely replacing failing batteries will help keep IT systems running to specifications and minimize the risk of costly downtime. IEEE standards recommend replacing a battery at the time its capacity reaches 80 percent. As we've discussed, a number

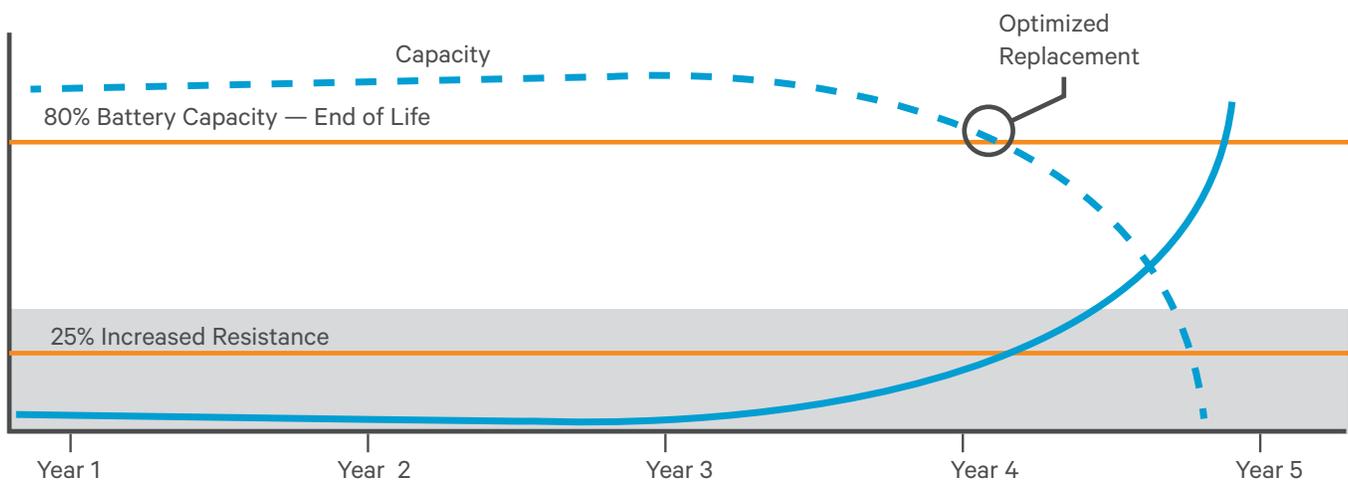


Figure 5: Batteries lose capacity as they age justifying the need for a preventive maintenance program.

of factors affect the capacity of the battery, including age, usage, environment and maintenance. Based on factors such as these, a typical VRLA battery may reach 80 percent of rated capacity and need to be replaced within three to five years. Keep in mind, mixing new and old batteries may have an adverse affect on the float characteristics between cells.

Keeping on-site spares eliminates the problem of ohmic mismatch and helps ensure replacing a cell does not bring down your IT system. An effective practice would be to have enough spares to cover five to 10 percent of the batteries in every cabinet, plugged in and housed similarly to the batteries in service (depending on battery type and criticality of the facility).

The spare batteries will age simultaneously with the main battery string, making replacement faster and more stable for your critical power supply. While it's impossible to replicate the exact same conditions, replacing a failing battery with one of the same age, even if some variance in the condition of batteries exists, is safer than replacing it with a new battery.

This is especially true with VLA batteries, which tend to last 12 or more years. Because very old batteries may be obsolete, without on-site spares the alternatives for replacing failing batteries are not optimal. Either cells would have to be bypassed out of the string or a new, potentially incompatible battery would have to be installed and stabilized. If the choice is to bypass cells, it reduces the capacity of the string over time and affects available run time.

Overall, having on-site spares in an effective battery management strategy because of the following benefits:

- Spare batteries are charged and ready when they are needed most.
- Batteries age with the original battery string, eliminating the risk of mismatch.
- The number of visits to repair a string is reduced.
- The risk of obsolescence is minimized.
- The problem of delivering batteries to facilities in crowded urban locales is minimized.

Conclusion

As business reliance on data center systems increases and more emphasis is placed on availability and reliability of critical power systems, organizations need to understand that without properly operating batteries, no UPS system can do its job.

Organizations should use trending data to optimize battery life instead of replacement based solely on age and should mitigate risk by being proactive in performing corrective actions and/or replacement.

Strategies to maximize the availability and performance of battery systems include following battery maintenance best practices, monitoring batteries, and keeping on-site spares. Devoting attention proactively to batteries will help organizations ensure their business critical systems remain up and running.

