Monitoring of Valve Regulated Lead Acid Batteries

– the what, why and associated cost – benefit analysis -

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ABSTRACT

The VRLA battery has a very high power density; provides flexibility of mounting orientation and location; eliminates electrolyte maintenance requirements and is relatively inexpensive. Consequently it has found application on traditional "open" racks in battery rooms as well as in cabinets utilized in data processing centers and at customer premise and remote telecommunications applications.

While the VRLA battery has many safety, facilities, installation, maintenance and economic advantages over the vented lead acid battery it is not typically as robust or as forgiving as related to abusive environments and operating conditions. Consequently, adherence to the battery manufacturers recommendations concerning the application, installation and maintenance is most critical when the VRLA battery is used.

To achieve the expected life, performance and reliability of a VRLA battery it is critically important that its installation and continuing operation be closely controlled and in accordance with the battery manufacturers recommendations. This requirement includes appropriate monitoring of operating conditions and prompt corrective action should a deviation from the standard occur.

The following provides a reference by which the "level" of monitoring can be classified as well as the suggested parameters to monitor and their "alarm" limits. This information is followed by a recommendation related to cost comparisons between manual and automatic monitoring programs.

INTRODUCTION

At first mention of battery monitoring it is assumed to mean an automated electronic system of wires, circuit components, alarms and printers--but this is not necessarily the case. Battery monitoring is simply the collection of data, which is used to indicate the present and/or the predicted status of the battery system. The monitoring can be in the form of manually collected data on a periodic basis or indeed, much of it can be automated with "on line" equipment that continuously collects and assimilates data for analysis upon demand. It is the analysis and the prompt corrective action when required that make the difference in attaining the expected reliability from the battery system.

As a DC power system utilizing a VRLA battery is being designed it is important that a conscious decision be made as related to the periodic maintenance program and system monitoring techniques to be employed.

THE PERIODIC MAINTENANCE PROGRAM, MONITORING AND RELIABILITY

There are several levels of sophistication in the monitoring of a battery ranging from a visual check of the battery to measuring the impedance of individual units and even prediction of the battery capacity based on partial discharges. Naturally, as the level of sophistication and quantity of data collected increases, weather the tasks are performed manually or automatically, the cost also increases.

The periodic maintenance program contains activities which are preventative in nature but for the most part the activities are focused on monitoring of the battery operating conditions and changes in characteristics which necessitate corrective action to assure the battery will deliver when required during an emergency.

Parameters Monitored

The battery system parameters to be monitored must be those which are beneficial. That is, they must provide meaningful data that can either define a present failure or predict a near term future failure; are accessible for manual or automated monitoring and are economic to monitor in terms of the value of the battery system itself and critical load utilizing the battery.

The battery periodic maintenance program consists of three types of activities:

1) visual observation of the "overall" conditions and environment of the facility and battery
2) monitoring of battery specific environmental conditions and physical properties as compared to a standard
3) monitoring of battery related electrical conditions as compared to a standard

The facility and battery visual checks are recommended on a monthly and quarterly basis respectively. However, as noted in Table 1, these are the types of items that should be generally observed whenever the technician is in the area. It is on the monthly and quarterly schedule that specific attention should be given to the noted items and the conditions recorded in a log.

The latter two monitoring activities can be done using manual techniques in accordance with the indicated frequency as recommended in the IEEE Std 1188 or continuously using automated techniques. Naturally, continuous automated monitoring will provide real time data and can provide early warning of an impending failure of the battery system and the need for corrective actions. Corrective actions are for the most part manually implemented.

Typically the monitoring of the battery system, as indicated in Table 2A, would be done directly at the rectifier/charger connected to the battery system. Display of the system charging voltage and current is typically provided via panel meters and there are optional internal alarms associated with float charging voltage high and low extremes and the lack of float current. While more sophisticated circuitry is required to monitor actual float current values and the AC ripple components of the charging power this information can be valuable in detection of various battery system and rectifier/charger abnormalities. The rectifier/charger can even be configured to control limited capacity tests while monitoring discharge current, voltage and time to calculate the battery actual Ampere-hour capacity and potential run time.

Due to reduced facility costs, increased reliability and convenience of installation, parallel strings of batteries are often used to power larger communications systems and UPS systems up to approximately 500 KVA. While the use of parallel strings does improve reliability, it will also increase somewhat the complexity of the troubleshooting process. Those electrical parameters that can be monitored on a "per string" basis are noted in Table 2B. Often times an imbalance in the performance of individual strings within a system is the early warning of the development of what will eventually become a serious problem. For example, increased float current or AC ripple current may be an early warning sign of shorting cells within the string. Likewise, monitoring of discharge current per string during a capacity test or an actual emergency may indicate one or more of the strings are of either higher resistance or lower Ah capacity. Obviously, if the string parameters can be automatically monitored on a continuous basis the development of a problem will be detected at the earliest possible time.

Naturally, as the degree of monitoring precision increases, that is as the number of individual units monitored increases (ref. Table 2C), the greater the cost of the monitoring. If performed manually, the increased cost is in the form of additional man-hours expended whereas if the monitoring is automated, it is the additional cost of the monitoring equipment and it's installation. Obviously, the more frequently the data is collected and acted upon, the earlier a deviation from the norm or progressive problem is detected. This is an obvious advantage of the automated monitoring system – it can detect and alarm on a deviation before it becomes a critical problem.

Parameters Monitored, Alarm Limits and Corrective Actions

It is one thing to monitor various parameters of the battery but it is quite another to interpret the results and determine what, if any, action is required and the urgency of any required corrective action. The following Tables 2A, 2B and 2C define the normal range of values measured for the parameters monitored and the corrective actions required to restore the system to normal operation should the "normal" range be exceeded. Additionally, the urgency of implementing corrective action is also indicated on a scale of 1 to 4 with a "1" being the most urgent. This guideline used to establish the "Urgency to Correct" was based on the situational threat to safety or system capability and is as follows:

Urgency to Correct	Explanation
1	Correct immediately – creates a significant risk to safety and potential for system failure under load.
2	Correct within 30 days – situation could result in reduced autonomy.
3	Correct within 60 days – situation could result in gradual degradation of battery and premature wear-out.
4	While not within the battery manufacturers recommendations, the situation will not have an immediate safety or performance impact however, operator should adjust related battery expectations.
NAR	No action required

Automated Battery Monitoring Systems

Automated battery monitoring systems can greatly enhance the safety, service life and reliability of a VRLA battery system. They can range in complexity from simply monitoring and alarming on battery system charging voltage to calculating the time remaining during a discharge or the % rated capacity. Naturally as the features and complexity of a system increases, so does the cost. Table 3 presents classes of automated monitors of increasing complexity, benefits and cost.

The Class 1 system provides the minimum in monitoring and this occurs at essentially the system level. This is the type of system that is typically selected as individual options within the more sophisticated charger/rectifiers.

The typical Class 2 system incorporates the Class 1 system features but with the additional capability to monitor and alarm on individual unit impedance and float voltage. This is the typical monitor sold as an accessory to the battery system. Typically the Class 2 and higher systems will also have provision for a modem that allows for central monitoring within a facility or geographic area. This feature alone can provide tremendous cost savings where remote or multiple sites are involved.

The Class 3 and 4 systems go beyond the monitoring and alarm functions and typically contain microprocessors and control functions providing for such information as "time remaining" during discharge, "state of charge" and "per-cent rated capacity". This can be invaluable information to the site operator during an emergency while the system is supporting a critical load.

MANUAL OR AUTOMATED MONITORING – It's Time to Choose

When making the "manual vs. automated monitoring" decisions there are a number of factors to consider such as:

1. Expected service life of the application and battery system at this location
2. Location of the battery system to be monitored (e.g. Within the facility or remotely located – higher monitoring labor and transportation cost may be associated with remote locations)
3. "Critical load" criticality (e.g. Life threatening vs. inconvenience and dollar value loss in the event of a back-up battery failure)
4. Availability of personnel to perform manual monitoring
5. Cost of providing training and special test equipment to facilitate manual monitoring
6. Cost of hardware and installation to do automated monitoring
7. Format and ease of analysis of the data collected

A general comparison of the characteristics of the manual and automated monitoring techniques is presented in Table 4. As noted in the table, the only disadvantage of the automated monitoring system is the initial cost for the hardware and installation.

However, when all costs are considered it can often be shown that a Class 2 monitoring system, which will improve overall system reliability, maintainability and availability, can be justified on cost savings alone for an 7 to 10 year system application. For example, consider a cost comparison of manual vs. automated monitoring of 400 KVA UPS with 3 parallel connected cabinets of 30 each 12-volt VRLA batteries. Notice in the example in Table 5 that the cost breakeven point is at approximately 7 years. For application service life of less than 7 years, use of the automated system has to be justified on the basis of improved safety or reliability. However note that as the application service life exceeds 7 years the cost savings accrue at the rate of approximately $1,500 per year.

Naturally, each situation will be somewhat different and different costs and circumstances will apply resulting in a different breakeven point. However, it is very important when justifying an automated monitoring system based on cost alone, that only that portion of the costs of the automated system that supplant the manual data gathering related costs be compared. Consider for example, that the automated system is a Class III or Class IV system capable or providing "run time remaining", controlling partial load capacity tests and calculation of per-cent rated capacity . The costs associated with these functions should not be included in the comparison in that these capabilities do not exist in the manually conducted periodic maintenance activity.

Parameters Monitored Visually	**Frequency (* IEEE Std 1188)**	**Objective**
	Facility & Battery Checks	
1. Room is clean and free of debris	Monthly*	Minimize personal safety and fire hazards.
2. All facility safety equipment is available and functional	Monthly*	Minimize facility, equipment and personal electrical, chemical and fire risks.
3. Battery room is well lighted	Monthly*	Minimize personal safety risks and facilitate accuracy of visually ascertained information.
4. Facility air temperature.	Monthly*	Detect facility-operating temperatures that would degrade either the performance or service life of the battery.
5. Battery is clean and does not show signs of container, cover or terminal damage.	Monthly*	Cracked containers or covers can result in electrical ground faults, gassing, dryout and increased risk of fire. Damaged terminals can result in opening circuits under high rate load conditions and potential fire hazard.
6. No indication of battery overheating.	Monthly*	Permanent deformation of the container or labeling could indicate the existence of a cell short circuit during discharge or a thermal runaway situation.

Table 1 – Periodic Maintenance Program – Facility and Battery Visual Checks

Parameter Monitored	Priority	Frequency	Minimum Normal Maximum	Possible Cause of Deviation	Result if not corrected	Urgency To Correct	Corrective Action
System Level:							
1. Facility air temperature	3	Monthly*	-4°F	Lack of or heater failure	Freezing of discharged unit below 30°F	1	Provide or repair heater
	2		77°F+/-10	Standard	Normal	NAR	Provide or repair air conditioning
	1		122°F	Lack of or air conditioning failure	Increased potential for thermal runaway – reduced service life	1	Provide or repair heater
2. Pilot unit temperature	3	Quarterly*	-4°F	Lack of or heater failure	Reduced autonomy – potential freezing of discharged unit - extended recharge time	1	Temp. compensate charger Provide or repair air conditioning Temp. compensate charger
	2		77°F+/-10	Standard	Normal	NAR	Disconnect charging current – reconnect when cooled to ambient
	1		122°F	Lack of or air conditioning failure – excessive charging current	Increased potential for thermal runaway Reduced service life	1	
	1		Ambient +18°F	Excessive charging current or early phase of thermal runaway	Increased potential for thermal runaway – reduced service life	1	
3. DC float voltage @ 77°F	1	Monthly*	2.24 v/c avg.	Charger misadjusted	Undercharging leading to sulfating, and reduced autonomy and service life	3	ncrease charging voltage
	2		2.25 to 2.30 v/c avg.	Standard @ 77°F		NAR	
	1		2.31 v/c avg.	Charger misadjusted	Overcharging leading to gassing, dryout and reduced service life	1	Decrease charging voltage – disconnect if greater than Increase charger equalize voltage
4. DC equalize voltage	3		2.34 v/c	Charger misadjusted or not capable	Less effective	4	Increase charger equalize voltage
	3		2.40 v/c	Standard @ 77°F		NAR	
	3		2.46 v/c	Charger misadjusted	Overcharging leading to gassing, dryout and reduced service life	1	Decrease charger equalize voltage * Equalization is not normally recommended with the exception of at installation
5. DC discharge voltage	1		Min. 1.65 v/c or 1.75v/c etc. dependent on load and discharge time	Lack of low voltage disconnect	Over discharge will damage active material on plates	1	Used as input to low voltage disconnects and time remaining calculators
6. Ground fault voltage	1		1.0 v/c +	Electrolyte wicking to ground from broken container	Shock hazard Fire hazard Failure to support the load Normal Reduced autonomy Shock hazard Fire hazard	1	Remove fault Replace damaged unit

Table 2A - System Level Parameters Monitored and Alarm Limits

Parameter Monitored **System Level (Continued)**	**Priority**	**Frequency**	**Minimum Normal Maximum**	**Possible Cause of Deviation**	**Result if not corrected**	**Urgency**	**Corrective Action**
7. DC float current @ 77°F	2		0.0001A/Ah	Open or high resistance circuit Very cold operating temp.	Failure to support load Reduced run time	1 3	Replace or repair open unit or connection Heat the battery
	2		0.0005 to .002 A/Ah	Typical within 48 hours of start of recharge		NAR	
	2		0.010 A/Ah	Shorted cells or ground fault Elevated operating temp.	Reduced run time Potential thermal runaway	1 2	Replace defective unit Replace damaged unit Cool the battery or reduce charging voltage
8. DC load current	3		Load dependent	Used as input to time remaining and capacity calculators Excessive load results in premature system shutdown	Insufficient load can result in over discharge	----- -----	Can be used with time to calculate Ah removed and DOD
9. DC charging current	3	Monthly*	Charger dependent	Excessive charging current can result in battery heating and damage to plate active material	Insufficient charging current flow can be an indication of a high resistance string/circuit		Can be used in calculating Ah restored and state of charge
10. AC ripple voltage	3	Annually*	0% to 0.5% rms of float voltage	Less is best		NAR	
			1.5% rms of float voltage	Too small or failing filter capacitors in charger Charger overloaded	Induces excessive ripple current in the battery thus causing battery heating	2	Increase charger output filter capacity
11. AC ripple current	2	Monthly*	0 to 0.05 Amp/Ah	Less is best		NAR	
			0.10 Amp/Ah		Excessive ripple current in the battery will cause battery heating		Increase charger output filter capacity
12. Discharge time elapsed	3			Can be used to calculate Ah removed and time remaining etc.			
13. Discharge cycle count	3			May be required in battery warranty policy			
14. Recharge time elapsed	3			Can be used in calculating Ah restored and state of charge			

Table 2A (Continued) – System Level Parameters Monitored and Alarm Limits

Parameter Monitored	Priority	Frequency	Minimum Normal Maximum	Possible Cause of Deviation	Result if not corrected	Urgency	Corrective Action
Individual String Checks							
String float current	2		0.0001A/Ah	Open or high resistance string	Failure to support the load	1	Replace or repair open unit or connection
				Very cold temperature.		3	Heat the battery
	3		0.0005 to .002 A/Ah	Typical within 48 hours of start of recharge	Normal		
	2		0.010 A/Ah	Shorted cells or ground fault in string	Reduced autonomy Shock hazard Fire hazard	1	Replace defective unit Replace damaged unit
				Elevated operating temp		1	Cool the battery or reduce charging voltage
String discharge current	3		- 10%	Low capacity string	Reduced autonomy	2	Replace string/units
				Shorted cells		1	Replace unit(s)
				High resistance path		1	Use larger size connectors / clean and retorque hardware
	3		Load/strings			NAR	
			+ 10%	Other string(s) @ -10%			
AC ripple current	2	Annually* Ann	- 10%	High resistance path	Reduced autonomy	1	Clean & retorque hardware
						1	Replace unit(s)
				Open cell(s)		1	Replace unit(s)
				Low capacity cells/string		2	
			Load/# strings			NAR	
			+ 10%	Other string(s) @ -10%			

Table 2B – String Parameters Monitored and Alarm Limits

Parameter Monitored	Priority	Frequency	Minimum Normal Maximum	Possible Cause of Deviation	Result if not corrected	Urgency	Corrective Action
Individual Unit Checks							
Container / terminal temperature	3	Quarterly*	-5°F	Location in cabinet etc. Restricted vents.	Reduced autonomy	3	Increase circulating airflow – assure 0.5 inch spacing between all units.
	3		Avg.			NAR	
	3		+5°F	Location in cabinet etc. (e.g. Upper shelf or tier)	Unequal wearout rate	2	Replace unit Clean & retorque conn.
				Shorted cell & discharge	Reduced autonomy	1	Space units 0.5 inch.
				Loose conn. & discharge	Sudden terminal failure	1	
				Lack of unit spacing		1	Disconnect charging current until units cool to 104oF
	1		Ambient + 18°F	Shorted cells in string.	Potential thermal runaway	1	
				Excessive charging current		2	
				Excessive cycle rate		2	Use light color cabinet etc. Use larger Ah capacity and reduce charging current
	1		122°F	Solar heating	Potential thermal runaway	1	
						1	Clear the vent system
				Cycling (Dischg. - Chg.)			Repair air conditioner
				Restricted vents		1	
				A/C failure		1	
DC Float voltage (6 cell blocks)	1		Under 13.0 vdc (6 cells)	Shorted cell in unit	Reduced autonomy Hot cell during discharge	1	Replace unit
	1		13.2 & less v/c (6 cells)	Open string (all units)	No autonomy	1	Replace suspect unit or connection Enable circuit / charger
				Charger disconnected	Will not recharge	1	Enable circuit breaker
					Gradual self discharge	1	Replace fuse
				Could result from too many "high voltage" units in the string	Undercharging until string balance achieved	2	Equalize 24 hr. but only if new string. Otherwise string balance should occur with in 6 months at 2.30 v/c average
				Marginally low system charging voltage	Undercharging until string balance achieved	2	Increase system float voltage from 2.25 to 2.27 or 2.30 v/c average.
	3		13..3 to 14.1 vdc	Normal @ 77oF		NAR	Equalize 24 hr. but only if new string. Otherwise string balance should occur with in 6 months at 2.30 v/c average
	1		14.2 + vdc	Could result from too many low voltage (dry) cells in the string	Accelerated gassing of higher voltage units until string balance achieved	2	Replace unit
						1	Replace unit
	1		15.0 + vdc	Open cell if other units near OCV High resistance cell	No autonomy Potential safety hazard	1	
DC Equalize voltage	3		14.0 vdc & less			4	
	3		14.1 to 14.9 vdc			NAR	
	3		15.0 + vdc			2	

Table 2C – Individual Unit Parameters Monitored and Alarm Limits

Parameter Monitored **Individual Unit Checks (continued)**	**Priority**	**Frequency**	**Minimum Normal Maximum**	**Possible Cause of Deviation**	**Result if not corrected**	**Urgency To correct**	**Corrective Action**
Impedance, resistance or conductance	2	Quarterly*	-40% (C) Average +40% (Z or R)	Indicates increase in impedance perhaps due to shorted cells, undercharging, dryout, conductive path corrosion or normal wear-out	Reduced autonomy	2	Suspect unit(s) should be further tested to determine extent and nature of problem.
Average of impedance, resistance or conductance	2	Quarterly*	-25% Avg. @ installation +25%	The impedance of a battery string will increase as a result of normal wearout.	Reduced autonomy	2	Perform capacity test to determine % rated capacity and need to replace.
Momentary load terminal voltage	2		-0.1 vdc Average +0.1 vdc	Indicates increase in impedance perhaps due to shorted cells, undercharging, dryout ,conductive path corrosion or normal wearout Suspect measurement	Reduced autonomy Failure under load	2 1	Suspect unit(s) should be further tested to determine extent and nature of problem.
Interunit connection resistance	1	Annually* (Sample	-20% Average @ Installation +20%	Suspect measurement Loose connections Corroded connections	Sudden terminal failure under load Reduced autonomy due increased voltage drop	1 2	Retorque connection hardware Clean and retorque connection hardware

Table 2C (Continued) – Individual Unit Parameters Monitored and Alarm Limits

Class	System Level	String Level	Unit Level	Possible Alarms or Indications
I				
	System voltage			Low charging voltage alarm High charging voltage alarm Low Voltage disconnect caution
	Charging mode status			Charging mode status
	Temp. environment			High Temperature caution Low Temperature caution
	Ground fault voltage			Battery unsafe/fault alarm
		Float current		Open circuit alarm by string
		Temperature of pilot units		Battery high temperature caution Charging disconnect alarm Thermal runaway alarm
II				
	AC ripple voltage			Rectifier performance caution
	AC ripple current			High ripple current caution
		AC ripple current		String performance caution
			Z/R/C or Vrms/unit	Caution by unit String performance caution Recc. to run capacity test
			DC Float Voltage	Low voltage alarm by unit High voltage alarm by unit
III				
	Time Discharge current System voltage Battery temperature Charging current			Elapsed time on discharge Time remaining on disc. Elapsed time on recharge Recharge time remaining to 95% SOC
		Discharge current balance		String performance caution
IV				
				% Rated capacity
			Connector voltage drop	Connection caution by unit

Table 3 – Parameter s Monitored and Potential Alarms and Indications

Manually Monitoring		Automated Monitoring	
Advantages	**Disadvantages**	**Advantages**	**Disadvantages**
Costs incurred gradually	Annual cost cumulative throughout system lifetime	One time hardware cost Reusable with "next" system	Up front costs Break even point at between 5 and 9 years
	Extensive training required	Minimal training required	
	Periodic notice of "deviations"- problems can develop between inspections	Instant notice of "deviations" enhances safety and reliability	
	Access to batteries in cabinets is difficult in most cases – in some situations, the system must be off line and partially disassembled	Personal access to monitor is not required thus safety is improved	
	Exposure to high voltage and current during monitoring activities	Personal access to monitor is not required thus safety is improved	
	Variability of monitoring and data collection technique	Consistent "wired in" data collection and logging	
	Technician must be on site	Provides for monitoring at a central or remote location	
		Can incorporate logging, trending and predictive algorithms	
		Increased confidence in the system reliability	

Table 4 – Manual vs. Automated Monitoring Systems

Cost Item	Manual Monitoring	Automated Monitoring
Technician training per 5 year interval	$1,440 (3 days)	$480 (1 day)
Special monitoring / testing equipment	$3,000 (could be used for multiple systems)	$12,000 (est. for 3 cabinet system)
Monitoring system installation	N/A	$3,600 (est. for 3 cabinet system)
Recurring inspection / monitoring cost per year	$1,680 (28 Mh)	$240 (4 Mh -visual only)
4 year total	$11,160	$16,800
6 year total	$15,960	$17,760
8 year total	$19,320	$18,240
10 year total	$22,680	$18,720
12 year total	$26,040	$19,200

Table 5 – Relative Monitoring Costs