Vertiv™ Services eBook Series

Battery Maintenance Solutions for Critical Facilities

Costs and Causes of Downtime

Meeting Regulatory Requirements and Observing Best Practices

Comprehensive Preventive Maintenance

Service Life and Proactive Replacement

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Battery Maintenance Solutions for Critical Facilities

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The uninterruptible power supply (UPS) system is vital to sustaining the critical operations of data centers, utilities, and industrial facilities if and when power outages occur. While assessments and preventive maintenance programs are often implemented to maintain and protect this system, the reality is that a UPS is only as reliable as the batteries that support it. In fact, in the Ponemon Institute's "2013 Study on Data Center Outages," UPS battery failure was the leading root cause of downtime as cited by 55% of survey respondents.

A single bad cell in a string of batteries can compromise a facility's entire backup system during a power outage, leading to extended downtime and leaving an organization without protection. When downtime does occur, business leaders look to the facility manager or whoever is responsible for data center operations to explain the cause of the outage and how the situation can be avoided in the future.

Facility managers can benefit from working with data center experts and service technicians who truly understand battery performance and how to get the most out of this critical asset. However, they must also educate themselves to fully protect their operation and achieve business stability. This eBook is intended to give facility managers the information and tools needed to properly take care of UPS batteries and ultimately achieve optimal availability of their critical infrastructure. Topics to be covered include the causes and costs of downtime; meeting regulatory requirements for battery testing and ongoing maintenance; best practices for preventive maintenance; design and service life of UPS batteries; and proactive replacement of batteries and other related components.

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Batteries may be the simplest component in a UPS system, but battery-related failures accounted for half of all UPS system failures during a recent Vertiv™ down unit analysis. This failure rate includes batteries that reached the end of their discharge.

When considering battery lifespan, it is common to confuse 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. In general, the service life is significantly shorter than the design life.

Battery Systems:
The Weakest Link in the Power Chain
Causes of unplanned data center downtime

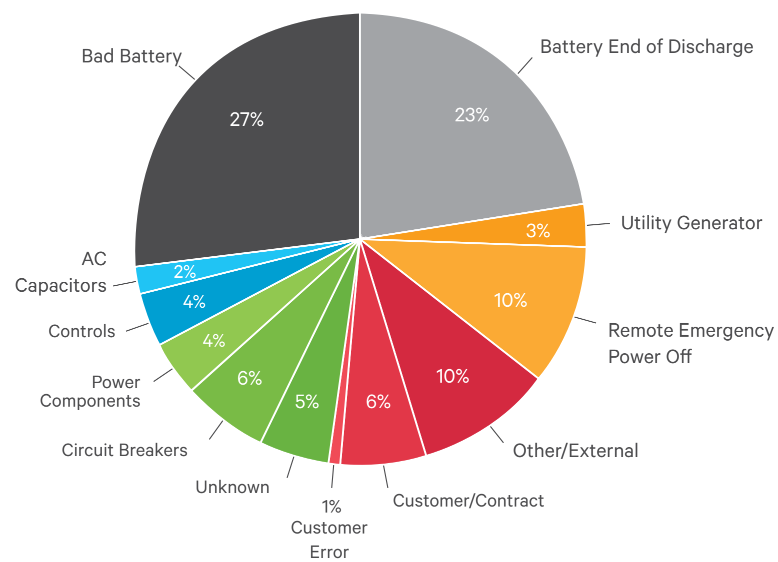

Figure 1: *A recent Vertiv analysis found that batteries are the most frequent cause of unplanned data center downtime.*

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Additionally, a recent study by the Vertiv™ Services team on real-world results of valve-regulated lead-acid (VRLA) batteries in the UPS environment combined with the company's extensive field experience, revealed that battery service life varies far too much to rely on manufacturer's initial resistance baseline data. In fact, Vertiv found that initial baseline considerations should begin 90 days after installation. When a new battery is replaced due to premature failure or cause, often the initial change in resistance will be downward and then remain constant. Figure 1 details an example of a battery change-out occurring after 600 days of life. Note that this battery's initial baseline resistance will likely settle near 5250 µOhms, instead of at 5650 µOhms seen at installation.

These common misunderstandings about battery service life often lead to improper battery maintenance. If facility managers only consider the manufacturer's design life or published baselines, batteries are often set up and then ignored for years, with no preventive maintenance or testing throughout the life cycle. This can lead to costly battery failures and unplanned downtime.

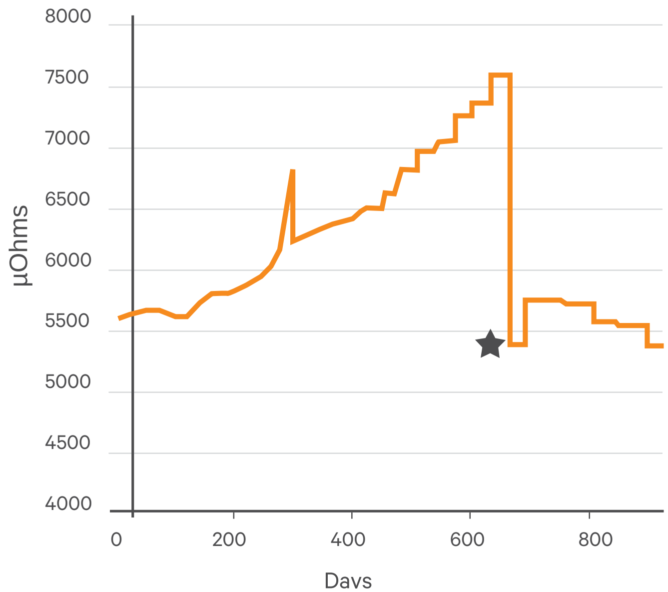

Figure 2: *The trending results that were typical for 70 ampere-hour VRLA batteries during the study has caused Vertiv to reconsider manufacturer-provided baselines. The service team found that when a specific unit settled to its running baseline, the initial variance from the manufacturer's baseline was as much as 25%.*

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In reality, when supporting the UPS, batteries fail in less than half the time stipulated by the manufacturer design life due to a variety of issues, including the following:

- Incoming power faults resulting in UPS engagement
- Manufacturing defects
- High or improper room temperatures
- Excessive charge current
- Overcharging and over-cycling
- Loose connections
- Strained battery terminals

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With so many things that can go wrong with UPS batteries, in addition to misunderstanding their true lifespan, regular **battery maintenance** and **replacement** is critical. Facility managers should ensure battery maintenance best practices are observed to keep backup power systems operating as intended in order to minimize unplanned downtime.

The Institute of Electrical and Electronics Engineers (IEEE) publishes maintenance standards, and UPS battery manufacturers provide schedules for maintenance checks. Adhering to these standards and schedules will ensure batteries are properly maintained and/or replaced before they become too risky for mission-critical applications. (**Chapter two** of this eBook will take a closer look at the IEEE guidelines, and we'll go deeper into preventive maintenance and replacement in chapters **three** and **four**.)

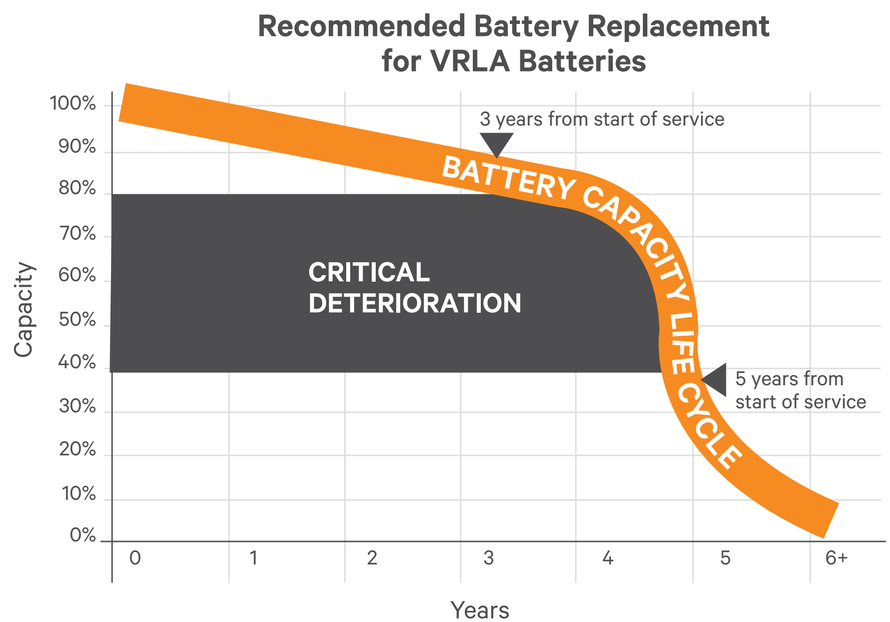

Figure 3: *Recommended battery replacement for VRLA batteries.*

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Misunderstanding the lifespan of a battery and not implementing UPS battery maintenance best practices for optimal performance can have serious consequences on a data center. Failure of the UPS backup system in the event of an outage with extended and costly business interruption is a likely scenario.

Given that high data demand requires organizations to be available 24/7, unplanned downtime is simply unacceptable, and rightfully so, considering that the overall average cost per downtime incident due to UPS system failure is nearly $710,000. This figure includes both the direct and indirect costs associated with downtime such as:

- Damage to mission-critical data, equipment and other assets
- A negative impact on organizational productivity
- Costs associated with detection and remediation
- Legal and regulatory impact
- Lost confidence among customers and other stakeholders
- Diminishment of a business' brand and reputation

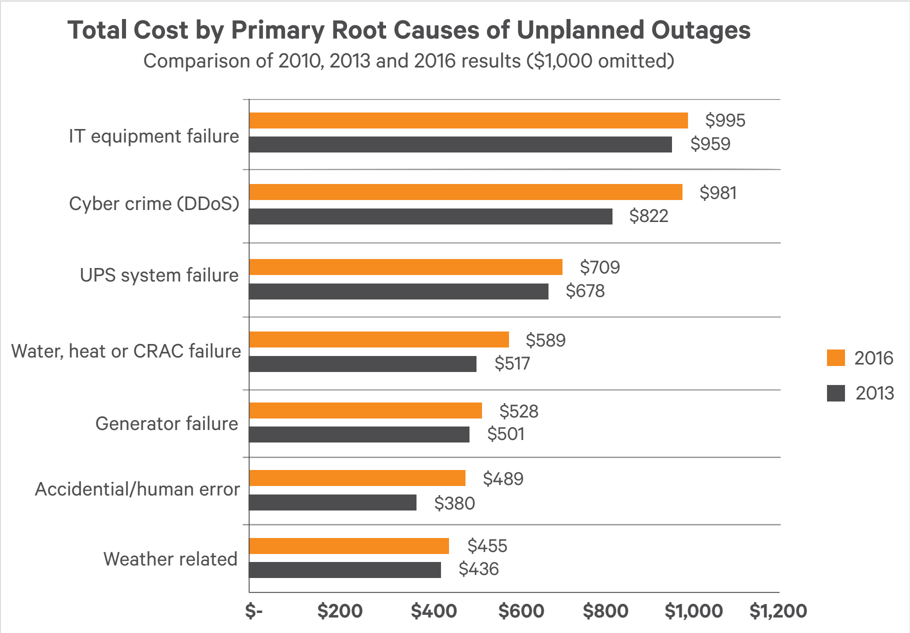

Figure 4: *The Ponemon Institute's "2016 Cost of Data Center Outages" report shows UPS system failure as the third most expensive root cause of unplanned outages.*

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While facility managers understand the drastic consequences of downtime, which can include the loss of their job, it remains a pressing issue that is plaguing data centers around the world. Most of the organizations surveyed in Ponemon Institute's "2013 Study of Data Center Outages" had at least one unplanned outage in the previous 24 months. Respondents averaged two complete data center shutdowns over a two-year period, with an average duration of 91 minutes. The findings suggest that companies do not have practices and investments in place to reduce or respond to some of the most preventable outages such as those related to battery failure.

The lengthy duration of data center outages correlates to a lack of resources and planning, as only 38 percent of survey respondents agree there are ample resources to bring their data center up and running if there is an unplanned outage. Another indication that organizations are not proactively addressing the risk of unplanned data center outages is that only 36 percent of those surveyed believe they utilize all best practices in data center design and redundancy to maximize availability.

This is unfortunate considering that 71 percent of respondents to the "2013 Study of Data Center Outages" survey agreed their company's business model is dependent upon the data center to generate revenue and conduct e-commerce. High-profile outages also caught the attention of these respondents. From Super Bowl XLVII to Twitter's Fail Whale to outages of Amazon and Google, major disruptions to IT services around the globe helped bring downtime to the forefront and reinforce not only the importance of availability, but the potential financial cost of downtime.

Facility managers need to understand and communicate to company executives the link between battery life expectancy and system failure. The investment to properly maintain battery strings is worth the peace of mind sought by many facility managers and is almost always less costly than what an organization would incur during a lengthy outage.

> Click here to read the Ponemon Institute's "2016 Cost of Data Center Outages" report

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Without reliable battery operation, no UPS system can do its job of providing consistent data center performance and business stability. This is precisely why facility managers or those responsible for data center operations need to fully understand the lifespan of batteries and how to incorporate a proper **preventive maintenance program.** Additionally, facility managers need to have a clear understanding of both the direct and indirect costs associated with downtime and communicate those business impacts to others in the organization in order to get buy-in regarding implementation of a UPS battery maintenance program. While seemingly simple, batteries are the heartbeat that support mission critical facilities and have a direct impact on availability and overall business success.

How much is the fine for a utility company that is not properly maintaining the batteries that support equipment connected to the Bulk Electric System? And who determines "proper" maintenance? Find out in chapter two of our battery maintenance eBook.

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In **chapter one** of this eBook, we highlighted the causes of downtime including the misunderstanding of battery lifespan. Additionally, we delved into the high costs, both direct and indirect, associated with UPS battery failure that leads to unplanned downtime. To help avoid this downtime, we shared that critical facility managers need to fully understand the true service life of batteries and then work to implement a proper preventive maintenance program.

In this chapter, we will look at consensus recommendations for preventive maintenance including industry standards from the Institute of Electrical and Electronics Engineers (IEEE) and regulatory requirements specific to utilities as stipulated by the North American Electric Reliability Corporation (NERC).

As these standards and regulations outline minimum maintenance activities, we will also share how many critical facilities can and should go beyond these minimums for additional system protection and added peace of mind.

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As the leading developer of industry standards in a broad range of technologies, IEEE has the most well known standards regarding UPS battery maintenance practices including inspections and capacity testing. In fact, battery manufacturers often cite the standards and require adherence in order to maintain a valid product warranty.

Whether a data center, industrial facility or utility, Vertiv™ encourages adherence to the following standards based on the type of battery being serviced:

- **IEEE 450** for vented lead-acid (VLA)
- **IEEE 1188** for valve-regulated lead-acid (VRLA)
- **IEEE 1106** for nickel-cadmium (NiCad)

All of these standards provide recommended practices for maintenance, testing and replacement of batteries for stationary applications. They address the frequency and type of measurements that need to be taken to validate the condition of the battery.

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The measurements needed such as string/cell voltage or battery float charging current are outlined based on monthly, quarterly and annual inspections. The more frequent the inspection or testing intervals, the better. Gathering data on a more regular basis can be very helpful for trending battery performance and ultimately extending the useful life of these critical assets.

Capacity Tests

Recommendations for capacity testing of VLA and VRLA batteries are very similar. Both should be tested at installation, during periodic intervals (no greater than 25% of the expected service life), and annually when the battery shows signs of degradation or has reached 85% of the expected service life. However, VLA batteries should have a capacity/discharge test within the first two years of service, and VRLA batteries should be tested when internal ohmic values have changed significantly between readings or physical changes have occurred. For these two battery groups, degradation is indicated when the battery capacity drops more than 10% from its capacity on the previous capacity test or is below 90% of the manufacturer's rating.

For NiCad batteries, capacity/discharge testing should be done within the first two years of service, at five-year intervals until the battery shows signs of excessive capacity loss, and annually at excessive capacity loss.

Battery Replacement

Both IEEE 450 and 1188 recommend replacing the battery if its capacity is below 80% of the manufacturer's rating. Maximum time for replacement is one year. Physical characteristics such as plate condition or abnormally high cell temperatures are often indicators for complete battery or individual cell replacements.

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The PRC-005-2(i) standard from the National Electric Reliability Corporation (NERC) applies to electric utilities, including all electric utility functional entities, including substations and power generating plants. It mandates certain minimum maintenance requirements for batteries that support equipment connected to the Bulk Electric System (BES)—the electrical grid responsible for power across large regions of the United States—within a certain amount of time.

PRC-005(i) exists because of the major blackout on August 14, 2003, in which more than 50 million people lost power. An aging electrical grid, technology issues and trees impinging on electrical lines created a perfect storm that led to a cascading series of outages from New York to Ohio and up into Ontario, Canada. Soon afterward, NERC was established to create standards that would ensure total reliability of the BES.

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NERC Standard PRC-005-2(i) — Protection System Maintenance

PRC-005-2(i) comprises regulations that require the electric utility backup battery "perform as manufactured." There is some controversy, however, about PRC-005-02(i), because it mandates only the minimum required maintenance be performed, and might result in batteries backing up the BES being less reliable. The PRC-005-2(i) standard does recommend service technicians use the best-practice battery maintenance procedures published by IEEE.

Additionally, the standard allows ohmic testing, which measures the internal qualities of a battery cell on VRLA and VLA batteries, in lieu of performance tests as long as the user can verify that the station battery can perform as manufactured. Battery manufacturers and other experts in the industry don't agree that ohmic testing meets this requirement. In fact, a study by the Electric Power Research Institute concluded that internal ohmic measurements can provide insight into internal degradation, but ohmic measurements alone "do not necessarily provide absolute verification of a battery's capacity; only a battery capacity test can determine the total battery capacity." If the assumption is true that there is widespread use of the faster, less expensive ohmic measurements, this also raises concerns that utility companies can follow PRC-005-2(i) and still not have a reliable battery backup.

The PRC-005-2(i) standard for protection system maintenance combines the following older standards:

- PRC-005-1 – Transmission and Generation Protection System Maintenance and Testing
- PRC-008-1 – Underfrequency Load Shedding Equipment Maintenance
- PRC-011-1 – Undervoltage Load Shedding Equipment Maintenance and Testing
- PRC-017-1 – Special Protection System Maintenance and Testing

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Section 1-4 of the standard covers the requirements for stationary (stand-by/backup) battery maintenance and testing. The PRC-005-2 standard requires time-based maintenance for stationary batteries. This means that protection systems are maintained or verified according to a defined time schedule.

Tables 1-4(a), (b) and (c) cover the requirements for protection system station direct current (DC) supply using VLA, VRLA or NiCad batteries. The following tables show the system component; maintenance activities for each type of battery; and the maximum amount of time before the battery should undergo maintenance again.

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PRC-005-2(i) Battery Maintenance Tables 1-4 (a), (b) and (c)

TABLE 1-4 (A)

COMPONENT TYPE - PROTECTION SYSTEM STATION DC SUPPLY USING VENTED LEAD-ACID (VLA) BATTERIES EXCLUDING DISTRIBUTED UFLS AND DISTRIBUTED UVLS

Protection System Station DC Supply Used Only For Non-BES Interrupting Devices for SPS, Non-Distributed UFLS Systems, or Non-Distributed UVLS Systems Is Excluded.

Component Attributes	Maximun Maintenance Interval	Maintenance Activities	
Protection System Station DC supply using VLA batteries not having monitoring attributes of Table 1-4(f)	4 calendar months	Verify: • Station DC supply voltage	Inspect: • Electrolyte level • For unintentional grounds
	18 calendar months	Verify: • Float voltage of battery charger • Battery continuity • Battery terminal connection resistance • Battery intercell or unit-to-unit conection resistance	Inspect: • Cell condition of all individual battery cells where cells are visible or measure battery cell/unit internal ohmic values where the cells are not visible • Physical condition of battery rack
	18 calendar months -or- 6 calendar years	Verify that the station battery can perform as manufactured by evaluating cell/unit measurements indicative of battery performance (e.g. internal ohmic values or float current) against the station battery baseline. -or- Verify that the station battery can perform as manufactured by conductiong a performance or modified performance capacity test of the entire battery bank.	

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TABLE 1-4 (B)

COMPONENT TYPE - PROTECTION SYSTEM STATION DC SUPPLY USING VALVE-REGULATED LEAD-ACID (VRLA) BATTERIES EXCLUDING DISTRIBUTED UFLS AND DISTRIBUTED UVLS

Protection System Station DC Supply Used Only for Non-BES Interrupting Devices for SPS, Non-Distributed UFLS Systems, or Non-Distributed UVLS Systems is Excluded.

Component Attributes	Maximun Maintenance Interval	Maintenance Activities	
Protection System Station DC supply using VRLA batteries not having monitoring attributes of Table 1-4(f)	4 calendar months	Verify: • Station DC supply voltage	Inspect: • For unintentional grounds
	6 calendar months	Inspect: • Condition of all individual units by measuring battery cell/unit internal ohmic values	
	18 calendar months	Verify: • Float voltage of battery charger • Battery continuity • Battery terminal connection resistance • Battery intercell or unit-to-unit conection resistance	Inspect: • Physical condition of battery rack
	6 calendar months -or- 3 calendar years	Verify that the station battery can perform as manufactured by evaluating cell/unit measurements indicative of battery performance (e.g. internal ohmic values or float current) against the station battery baseline. -or- Verify that the station battery can perform as manufactured by conductiong a performance or modified performance capacity test of the entire battery bank.	

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TABLE 1-4 (C)

COMPONENT TYPE - PROTECTION SYSTEM STATION DC SUPPLY USING NICKEL-CADMIUM (NICAD) BATTERIES EXCLUDING DISTRIBUTED UFLS AND DISTRIBUTED UVLS

Protection System Station DC Supply Used Only For Non-BES Interrupting Devices for SPS, Non-Distributed UFLS Systems, or Non-Distributed UVLS Systems is Excluded.

Component Attributes	Maximun Maintenance Interval	Maintenance Activities	
Protection System DC supply using NiCad batteries not having monitoring attributes of Table 1-4(f)	4 calendar months	Verify: • Station DC supply voltage	Inspect: • Electrolyte level • For unintentional grounds
	18 calendar months	Verify: • Float voltage of battery charger • Battery continuity • Battery terminal connection resistance • Battery intercell or unit-to-unit conection resistance	Inspect: • Cell condition of all individual battery cells • Physical condition of battery rack
	6 calendar years	Verify that the station battery can perform as manufactured by conducting a performance or modified performance capacity test of the entire battery bank.	

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Exclusions for Protection Systems Station DC Supply Monitoring Devices and Systems 1-4(f)

Table 1-4(f) covers the exclusions for protection systems station DC supply monitoring devices and systems. We will discuss battery monitoring in detail in **chapter three** of this eBook; however, note that the PRC-005-2(i) requirements allow exceptions when a monitoring system is in place. This section of PRC-005-2(i) shows what testing and maintenance procedures do not need to be applied based on the extent of battery monitoring.

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For example, any VRLA or VLA station battery with internal ohmic value or float current monitoring and alarming (that evaluates present values relative to baseline internal ohmic values for every cell) doesn't require periodic evaluation relative to baseline measurements in order to verify it can perform as manufactured. Other component attributes that may be excluded from periodic maintenance activities include:

- Any station DC supply with high- and low-voltage monitoring and alarming of battery charger voltage
- Any battery-based station DC supply with electrolyte level monitoring and alarming in every cell
- Any station DC supply with unintentional DC ground monitoring and alarming
- Any station DC supply with charger float voltage monitoring and alarming
- Any battery-based DC supply with monitoring and alarming of battery string continuity
- Any battery-based DC supply with monitoring and alarming of the intercell and/or terminal connection detail resistance of entire battery

When looking at all the exclusions outlined in Table 1-4(f), it is clear to see that implementing a battery monitoring solution can significantly simplify efforts needed to comply with PRC-005-2(i).

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The reason to test and maintain batteries regularly—whether in a data center, an electric utility or industrial facility—is to protect against downtime. When batteries back up critical equipment, more care in battery maintenance is preferable to less.

When compared to the cost of downtime, UPS batteries are inexpensive. Vertiv™ recommends the following activities as part of battery maintenance best practices:

- Ensure batteries are fully charged and properly installed—physically, electrically and environmentally—before they are placed in service.
- Verify condition of batteries after installation in order to minimize the likelihood of costly retests and equipment damage.
- Inspect batteries before startup and/or load testing to gather valuable information that can be applied immediately and serve as a baseline for any testing conducted throughout the service life of the batteries. 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.
- Implement a battery monitoring solution to improve mean time between failures (MTBF).
- Follow the IEEE best practices for the type of battery being used.
- Utilize a service provider with experience specific to your application and one that is versed in regulatory requirements.

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Facility managers should be familiar with and follow regulations affecting battery maintenance in order to maintain valid product warranties and avoid unexpected outages. Perhaps more important for a critical facility operator in any industry is understanding how best practices for battery testing and maintenance can go beyond minimum regulatory requirements in order to optimize system performance and improve availability.

Working with an experienced professional services organization that is well versed in regulatory requirements and industry best practices can give facility managers added confidence. A proper maintenance program ensures their batteries will support their power generation, transmission and distribution systems, or that their emergency power system is ready when it's needed.

Ensuring proper battery performance and getting the most out of your investment in this critical asset may take more than just sporadic checks. That is why monitoring is a critical component of a comprehensive preventive maintenance program. Learn more in chapter three of our battery maintenance eBook.

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COMPREHENSIVE PREVENTIVE MAINTENANCE

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Methods for Maintaining Battery Health

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As highlighted in **chapter one** of this eBook, the UPS supporting critical systems is only as reliable as its batteries, and those are oftentimes the weakest link in the entire system. If there's a power outage, even a single bad cell in a string of batteries could compromise the entire backup power system and lead to unexpected downtime. No facility manager wants to experience downtime because of the business disruption, lost revenue, and possible impact to their organization's reputation; yet low-tech batteries often don't get the same care as other components in the power system. In **chapter two**, we addressed the importance of preventive maintenance for batteries including the need to meet regulatory requirements from organizations such as the Institute for Electrical and Electronics Engineers (IEEE) and the North American Electric Reliability Corporation (NERC). Additionally, best practices were shared for how to meet these requirements and ensure availability.

In this chapter, we discuss ways to mitigate the risk of downtime that go beyond minimum maintenance requirements; the features of a regular, ongoing preventive maintenance program; and how incorporating monitoring into the maintenance program can significantly improve asset management and availability.

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UPS battery systems can be like old holiday lights. It only takes one bulb to go bad and the whole string is affected. While holiday lights are easy to buy and replace, UPS battery systems are not so simple. Adding a second battery string offers some protection (see Figure 1). But if one of the strings has a bad battery and there is a bad connection between the strings, the load can still be dropped. For these reasons, it's very important to have a plan for dealing with the risk of battery failure.

As discussed in **chapters one** and **two** of this eBook, the reason to maintain batteries in good working condition is to prevent downtime and minimize the costs associated with it. Figure 2 on the following page illustrates the cost of building a critical facility infrastructure including the IT equipment, as well as the cost of downtime in specific industries.

Batteries in Series

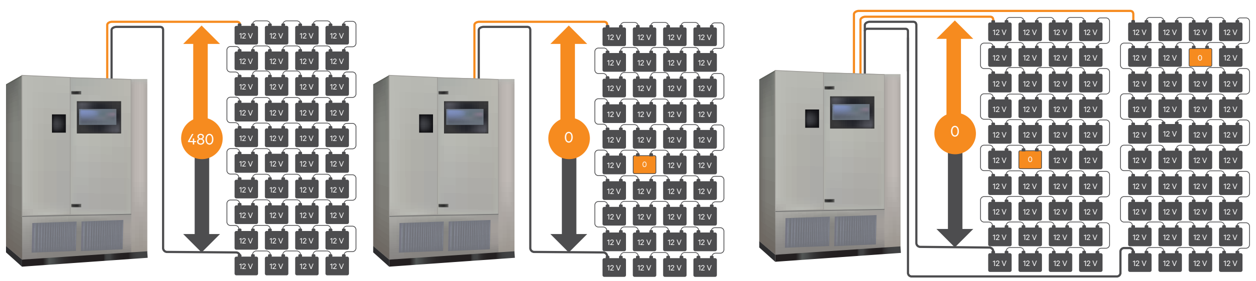

Figure 1: *For UPS units with a single battery string or multiple strings for capacity, one open cell during utility power loss will cause a load to be dropped. While adding a second, redundant string adds a layer of protection, it does not eliminate the risk.*

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For five-nine (Tier 2) facilities, infrastructure costs about $1,000 per square foot and IT equipment costs $50,000 per rack (excluding software). Add to that the revenue the applications on the servers generate and an hour of downtime can result in significant negative impact to the bottom line.

Cost of High 9's Environment

TIER	UPTIME (9'S)	DOWNTIME/YEAR	$BLDG	$CAPITAL
1	99.99% (4)	52 min	$1,000/Sq Ft	$50K/Rack
2	99.999% (5)	5 min		
3	99.9999% (6)	30 sec		
4	99.99999% (7)	3 sec		

INDUSTRY	DOWNTIME/YEAR
Brokerage Operation	$7,840,000
Credit Card Operation	$3,160,000
Pay-Per-View	$183,000
Catalog Series	$109,000
Airline Reservation	$108,000
Telephone Ticket Sales	$83,000

Figure 2: *The high cost of downtime justifies ongoing preventive battery maintenance and monitoring.*

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There are four approaches to mitigating the risk of battery failure and the resulting costly downtime: reactive, time-based, predictive and proactive.

Reactive

This approach, also known as break/fix, is the riskiest method for determining the health of the battery string. In this case, corrective action is only taken when an outage occurs. This is not a method for a high-nines facility. It is often the approach used when the consequences of downtime aren't viewed as business critical or the budget is very limited.

Time-Based

With a time-based approach, facilities receive regular preventive maintenance visits in which batteries are visually inspected and serviced. This is much better than no preventive action, but does not allow for battery oversight outside of these periodic visits. This approach is still risky because of external factors that can cause a significantly shorter service life than what is expected by the critical facility manager.

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Predictive

Implementing a predictive approach combines battery monitoring with regular preventive maintenance visits which adds a layer of protection. With mobile or embedded monitoring technology, technicians are able to measure AC impedance and DC resistance. While AC impedance testing is generally more affordable, the resolution of testing data is not as accurate as with DC resistance testing. Additionally, testing DC resistance is an approach that often leads to an overall lower total cost of ownership.

- With AC impedance, an AC signal is injected into the DC battery. This will not always give an accurate picture because DC bus noise will affect an AC test signal. It also is not helpful in providing advance warning that the battery's internal resistance is increasing, which is a sign of battery degradation. When a warning is finally given, the battery is already compromised.
- With DC resistance, a momentary load is applied while the battery voltage is monitored to ensure the battery isn't put in a state of discharge. The battery's internal resistance can be measured as the current flows through it. The test is stopped before the battery crosses the open circuit voltage (OCV) level. Determining the battery's health in this manner is consistent with how a battery is designed to function. This is the approach that most accurately measures internal resistance.

While this approach has many benefits, predictive maintenance alone is not sufficient to ensure high nines availability. Adding another layer of protection is highly recommended.

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Proactive

The proactive approach is the most reliable and effective method of mitigating battery risk. This approach uses regular battery testing and the same battery monitoring that may be used in the predictive approach. However, the proactive approach combines testing and monitoring with remote services. It gives infrastructure experts complete visibility into all pre-established critical battery parameters—cell voltage, internal resistance, cycle history, overall string voltage, current and temperature.

A proactive approach allows infrastructure experts to detect weak batteries before they ever become bad batteries making mean time to repair (MTTR) a non-issue. Batteries are simply replaced before failure occurs. Mean time between failures (MTBF) is also improved as facility managers know the true health of their batteries which allows them to utilize those critical assets longer and with confidence.

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As seen in the proactive approach, several layers of protection are needed to minimize the risk of downtime from battery failure. The first layer is a preventive maintenance program. Preventive maintenance can include activities such as inspections, tests, measurements, adjustments, parts replacement and general housekeeping practices.

A comprehensive preventive maintenance program for the power protection system is the key to ensuring maximum reliability of critical equipment by detecting and correcting incipient failures that can translate into unplanned, costly downtime. By heading off potential problems before they become extensive and expensive, preventive maintenance programs actually reduce total cost of ownership.

The number of preventive maintenance visits has a substantial impact on system reliability and downtime. The return on investment for preventive maintenance can be observed by calculating MTBF, an industry-recognized measure of availability that uses the number and types of failure that products actually experience in real applications. A higher MTBF number indicates a more available unit.

Regular preventive maintenance increases MTBF. In one study of 185 million operating hours for more than 5,000 three-phase UPS units, and more than 450 million operating hours for more than 24,000 strings of batteries, the impact of regular preventive maintenance on UPS reliability was clear. This study revealed that the MTBF for units that received two preventive maintenance service visits a year is 23 times better than a UPS with no preventive maintenance visits. According to the study, reliability continued to steadily increase with additional visits when these visits were conducted by highly trained technicians.

> Click here to read white paper on the effect of regular, skilled preventive maintenance.

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After preventive maintenance, battery monitoring is the second layer of protection against battery failure. Rather than waiting for an inevitable failure or replacing batteries prematurely to prevent problems, battery monitors allow organizations to continue to utilize their batteries longer and with confidence by having access to real-time information on all critical battery parameters. A battery monitoring system provides a continuous watch of the battery to assess its true state of health.

The best practice is to implement a monitoring system that connects to and tracks the health of each battery within a string. The most effective battery monitoring systems continuously track all battery parameters using a DC test current to ensure measurement accuracy and repeatability. Supported by a well-defined process for preventive maintenance and replacement, monitoring batteries can significantly reduce the risk of dropped loads due to battery failure and optimize battery life.

Because facility managers have their plates full with responsibilities for running an efficient, available, and optimized space, battery monitoring may fall to the bottom of the list of priorities. In some cases, organizations don't have enough internal personnel to dedicate someone to this task.

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In these cases, remote services, managed by an organization with resources devoted to battery monitoring, can be an easy solution. This organization is the third layer of protection against battery failure. Remote services lift the burden of infrastructure monitoring from internal personnel. They allow for real-time diagnosis and near instant notification when a problem occurs. When actual performance data falls outside of the established parameters, signaling performance degradation, an alert can be transmitted to remote power system engineers and/or product experts who assess the situation through data analysis. This in turn can generate a work order to inspect, repair, or replace the part that caused the alert.

In addition to improved resource utilization, a dedicated monitoring organization can respond more quickly to larger infrastructure issues. For instance, in monitoring data across multiple facilities, they may be alerted to a problem caused by a certain manufacturer's equipment. Very quickly, the manufacturer can be notified so as to avoid a potential problem occurring across hundreds of sites, many of which contain similar equipment.

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A remote monitoring solution may also have engineers on staff that analyze data returned remotely, and who systematically examine that data. For example, remote monitoring tracks the inbound frequency of power provided to a UPS. If the UPS is receiving utility power, the input power frequency will be precisely 60 Hz. When the monitoring staff sees the input frequency vary within 58-61 Hz, they immediately recognize that the generator has started and is sourcing power—but potentially at the wrong time and for the wrong reason. This exemplifies the importance of trended and historical data that can be collected with a remote monitoring service. Such data can help technicians identify conditions that deviate from normal operating conditions, but fail to trigger an alarm. Anomalies like these could indicate impending equipment issues, but are easy for technicians to miss when they lack access to trending data that can be compiled into equipment profiles.

Finally, telemetry-based monitoring enables remote management of systems where authorized, allowing the monitoring partner to control systems remotely. This is particularly valuable when a facility is undergoing changes and updates.

There's an inherent benefit in having a centralized expert group that can conduct detailed analysis and proactively manage it. If a problem occurs, they can immediately alert personnel of the situation, diagnose the problem, alleviate the problem prior to deterioration or failure, and dispatch a technician if needed.

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Batteries represent the least reliable component in the critical power system. They are an electrochemical device with a finite lifespan and lose capacity over time. Adverse conditions such as over cycling, excessive charge current and high temperatures accelerate this aging process. But these conditions need not lead to the adverse effects of unplanned downtime.

By going beyond the reactive approach to preventive maintenance and layering on levels of protection through monitoring, preferably in tandem with remote services, facility managers extend the service life of batteries—significantly reducing the risk of dropped loads and ensuring system availability.

A regular, ongoing preventive maintenance program is essential for business-critical facilities, and proactive replacement of batteries and capacitors should be part of that program. Learn more in the final chapter of our battery maintenance eBook.

Vertiv™ Services eBook Series

Battery Maintenance Solutions for Critical Facilities

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In previous chapters of this eBook, we discussed the necessity of regulatory-compliant preventive maintenance programs in order to take care of an uninterruptible power supply (UPS) and its batteries, and avoid the potentially devastating impacts of downtime. Additionally, **chapter three** highlighted four approaches for mitigating that downtime risk. We concluded that the reactive (also known as break/fix) approach in which corrective action is only taken when an outage occurs, and the time-based approach in which battery strings are replaced at specific intervals whether they need it or not, are the least efficient means of managing risk. Predictive and proactive approaches which combine regular maintenance with monitoring are much better strategies for attempting to eliminate the risk of battery failure.

In this chapter, we continue discussing causes of battery-related downtime and how to prevent it. We'll look at what real-world testing revealed about the manufacturers' published battery baselines and lifespans; when battery and capacitors should be replaced; and why it is beneficial to keep on-site spares.

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Vertiv conducted an analysis of valve-regulated lead-acid (VRLA) batteries in real-life UPS environments to assess the accuracy of the manufacturer's published baseline data and lifespan estimates. Additionally, field experience with more than 40,000 battery strings and 600,000 inspection visits or preventive maintenance visits were evaluated.

A significant finding of this research is that battery life cycles vary far too much to rely solely on manufacturers' published baseline data and lifespan estimate when determining when to replace batteries.

In order to get the most accurate resistance baseline measurements of the thousands of VRLA batteries in the study, stationary resistance instruments were chosen because other popular methods could not indicate battery health in high-voltage, high-unit-count UPS implementations. Also for this study, an alarm-based method was considered particularly unsuitable for increasing availability. Comparatively, resistance methods provided an indicator of battery health status data. This was especially true when data was compared over the full lifetime of a given unit, as well as against an initial baseline.

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It was important for the analysis to capture accurate unit-specific, situation-specific baseline resistance and periodic resistance readings. As such, using stationary instruments was a good option for taking more frequent measurements because it is a lower-cost method, and one that enables a high degree of repeatability.

What was found during the analysis is that the initial baseline resistance measurement should be taken 90 days after installation. When a new battery is replaced due to premature failure, often the initial change in resistance will be downward and then remain constant. In a previous example, with a battery change-out that occurred after 600 days of life, the initial baseline resistance settled near 5,250 µOhms instead of at the 5,650 µOhms seen at installation **(see chapter one, Figure 2)**. Capturing the true baseline of the replacement battery requires a stationary instrument that provides reliable measurements.

Several units experienced this same result, which has caused many to doubt manufacturer-provided baselines. The study found that when a specific unit settles to its running baseline, the initial variance from the manufacturers' baselines could be as much as 25 percent. It's recommended that facility managers closely monitor batteries that are 40 percent over the initial, true baseline. A battery is considered to be failing at 50 percent over true baseline.

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Knowing when batteries are considered to be failing relative to the true baseline is critical for avoiding downtime due to battery failure. Knowing the actual service life of batteries compared to the manufacturers' published design life is also important for preventing battery failure.

Battery Replacement

A second significant finding of the real-world testing performed by Vertiv™ is that batteries lose capacity in as little as three years due to several factors including usage, operating environment, and maintenance.

While UPS battery manufacturers may market their batteries with a 10-year or longer design life or lifespan, the reality is that the actual service life of the battery will be much shorter due to external factors that cause them to degrade. Several issues that can shorten the life of a battery string include:

- Incoming power faults resulting in UPS engagement
- High or improper room temperatures
- High or low charge voltage
- Excessive charge current
- Manufacturing defects
- Overcharging and over-cycling
- Loose connections
- Strained battery terminals
- Poor and improper maintenance

The Institute for Electrical and Electronics Engineers (IEEE) states that the useful life of a UPS battery ends when it can no longer supply 80 percent of its rated capacity in ampere-hours. This is when a battery should be replaced because the aging process accelerates **(see chapter one, Figure 3)**.

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Because of the many factors that can affect the useful life of a UPS battery, it is important that as soon as it is placed into service, it is maintained with a program that identifies system anomalies and monitors end-of-life trends. Batteries that are beginning to fail cause an imbalance that adversely affects the life of other batteries in the string, and they should be removed from service.

Capacitor Replacement

While we haven't previously discussed capacitors in this eBook, they are an important component of UPS systems, and they affect the batteries. Where high reliability is a must, it's necessary to supply a mechanism for maintaining power stability to UPS modules during a brief power interruption. This is the job of the capacitors. The UPS modules connect to a DC bus containing both a large battery bank and a DC capacitor bank that stores energy and enables the DC bus to continue operating during a fault. It also filters noise and irregular voltage out of the DC current. Like batteries, capacitors can fail unexpectedly, and like batteries capacitors should be monitored and replaced before failure occurs.

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UPS systems use large capacitor banks made up of both DC electrolytic and AC polymeric film capacitors, and these can degrade in the UPS environment. Chemical reactions through heat, oxygen and moisture cause the materials that can withstand the high voltage applied to capacitors to deteriorate. All insulating materials experience some leakage current that flows through a small channel and gives rise to localized heat.

Capacitors are not static electrical components that operate in a circuit. Over time, their ability to withstand voltage and pressure changes diminishes, which can lead to downtime. Figure 1 in the **Capacitors Age and Capacitors Have an End of Life** white paper from Vertiv™ shows the difference between ideal capacitor aging (design life) and real aging (service life). Replacing aging capacitors will help ensure longer mean time between failures (MTBF) of the UPS and extend the service life of UPS batteries.

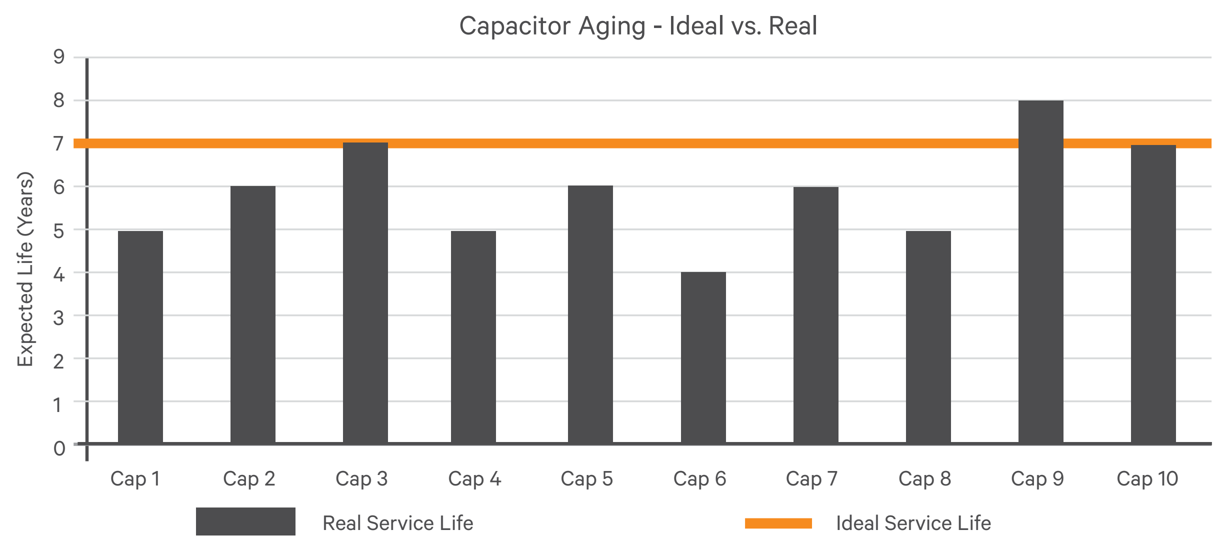

Figure 1: *Varying factors such as operating conditions and load cause the real service life of capacitors to deviate from the ideal. This chart exemplifies failure rates witnessed in the field when a group of capacitors with the same model number are operated under the same max rated conditions.*

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Most capacitor manufacturers provide a capacitor design-life rating. This rating is, at best, a guideline. The number lacks sufficient accuracy to be used to predict when the first capacitor in a large population will fail. Capacitor failure models can be used to generate a failure time for a specific failure rate, but unfortunately, the number contains a large variance that brings with it a low confidence level.

Because the expected service life of capacitors can vary significantly, replacing them before they fail or show significant signs of degradation will help achieve a long service life and help critical facilities avoid unplanned downtime. Figure 2 shows replacement hours for both types of capacitors under specific conditions, based on our years of field experience.

Ideally, a replacement program should be based on historical data in the field. This is the most reliable way to predict the best replacement time. A predictive monitoring system can provide that type of information. When it becomes necessary, capacitors can be replaced during a preventive maintenance visit with no damage to the UPS.

COMPONENT	AC POLYMERIC FILM	DC ALUMINUM ELECTROLYTIC
Expected service life at max rated conditions	60,000 to 150,000 hours	1,000 to 12,000 hours
Typical life test conditions	Accelerated rated (125% or rated voltage and 10˚ above max ambient)	max rated
Typical life testing time at test conditions	2,000 to 3,000 hours	2,000 to 5,000 hours
Expected service life at operating conditions	100,000 hours	150,000 hours
Recommended replacement time	45,000 to 50,000 hours	45,000 to 50,000 hours

Figure 2: *Recommended capacitor aging program.*

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Having seen that manufacturer ratings are not the best indicator of battery or capacitor life cycles, and that replacement programs can overcome these problems, the matter of cost may now come to mind.

Batteries are inexpensive compared to the cost of a critical facility's unplanned downtime. If spare batteries aren't kept on site and one fails, the UPS system will be down until a new battery arrives. Then the impact to revenue and reputation may come into play.

Typically, a battery backup system will consist of one or more strings, each composed of many jars. The jars within a string are connected in series, meaning a failure of just one jar will degrade an entire string, and unless there are multiple redundant strings powering the same equipment, the protected system will lack backup power. Additionally, placing unmatched or new batteries into a string of aged batteries diminishes the characteristics of that new battery, negatively affecting lifespan and system availability.

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Current takes the path of least resistance, so placing a factory-new battery in a string of aged batteries that have varying levels of internal resistance causes the factory-new battery to be overcharged. In time, this could shorten the lifespan of the entire string and diminish the return on a battery investment.

Ideally, facilities should have fully charged, ready-to-install batteries on site that match the type and condition of the in-service batteries. This can be accomplished with a battery spares cabinet equipped with an onboard charger. This supply of batteries supports a fast, first-time fix and eliminates problems involved with mixing new and old batteries in a string.

Depending on the criticality of the facility and battery type, it is recommended that data centers have enough spare batteries to cover five to 10 percent of the batteries in every cabinet plugged in and housed similarly to the batteries in service. The spare batteries will age simultaneously with the main battery string, making replacement faster and more stable.

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.

Other advantages of keeping on-site spare batteries include:

- Spare batteries will be charged and ready when they are needed most
- The number of visits to repair a battery string is reduced
- The risk of obsolescence for both VLA or VRLA batteries is minimized

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Analysis of real-world testing and field data by Vertiv™ demonstrates that manufacturer-published design life for batteries is significantly higher than the actual service life of batteries operating in a UPS environment. The same kind of disconnect also occurs when it comes to capacitors, which can fail unexpectedly and affect battery performance and lifespan.

It's clear that batteries and capacitors should be included in comprehensive preventive maintenance programs in order to mitigate the failure of the UPS and avoid unplanned downtime. It is also clear that being proactive when maintaining and replacing these critical UPS components offers the most benefits in terms of system performance and availability.

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