ANNUAL PREVENTATIVE MAINTENANCE INSPECTION REPORT

Inspection Performed: 04/08/2014

Ticket Number: 2390504
Serial Number: ED042CAB06

NATIONAL INSTITUTE OF STANDARD

100 BUREAU DRIVE

GAITHERSBURG, MD 20899

Attention: DENNIS BRADY
Phone: 3019756264

Battery Services Performed By:

Allen L. Fowler
Battery Ops Manager
Six Forks Road,
Raleigh, NC 27615
Phone: 919-730-5744 E-mail: AllenLFowler@eaton.com

Service Dispatch: (800)843-9433
www.powerware.com

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NATIONAL INSTITUTE OF STANDARD

ANNUAL PREVENTATIVE MAINTENANCE INSPECTION REPORT

Date: 04/08/2014

Overview

Green - No Problems Found.

No repairs performed.

Services Performed

Service Description	VRLA/SEALED
Charger output current and voltage	•
AC ripple voltage	•
0 % Open Cell/Jar Voltage	•
0 % Float Cell/Jar Voltage	
Cell/jar voltage	
Internal resistance/impedance	•
0 % of inter-cell connection resistances	•
Re-torque as necessary	
Ambient temperature	
Temperature of negative terminal	•
0 % of specific gravity (flooded cells)	
Visual Inspection	•
Inspect ventilation	
Inspect battery monitoring equipment	
Load Test performed	

Technician Notes

ALL UNITS TESTED WITHIN MANUFACTURER'S SPECIFICATIONS.

EATON

NATIONAL INSTITUTE OF STANDARD

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Date: 04/08/2014

Charger Information

UPS Mfr: Eaton	UPS Serial: ED042CAB06
UPS Model: 9390 - 80 / 80	Charger Qty: 1

Battery Information

Battery Mfr: EATON	Battery Type: Sealed
Battery Model: PWHR12390W4FR	Mfr. Date: 11/2009

Battery System Information

DC Link Nominal: 540	Fixture Type: Tray
Trays per String : 9	Jars per Tray : 4
String Qty: 1	String Isolation: Yes
Seismic Rating:	Cycle Counter: None
System Float Voltage: 497.0	System Float Charging Amps: 0.0
System Equalize Voltage: 0.0	
Charger AC Ripple Voltage: 1.53	Charger AC Ripple Current: 4.0
Room Temperature (Fahrenheit) : 73.0	Rack/Cabinet Condition: Good
System Load: 11.0 %	Total Electrolyte Vol:
Positive Voltage to Ground: 107.9	Negative Voltage to Ground: 390.0
Retorque Connections: No	Recommended Value:
Value Used:	

Safety Equipment

Fire Suppression: Not Tested	Spill Kit: Not Present
Eye Wash Station: Not Present	Hydrogen Detector: Not Present
Shower: Not Present	Vent Fan: Not Tested
Spill Containment: Not Present	Lighting: Not Tested

Test Parameters

	Minimum			Maximum	
Test Type	Critical	Warning		Warning	Critical
Voltage Float	12.840	12.840		14.500	14.500
Voltage Open	12.840	12.840		14.500	14.500
Specific Gravity					
Neg Post Temp.	68.000	70.000		84.000	86.000
Cell Temp.					
Ohmic				1000.000	1000.000
Resistance				5300.000	5521.000

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Date: 04/08/2014

Charger Mfr: Eaton
Model: 9390 - 80 / 80
Serial #: ED042CAB06

Battery Mfr: EATON
Model: PWHR12390W4FR

Inspection Data

String 1	Volts		Load				Specific	Micro-Ohms			Inter	
Unit	Float	Open	Open	End	Resistance	Temp	Gravity	Post 1	Post 2	Post 3	Tier	Status
Tray 1												OK
Jar 1		13.157			4561.000			375.000				OK
Jar 2		13.103			4425.000			866.000				OK
Jar 3		13.130			4317.000			383.000				OK
Jar 4		13.102			4353.000	73.0		22.000				OK
Tray 2												OK
Jar 1		13.085			4434.000			512.000				OK
Jar 2		13.072			4240.000			473.000				OK
Jar 3		13.134			4344.000			384.000				OK
Jar 4		13.105			4355.000	73.0		105.000				OK
Tray 3												OK
Jar 1		13.095			4411.000			333.000				OK
Jar 2		13.093			4382.000			392.000				OK
Jar 3		13.125			4378.000			371.000				OK
Jar 4		13.100			4375.000	73.0		122.000				OK
Tray 4												OK
Jar 1		13.077			4368.000			440.000				OK
Jar 2		13.097			4337.000			545.000				OK
Jar 3		13.105			4384.000			423.000				OK
Jar 4		13.179			4385.000	73.0		147.000				OK
Tray 5												OK
Jar 1		13.163			4437.000			372.000				OK
Jar 2		13.196			4322.000			418.000				OK
Jar 3		13.105			4399.000			452.000				OK
Jar 4		13.175			4368.000	73.0		51.000				OK
Tray 6												OK
Jar 1		13.119			4487.000			343.000				OK
Jar 2		13.112			4399.000			448.000				OK
Jar 3		12.966			5233.000			401.000				OK
Jar 4		13.115			4265.000	73.0		44.000				OK
Tray 7												OK
Jar 1		13.094			4401.000			333.000				OK
Jar 2		13.103			4372.000			390.000				OK
Jar 3		13.115			4502.000			341.000				OK
Jar 4		13.079			4382.000	73.0		66.000				OK
Tray 8												OK
Jar 1		13.112			4409.000			342.000				OK
Jar 2		13.068			4434.000			429.000				OK
Jar 3		13.111			4444.000			368.000				OK
Jar 4		13.125			4481.000	73.0		36.000				OK

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Date: 04/08/2014

Charger Mfr: Eaton
Model: 9390 - 80 / 80
Serial #: ED042CAB06

Battery Mfr: EATON
Model: PWHR12390W4FR

Inspection Data

String 1	Volts		Load				Specific	Micro-Ohms			Inter	
Unit	Float	Open	Open	End	Resistance	Temp	Gravity	Post 1	Post 2	Post 3	Tier	Status
Tray 9												OK
Jar 1		13.145			4459.000			349.000				OK
Jar 2		13.181			4427.000			386.000				OK
Jar 3		13.135			4310.000			422.000				OK
Jar 4		13.134			4437.000	73.0		159.000				OK

"Eaton Power Quality Corporation offers maintenance and replacement services on ALL types of Battery Systems - UPS, Telecommunications, Industrial, etc. For more information contact your local represenative."

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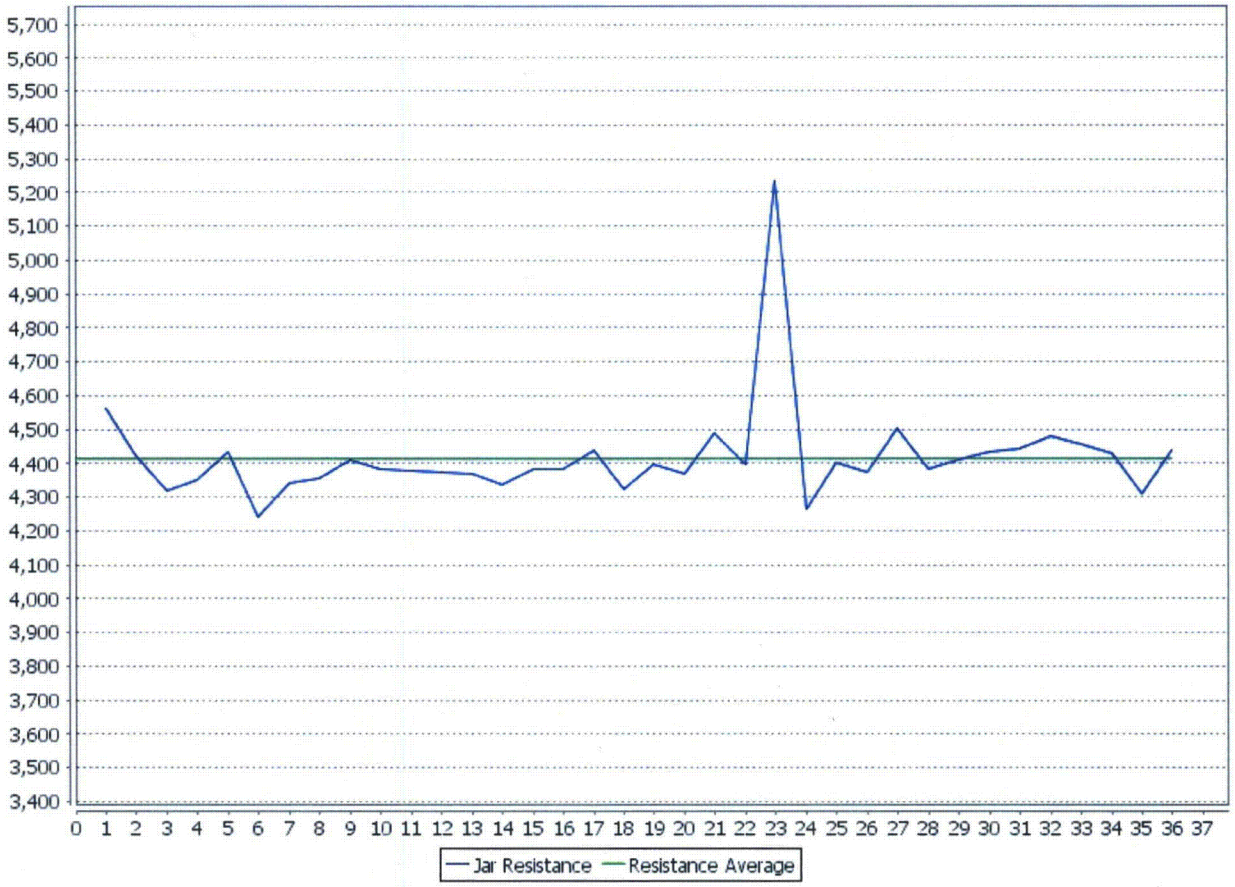
Resistance Graphical Representation



Supplementary Response to RAI Questions 3 and 5

This supplement expands the NCNR response of February 26, 2015, to RAI Questions 3 and 5 (please see Attachment 1) of January 30, 2015. Specifically, this response will clarify the NCNR commitment to VRLA battery maintenance to justify battery bank measurements in lieu of battery measurements, thus ensuring the emergency power capacity to meet the station battery duty cycle.

In the June 23, 2014 license amendment request, the NCNR committed to meeting the VRLA battery maintenance guidance found in the UPS owner manual and committed to following the performance test recommendation found in IEEE 1188-2005. The structure of the paragraph with those commitments clearly obligates the NCNR to complete the 2 year performance test described in the standard with satisfactory results, and to nothing else in the standard.

The commitment to only the 2 year test is consistent with previous NCNR technical specification surveillances described in the following paragraph. Commitment to the guidance in in the UPS owner manual will be demonstrated through a semi-annual or annual service that records selected parameters for each battery during a partial loading of that battery. The condition of each battery will be defined as pass or fail based upon the data collected and the effect of failed batteries upon bank capacity will be assessed, followed by battery replacement or additional monitoring. See Attachment 4 for a summary of the data.

Per Technical Specification (TS) 3.6, confirming ". . . the station battery . . . operable, including associated distribution equipment . . ," not individual battery capacity, is the objective of the emergency power technical specification in order to maintain power to specific equipment for a given period of time, assuring the assumptions of the safety analyses (NBSR 14, 2009) remain valid and other technical specifications, e.g. confinement integrity, are met (NBSR 15, 2009). TS 3.6 requires the station battery to be operable, i.e. have the capability to supply power to the nuclear instrumentation and the emergency exhaust fans for 4 hours.

ANSI/ANS-15.1-2007 *The Development of Technical Specifications for Research Reactors* defines operable as, "Operable means a component or system is capable of performing its intended function." The component or system here is the station battery, which consists of 60 single-cell wet batteries in series and 72 multi-cell VRLA batteries (see Attachment 2), 36 of which are in series, with two 36 battery groups in parallel to generate the proper voltage with the required current for the minimum time. Only a bank of batteries can fulfill the intended function described in TS 3.6. Note that the previous station battery was also a bank of batteries. The design philosophy was, as it is now, to have an excess of batteries that allows the battery bank to meet bank duty cycle. Consistent with this design is the assertion that a single battery failure which does not interrupt the electrical circuit of the battery does not constitute component failure. Other examples from NBSR license documents of this approach are: Total coolant flow is specified, not the number of coolant pumps (NBSR 15, 2009); total reactor power is limited,

not power per fuel assembly (TR-5, 2009). Certainly a bank of batteries with the exact number of batteries necessary to meet the station battery duty cycle could not sustain a single battery failure; the NCNR has rejected that design through three operating license renewals over the previous 40 years.

A surplus of batteries is also consistent with the single failure analysis and defense-in-depth approach to reactor safety (NUREG 1537, 2012) used by research and test reactors licensed by the NRC. A common mode failure originating from improper charging voltage for every battery in the bank is addressed through the battery monitoring system that is integral to the UPS. Designated "ABM Technology" (ABM) by the UPS manufacturer, the ABM monitors bank parameters to continuously assess the bank condition and produces notices and alarms if the parameters are found to be abnormal. Local alarms produce a single remote alarm in the Control Room. Notices indicate a potential problem and alarms indicate an impending UPS shutdown, if additional action is not taken. Additionally, the ABM controls the charging scheme for the UPS battery bank. The ABM charges the battery bank, applies a float charge for approximately a day, performs two tests, secures the float charge for 28 days, and produces an estimate of battery bank service life for the design load of the UPS, i.e. 20 KVA. The manufacturer claims increased lifetime for a battery charged in the manner described above. Their claim is based upon 22 years of data and observation.

The design load is programed during the setup of the ABM based on the capacity of the installed battery bank. The design load is twice the normal load that is presently being supplied by the UPS. If conditions were such that the UPS had to supply the power from the battery bank, the ABM estimates the battery bank service life based on the actual load. The required load specified in the Limiting Conditions for Operation (LCO) for emergency power, TS 3.6, i.e. the nuclear instrumentation and the emergency exhaust fans, is significantly less than the normal load. In an emergency, with the battery bank supplying the power, the service life could be greatly extended by shedding the load to only what is required by the LCO. See Attachment 3 for a detailed description of the ABM.

To summarize, the NCNR has a proven approach to surveillance and maintenance for LCO as described in ANSI/ANS-15.1-2007. That approach is applied to the VRLA battery banks through alarms and notices (continuous), bank life estimate (monthly), individual battery service (semi-annual or annual), and a performance test (2 years) ensure the station battery duty cycle will be met.

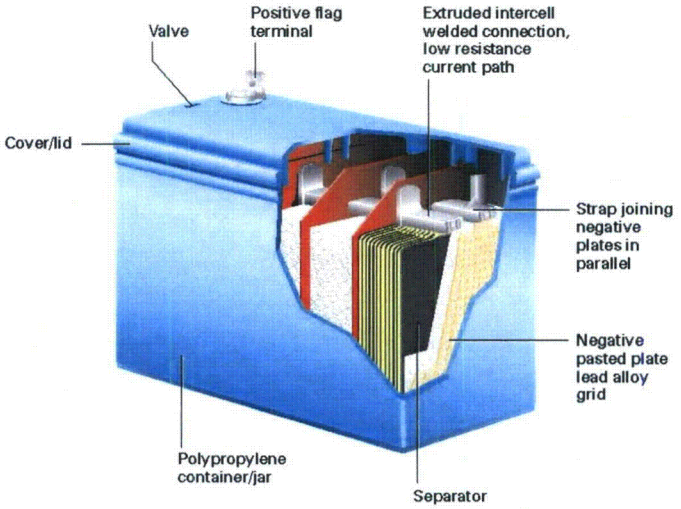
ATTACHMENT 1
NRC Email Message of May 7, 2015

In response to RAI Question 3, the licensee stated the following: "Battery cell voltage may be used as an indicator of individual cell degradation. It is not necessarily an indicator of battery bank capacity falling below minimum output. [...]. A two year discharge test is sufficient to reveal failing or failed battery cells." As recommended by IEEE Std. 1188-2005, the VRLA battery cell voltage should be checked periodically because prolonged operation of cells below or above the manufacturer's recommended voltage limits can reduce the life expectancy of the cells or have a detrimental effect (e.g., accelerated dryout) on the battery. In addition, a cell voltage consistently below normal float conditions and not caused by elevated temperature of the cell indicates internal cell problems that may require cell replacement.

In response to RAI Question 5, the licensee stated that the VRLA battery will not be subjected to a service test because of (1) the small number of cell failures for a bank of VRLA battery cells, (2) the number of VRLA battery cells, (3) the increase in necessary battery power from a supply of 100 amps/hour for a load of 8 amps/hour to a supply of 100 amps/hour for a load of 4 amps/hour (i.e., a doubling of the cells available for the same load). IEEE Std. 1188-2005 recommends the performance of a service test to determine the battery's ability to satisfy the design requirements (battery duty cycle) of the dc system in the as found condition. The staff notes that the VRLA battery having double of the cells available for the same load does not guarantee it meeting its duty cycle at all times. A periodic service test is needed to ensure the battery meets its duty cycle.

ATTACHMENT 2
Description of VRLA Battery

A VRLA cell is the manufacturer's term for the 6 sets of plates that make up the single VRLA battery used in the EATON 9390 UPS in service at the NCNR to provide emergency power to selected AC loads. For this unit, the terms *battery cell* and *battery* are not synonymous, as they are for the wet-cell units that make up the battery bank which provides emergency power to selected DC loads. Battery bank or station battery refers to a group of batteries that are connected in series to provide a specified voltage.



Internal and external components of a valve-regulated lead-acid (VRLA) battery.

The Uninterruptible Power Supply (UPS) battery bank comprises two groups of batteries, each group in parallel, and each group comprising 36 batteries in series. There are two UPS, each with 72 batteries.

The battery has a 10 year design life and a 3 year warranty. The minimum voltage for a battery to be considered operable by the manufacturer is 10.02 volts (1.67 V/cell x 6 cells). The minimum voltage for a battery bank to be considered operable by the manufacturer is 360.07 volts (36 batteries x 10.02 V/battery). The normal voltage of the battery bank is approximately 478 volts. Individual battery failure would be revealed by the battery monitoring system described in Attachment 3. Estimates of lifetime assume no damage to the circuit, such as could occur with thermal runaway, a condition that can result from dryout. The monitoring system, as well as previously described surveillance and maintenance activities, would provide indication of a potential dryout condition. Note that the NCNR does not limit the definition of operable only to output voltage. The bank must generate the proper voltage and have an expected lifetime of at least 4 hours for the specified AC loads. The battery monitoring system for the 9390 UPS provides an estimate of the bank lifetime.

ATTACHMENT 3
Description of Battery Monitoring System

Powering Business Worldwide

Technical Paper

ABM Technology and Battery Testing in Eaton UPS Products

Introduction

The battery system in a UPS represents the heart of the power protection benefit. This key element performs two functions: (1) it delivers energy during a power outage, and (2) it stores energy efficiently for extended periods of time. That stored energy is instantaneously available when needed to support the critical load on the UPS. In order to perform the above functions reliably, the charge level of the battery must be maintained. At the same time, battery charging should be controlled to maximize system efficiency and, more importantly, to maximize the float service life of the battery system.

The unfortunate fact is that Valve Regulated Lead Acid (VRLA) batteries are often marketed as having a 10-year design life. However, real world data shows that in UPS applications, the battery is replaced every four to five years on average. Because the battery often accounts for 30% of the cost of the UPS, users frequently request that UPS vendors extend the service life of the battery as much as possible. Considering that the benefit of longer service life is lower life cycle cost and capital expense, it is not surprising that users desire tangible evidence that battery monitoring and battery management systems actually perform as advertised.

Two types of battery charging schemes have traditionally been used for UPS battery systems. The older and more commonly known is the "float" charge, which involves applying a constant voltage charge to the battery continuously for purposes of maintaining full charge during day-to-day operation of the UPS. This works quite well in many conventional battery applications. However, battery life may not be optimal, due to overcharging, for batteries that are used very occasionally as in standby applications such as a UPS. In a UPS, the battery system may sit in float mode for many months, without ever experiencing a discharge. Float charging for long periods of time means that "trickle-charge" energy is constantly forced into a battery which is effectively already full. This results in very gradual degradation of the lead plates (positive grid corrosion), and it can impact float service life.

Standby applications are better suited for "opportunistic" charging schemes. The system Eaton® utilizes is called ABM technology, which is essentially a set of charger controls and automated battery tests. It is implemented in Eaton single-phase UPSs from 500 VA to 18 kVA and three-phase models from 10 kVA to 3.3 MVA. Opportunistic charging schemes like ABM allow for periods of time where the battery is being fully charged, and periods of time when the charger is disabled. This reduces the time that the battery is subject to grid corrosion when compared to a traditional float charger — a reduction in grid corrosion that yields a measurable increase in battery life for UPS applications.

ABM Operational Summary

As shown graphically in Figure 1, ABM consists of three operating modes:

1) Charge mode
2) Rest mode
3) Test mode

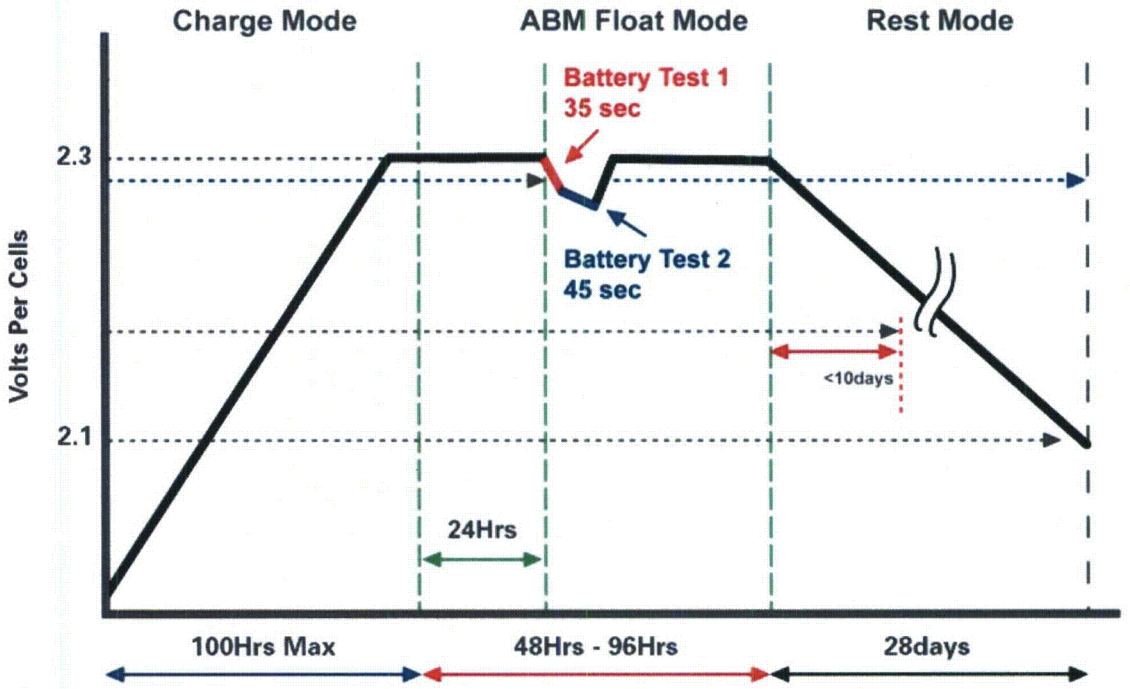


Figure 1: Depiction of ABM modes

Charge Mode

The UPS enters the charge mode under any of the following conditions:

- Whenever the UPS is commanded to turn on
- After any utility power outage lasting longer than 15 seconds
- Whenever the battery is replaced (or the battery breaker is opened and re-closed)

In charge mode, constant voltage charging of the batteries is used to recharge a discharged battery after a power outage, or whenever the ABM process is restarted. Charge voltage target is set to the manufacturers' float level, and charge current is greater than 0.1 C A. Constant voltage charging lasts only as long as it takes to bring the battery system up to a predetermined float level (there is a 100-hour maximum time limit). Once this level is reached, the UPS battery charger remains in constant voltage mode, maintaining a float level. The current is at trickle-charge levels during this time, and a 24-hour clock is started. At the end of 24 hours of float charging, the UPS automatically performs a battery test (see Figure 1) at two different load levels to verify that the battery is performing, and to collect data for comparison to previous and subsequent automatic battery tests. If the test fails, an alarm is activated on the UPS and also through the remote monitoring system that may be connected to the UPS. At the end of the test, the charger resumes constant voltage mode and remains in that state for an additional 24 hours.

Rest Mode

Rest mode begins at the end of charge mode; that is, after 48 hours of float charging, and after a successful battery test. In rest mode, the battery charger is completely turned off. The battery system receives no charge current during this mode, which lasts about 28 days. Then, the charge mode is repeated as described above. Since the battery clearly spends most of its time in rest mode, as a result, the following benefits are realized:

1) The battery is not subjected to constant forced charge current; therefore, overcharging is not possible.
2) Thermal runaway is not a concern with the charger off.
3) The battery system cannot be damaged by ripple currents, since the charger is off.

4) Positive grid corrosion is greatly reduced, allowing extended service life.

During rest mode, the open circuit battery voltage is monitored constantly, and battery charging is initiated if any of the following occur:

- A power outage lasting longer than 15 seconds
- The open circuit voltage (OCV) of the battery drops below a predetermined threshold after 10 days of rest mode
  (If OCV drops below the predetermined threshold during the first 10 days, an alarm is triggered)
- 28-day timer expires (end of rest mode)
- The battery is replaced, or the breaker is opened and re-closed

Test Mode

There are two other battery tests that are performed as a part of the ABM cycle. The first is meant to detect battery conditions which could lead to thermal runaway. The bulk charging period is timed and if the float voltage is not reached in a predetermined time, an alarm is triggered and the charger is shut down. The second test is performed after the charge cycle is completed (i.e., at the beginning of rest mode). The battery is discharged for 25% of the expected discharge time. Upon reaching this point, the battery voltage is measured. If the voltage is below a specified threshold, dependent on the load, then an alarm is signaled indicating the battery is nearing the end of its service life and should be replaced.

Other Modes

ABM may be disabled by the user or an Eaton field technician at any time. In this case, the UPS battery charger operates as a conventional float charger only. This is recommended when a wet cell or flooded electrolyte battery is used with the UPS. ABM is intended for use with VRLA batteries. As a result, wet batteries do not benefit from ABM controls.

Many observers express concern regarding the ability for the battery to maintain capacity if called upon to support the UPS near the end of its rest mode. In other words, how much battery capacity is available on day 27 of a 28-day rest mode? Using a 15-minute battery as an example, under this condition, the battery would provide all but about 30 seconds of its 15-minute backup time. This is proportionally true for other battery sizes, as well. The intent in selecting the 28 day rest period is to limit the loss of capacity to approximately 5%.

ABM Performance

The ABM process above describes the benefits of using a "opportunistic" charging scheme. Those benefits, specifically extended service life, are in fact substantiated by data and empirical testing performed by Eaton as well as other independent sources. Some of this testing is recent and some of it was performed as many as 20 years ago.

ABM is not a new battery management feature. In fact, Eaton has been using ABM in its UPS products for 22 years, and it has proven itself beneficial in the field for more than two decades.

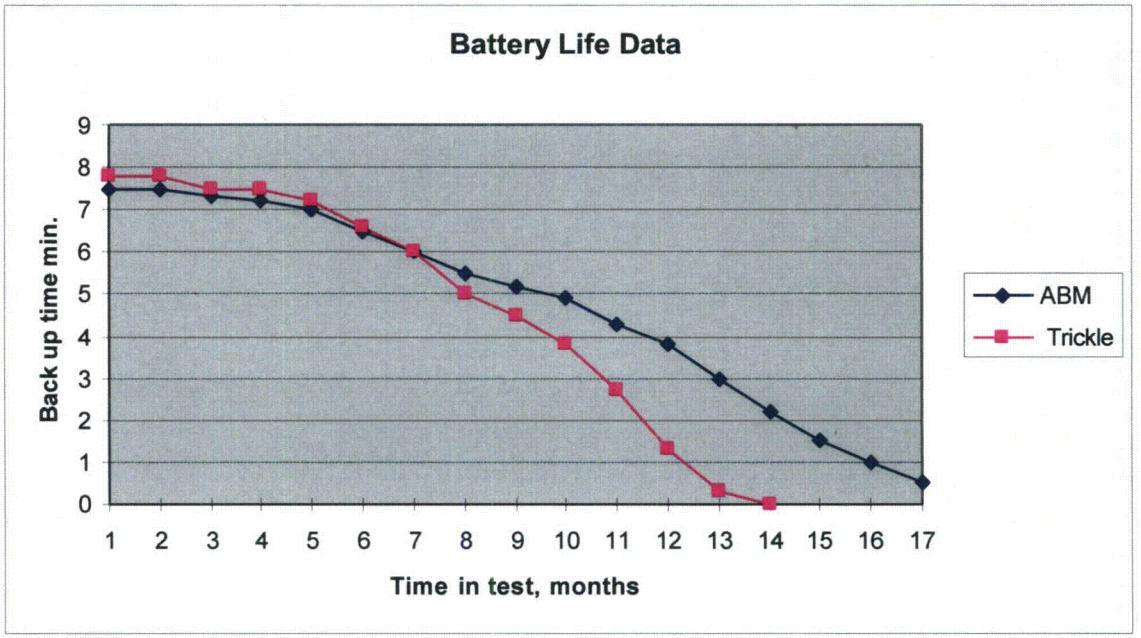


Figure 2: Accelerated Life Testing of ABM at 40 degrees C

In Figure 2, the testing was performed at a very high ambient temperature to provide meaningful data in a shorter period of time. The service life enhancements become evident after about only seven months of this accelerated test. This test was done with conventional UPSs and VRLA batteries.

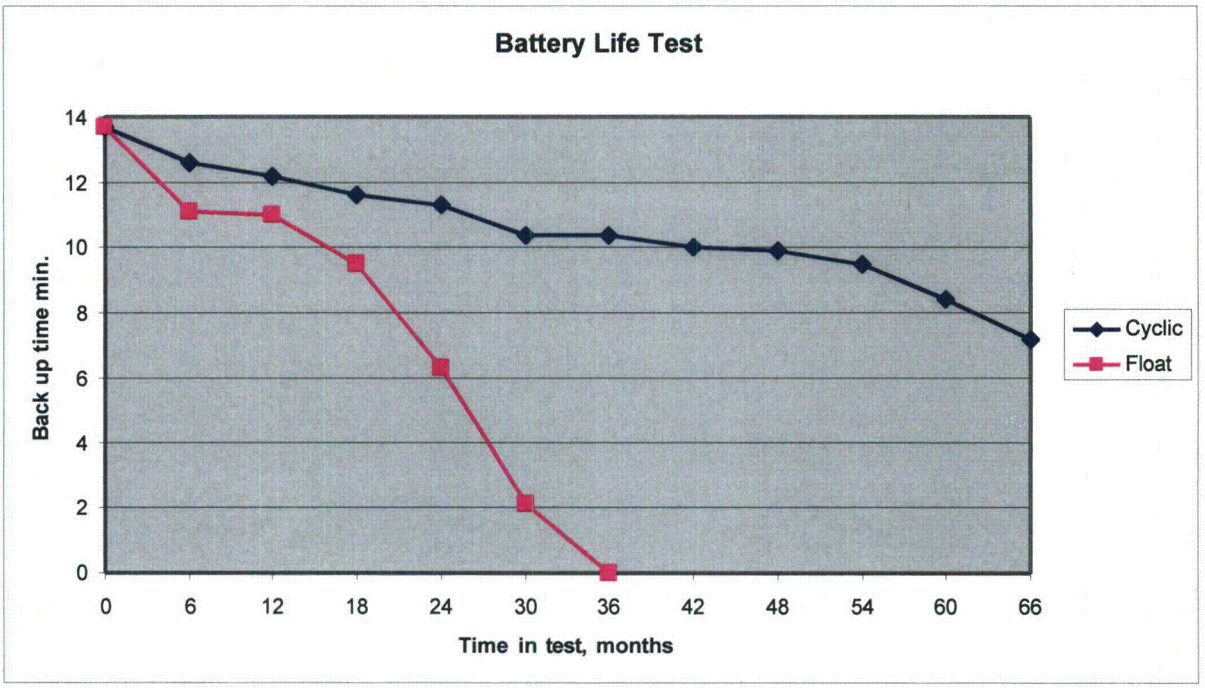


Figure 3: Long Term Cyclic Charge vs. Float Test

In Figure 3, the effect of a cyclic charging regime over several years is demonstrated. This testing was done almost 20 years ago, by a battery manufacturer not associated with Eaton or any UPS vendor.

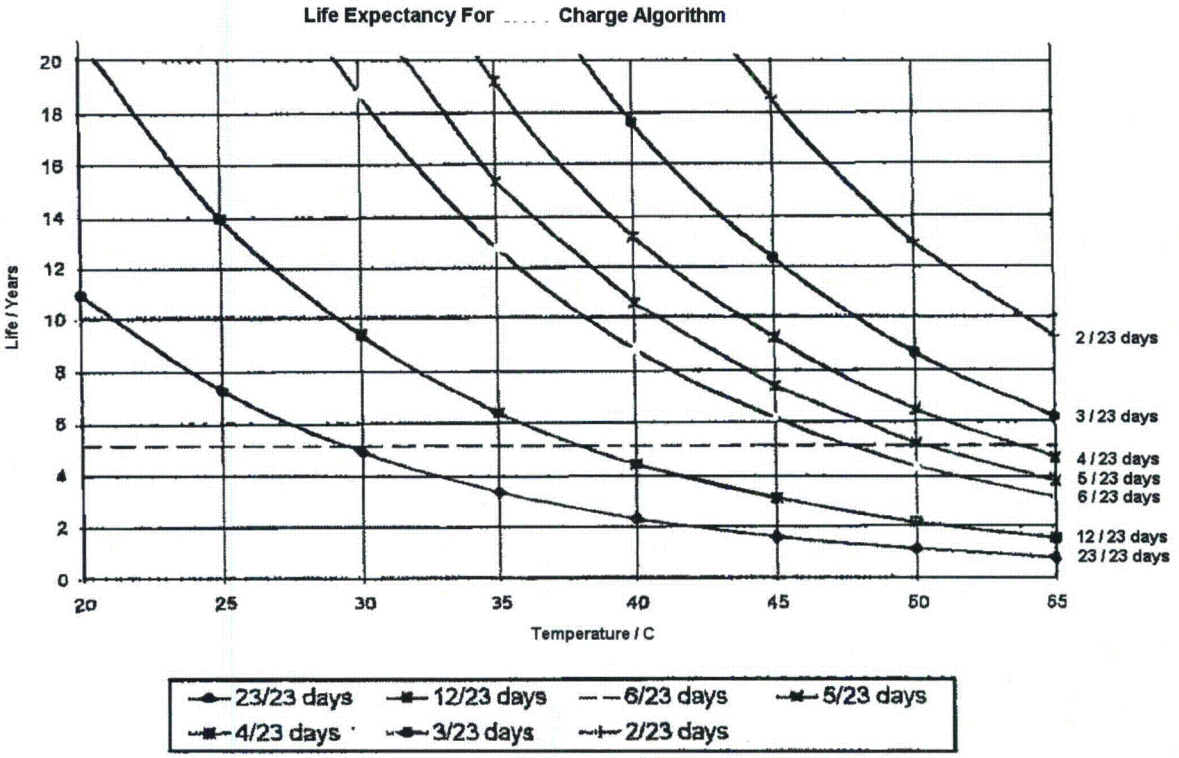


Figure 4: Calculated Service Life Extension for ABM Charge Algorithm

Note that in Figure 4, the curve identified as "23/23 days" represents a float charger, and ABM (as implemented today) is best represented by the curve labeled "12/23 days." At an ideal 25°C (77°F), there is a theoretical increase of six years in battery service life reflected in this analysis.

The above information shows a clear benefit of cyclic charging *in UPS applications*, both in simulated and in actual performance tests. These results would not be expected with non-VRLA batteries or in applications such as motive power chargers where the battery is discharged/recharged daily and therefore not deployed in a standby application.

Summary

ABM is unique in the UPS industry, but similar opportunistic designs are utilized by battery manufacturers and battery charger designers worldwide. The criticality and cost of the battery subsystem of any UPS dictates that special consideration be given to battery longevity. Additionally, with environmental concerns relating to battery removal and disposal becoming more prevalent, it is desirable to reduce the frequency of battery replacements during the life of the UPS electronics. ABM offers a significant benefit over conventional "battery monitors" which don't provide charging control, and "multi-stage chargers" which protect the battery, but do not provide useful extension of battery service life.

Over the past 22 years, ABM has proven itself in both large and small UPS products, from the desktop to the data center, and from the medical lab to the factory floor. Anywhere a UPS is installed, a battery system is depended upon to provide backup power protection for critical business processes and even for personnel safety. The battery is all too often ignored as a maintenance-free product, not requiring attention or inspection. This neglect, though common, can be costly and possibly disastrous. The ABM system, by its nature, helps to provide early detection of problem batteries and thus protect the battery from unnecessary failures like electrolyte dry out and thermal runaway, while functioning to extend the useful life of this key component of power quality.

SUMMARY OF VRLA BATTERY INSPECTiON DATA FOR NCNR UPS

Battery Inspection Specifications				
Range 12.840 - 14.5 V	Impedance Range ≤ 5048.871 Ohm	Range 74 - 80 °F	Post 1 Resistance Range 0- 300 µOhm	
UPS Unit	Date	Status of Batteries	Action	Status of Bank
UPS-1	2005-04	120 New Batteries	All batteries replaced	OK
UPS-1	2006-07-06	120/120 Batteries OK	None	OK
UPS-1	2007-04-07	120/120 Batteries OK	None	OK
UPS-1	2010-07-15	119/120 Batteries OK	#3 impedance low. Battery replaced.	OK
UPS-1	2010-12	120 New Batteries	All batteries replaced	OK
UPS-1	2011-07-19	120/120 Batteries OK	None	OK
UPS-1	2014-04-08	120/120 Batteries OK	None	OK
UPS-1	2014-12-23	120/120 Batteries OK	None	OK
UPS-2	2009-11	36 New Batteries	All batteries replaced	OK
UPS-2	2013-11-22	36/36 Batteries OK	None	OK
UPS-2	2014-04-08	36/36 Batteries OK	None	OK
UPS-2	2014-12-23	36/36 Batteries OK	None	OK
SUMMARY	UPS-1, For a period of 5 1/2 years, 1 battery failure UPS-1, For a period of 4 years, 0 battery failures UPS-2, For a period of 5 years, 0 battery failures			