COMPARISON OF VALVE-REGULATED LEAD-ACID BATTERY MONITORING REGIMES WITH CELL REPLACEMENT DATA: A UTILITY END-USER FOCUS

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ABSTRACT

A multi-phase project to investigate the reliability of Valve-Regulated Lead-Acid (VRLA) batteries, as used in stationary applications, has been conducted by U.S. industry and government research organizations. The focus of the study has been to characterize the relationships between VRLA technologies, service conditions, performance, and failure modes. Two surveys were conducted: one of VRLA end users, and the other of VRLA manufacturers. Data from end users were obtained for over 56,000 telecom and utility installations representing over 740,000 cells. Seven manufacturers participated in the study.

There has been much discussion at recent technical forums as to the best method for determining a VRLA battery's state of health. This paper will analyze the monitoring regimes of surveyed utility VRLA end users and compare them with the age of the installation at the first cell replacement. There were a variety of monitoring regimes implemented by the survey participants that included combinations of four parameters: voltage, ambient temperature, current, and internal ohmic measurements. End users measured these parameters at different intervals: daily, monthly, quarterly, semi-annually, and annually. Comparing monitoring parameters and frequency with first cell replacement patterns will provide the utility VRLA community with real-world scenarios to consider when designing and implementing their monitoring regimes.

INTRODUCTION

VRLA batteries have been commercially available for more than 20 years and have been enthusiastically embraced by users of uninterruptible power supplies (UPS) because of the anticipated reduction in installation and operating costs, smaller footprint, lighter weight, and fewer environmental concerns. However, as with any evolving technology, users have encountered varying degrees of performance reliability. Manufacturers and end users postulate that the premature failures experienced at some field installations may be due to temperature and charging sensitivities, manufacturing quality control, monitoring and maintenance follow-through, or compatibility issues with particular applications.

The International Lead Zinc Research Organization, Sandia National Laboratories, and the Advanced Lead-Acid Battery Consortium have sponsored a multi-phase project to investigate these issues. Energetics is the contractor on this effort, whose focus is to characterize the relationship between VRLA technologies, service conditions and failure modes. These organizations are impartial regarding VRLA battery choice, and their sponsorship of this effort has created an unbiased forum for evaluating VRLA product characteristics, operating conditions, field performance and service life.

This study consists of three phases:

- Confidential survey of manufacturers of VRLA cells for stationary applications
- Confidential survey of VRLA end users with stationary applications, primarily in the electric utility and telecommunications business sectors
- Analysis of the two surveys to characterize the VRLA population and identify parameters of design, manufacturing and operation that may affect VRLA performance and reliability

The survey of manufacturers identified differences in VRLA design and manufacturer quality control. Each manufacturer was asked to respond to questions describing a specific cell's physical, electrical, and performance characteristics. The survey of end users attempted to reveal installation and operating procedures that may have contributed to the apparent success or failure of the VRLA cells. Each end user was asked to respond to questions describing from whom they purchased their cells, a description of their VRLA installation, and operating and monitoring regimes.

Every effort was made to conceal the identity of participants. Two linked, password-protected Access databases were created for the VRLA battery end users and manufacturers. Manufacturer name, cell model, and end-user name are numerically coded to conceal identities. The data are provided as metric measurements. Queries have been developed to interrogate the databases, with analysis performed in Excel.

As of December 1, 2000, 16 utilities and eight telecommunications firms completed surveys. These responses represent over 56,000 installations with over 740,000 cells. Many respondents completed surveys representing hundreds or thousands of installations. This was particularly true among surveyed telecom end users, who typically provided responses for over 6,000 installations while the typical utility respondent represented 13 installations (see Table 1). These installations use cells produced by seven manufacturers.

Table 1. General Profile of End-Users Surveyed

Application	Respondents	Installations	Cells
Utility	16	215	15,522
Telecom	8	55,992	725,988
Total	24	56,207	741,510

In order to investigate the particular nature of the VRLA market, the two sectors had to be treated separately. The telecom market dwarfs the utility VRLA market in the U.S., and combined analysis would not reveal relevant information for utility operators. In addition, fundamental differences in configuration, age, operation, monitoring, and rate of failure all support distinct analysis for the two sectors. The present paper focuses on characterizing utility VRLA installations, considering:

- Operating environment - indoor/outdoor location, temperature control
- Monitoring regime - frequency and choice of voltage, temperature, current and/or internal ohmic measurements
- Year installed, date first cell replaced, and contributing factors

PROFILE OF SURVEYED UTILITY INSTALLATIONS

Utility VRLA end users responding to the survey operate 215 installations, distributed across 13 states. Utility respondents indicated that only four installations used gelled electrolyte in their 476 cells, with the remaining 211 installations employing AGM. Most (138) of the surveyed utility installations operate at 125 V for substations and industrial customer sites. This group accounts for 83% of the cells and 64% of the installations surveyed. A third of the installations (70) operate at 48 V, and these are employed in a wide variety of applications. Table 2 compares key characteristics of surveyed 125V and 48V utility VRLA installations.

Table 2. Profiles of 125V and 48V Utility VRLA Installations Surveyed

Description		125 V Installations	48 V Installations
Year Installed	1980-1985	1	9
	1986-1989	2	0
	1990-1993	75	32
	1994-1996	42	9
	1997-2000	18	20
Maximum Temperature	20-30°C	74	35
	30-40°C	55	18
	Unknown	9	17
Location	Indoor	129	57
	Outdoor	9	13
Temperature Controlled	Controlled	85	24
	Not Controlled	53	46

Location and temperature control define the operating environment of VRLA installations. Utility VRLA installations are primarily indoor facilities; almost 90% of the surveyed installations are indoors. Not surprisingly, maximum temperature exposure is not high for the surveyed utility respondents. In fact, none of the 215 installations is operated above 40 °C. Manufacturers by and large do not require temperature control. Nonetheless, almost half of the utility installations were temperature-controlled, typically by a fan or small air conditioning unit.

Over 85% of the 125 V batteries surveyed were installed in 1990-1996. Over 61% of the 125 V batteries are temperature-controlled even though not required by the manufacturer. By contrast, over 58% of the 48 V batteries surveyed were installed in 1990-1996. The 48 V batteries are primarily located indoors and are typically not temperature-controlled.

CELL HEALTH

Cell health can be monitored a number of ways (see Table 3). Monitoring temperature is important in VRLA batteries because they are more sensitive to heat than flooded lead-acid batteries, and increased temperature can result in water loss and thermal runaway. Temperature alone will not enable owners/operators to identify cell weaknesses and react accordingly. End users monitor voltage, current, and internal ohmic measurements alone or in combination with temperature.

Table 3. Some Common Battery Monitoring Parameters

Monitored Parameter	Technical Value
Battery Temperature	Can signal thermal stress problem
String Voltage	May indicate rectifier problem
Cell Voltage	True value only when measured at cell level
Float Current	Indicates high resistance battery/current path
Battery Discharge	Only indicates discharge is in progress
Battery Conductance	Passively identifies weak cells/batteries

Adapted from [1].

VRLA batteries are often closely packed in module racks or designed as monoblocks, making the measurement of individual cell voltages difficult. In addition, the spread of individual cell voltages during float service exceeds that of conventional flooded batteries, especially when the battery is new, making float voltage measurements less meaningful [2].

Because not all regimes are ideal for every installation, end users must decide for themselves which parameters are most effective in identifying their battery's state of health. There has been much talk of late regarding simply tracking ohmic measurements (which includes internal resistance, impedance, and conductance) to detect faults that impact a battery's capacity [3,4]. Impedance will increase due to loss of electrolyte or corrosion of the conducting components [2]. Conductance measures a battery's ability to produce current or its electrical efficiency. Conductance is measured in siemens or mhos (the reverse of ohms) and is the inverse of impedance and internal resistance. As the conductance value increases, so does the expected performance value of a cell, therefore correlating directly with capacity as measured in a timed discharge test.

There were six different sets of parameter combinations used by utility respondents (see Table 4). Two-thirds of the participating utility installations included monitoring three parameters in their regime. None of the end users monitored all parameters. Voltage, current and internal ohmic measurements were the favored combination, monitored at 59% of all surveyed 125V utility cells. The combination of voltage, temperature, and current was preferred by 30% of the surveyed utility 48V installations. None of the utility respondents indicated visually checking their cells for cover, case and post integrity.

Every surveyed utility installation measured voltage; 84% of the installations monitored it at the cell level. For only 29% of the 125 V and 48 V installations was the battery room's ambient temperature monitored. Internal ohmic measurements were taken on 62% of all 125 V and 48 V installations, always in combination with another measure. Although only two regimes included monitoring current, 55% of all surveyed installations are impacted by this measurement.

Table 4. Parameters Monitored by Surveyed 125V and 48V Utility VRLA Installations

Installations		Parameters			
125V	48V	Voltage	Temperature	Current	Ohmic Measurements
12	21	***X***	***X***	***X***	
4	17	***X***	***X***		***X***
6		***X***	***X***		
81		***X***		***X***	***X***
12	15	***X***			***X***
23	17	***X***			
138	70				

Not only must companies monitor their cells, they must do it consistently to assess battery health accurately. Only 4 of these installations monitored their cells on a daily basis, and voltage, current, and ambient temperature were checked. Table 5 compares the monitoring parameters and frequency for 125 V and 48 V utility VRLA installations. Multiple parameters are bundled in three groups: voltage only, voltage and temperature and/or current, and voltage and internal ohmic measurements and (at times) current or temperature. Monitoring frequency is displayed for monthly, quarterly, semi-annual, annual and other (which includes daily, by exception and unknown).

Table 5. Multiple Parameter Monitoring by Surveyed 125 V and 48 V Utility VRLA Installations

Frequency	Voltage Only		Voltage + Temp +/or Current		Voltage + Ohmic Measures	
	125V	48V	125V	48V	125V	48V
Monthly			8	21	75	
Quarterly	19	4	4			
Semi-Annual		1			6	1
Annual			2		4	17
Other	4	12	4		12	14
Total	23	17	18	21	97	32

Voltage only is measured either quarterly or semi-annually. Most 125 V installations measure voltage quarterly. Frequency of voltage readings at 12 48 V installations is unknown. Voltage and temperature and/or current is less popular for both 125 V and 48 V installations. Voltage and ohmic measures (and/or temperature or current) are typically measured annually at 48 V installations and monthly at 125 V installations.

FIRST CELL REPLACEMENTS

One way to derive the impact that monitoring regimes and temperature control have on battery performance is to examine the age of the installation when the first cell was replaced. The survey employs this tactic as a proxy for premature cell failure. Cell failures within the first year of operation are typically due to manufacturing defects, usually covered by the warranty. Given the negative publicity surrounding VRLA performance, the authors expected to find a large number of failures within the first year. However, only four utility installations had their first cells replaced within the first year. The range of ages for first cell replacement naturally broke at 1-3 years, 4-5 years, and greater than six years. The remaining category is "None Replaced," the most desirable condition for end users.

Having no cells replaced could easily indicate that the battery was recently installed, e.g., since 1997. For older installations, having no cells replaced means the battery has performed as expected. This could be due to any number of conditions, e.g., the end user's preventive maintenance program, a particular product's technical superiority, very little use, or no method of checking the capacity of the cells.

MONITORING REGIMES AND FIRST CELL REPLACEMENTS

Do certain monitoring regimes increase or decrease the probability of early first cell replacements? Table 6 examines the age of the installation at first cell replacement and the parameters monitored by 125 V and 48 V batteries in an attempt to tackle this question. The 125 V batteries monitoring voltage only had a 91% chance of never replacing any cells. Only 9% replaced their first cells within three years. It appears counter-intuitive, but the installations where multiple parameters were measured had the worse odds of postponing first cell replacements. Only 33% of those measuring voltage and temperature and/or current and 4% of those checking voltage and ohmic measures could boast of none replaced. In fact, 63% of those monitoring voltage and ohmic measures had their first cell replacements within three years.

Table 6. Effect of Monitoring Parameter Choice on First Cell Replacements

Age of Installation	125V Installations			48V Installations		
	Voltage Only	Voltage + Temp +/or Current	Voltage + Ohmic, etc.	Voltage Only	Voltage + Temp +/or Current	Voltage + Ohmic, etc.
<1 years		17%				
1-3 years	9%	11%	63%	12%	100%	47%
4-5 years		28%	32%			
6 years		11%	1%			
None replaced	91%	33%	4%	88%		53%

The 48 V installations that were surveyed either experienced their first cell replacement within three years or avoided it for at least six years. In fact, 88% of the installations measuring voltage only and 53% of those monitoring voltage and ohmic measures had yet to replace their first cell. These results appear surprising, particularly in light of the frequency of their monitoring regime (see Table 7). The 48 V installations monitoring 4 times or less per year (i.e., quarterly, semi-annual, or annual) had an 87% chance of not replacing any cells. One wonders whether these results are due to the fact that these 48 V installations are more remote and less often visited.

Table 7. Effect of Monitoring Frequency on First Cell Replacements

Age of Installation	125V Installations			48V Installations		
	12/yr	4/yr	Unknown	12/yr	4/yr	Unknown
<1 yr	3%					
1-3 yrs	59%	9%	69%	100%	13%	54%
4-5 yrs	34%	17%				
>6 yrs	2%		6%			
None Replaced	1%	74%	25%		87%	46%

The 125 V installations monitored four times a year or less also had a better chance of avoiding first cell replacements than the installations monitored monthly. Over 60% of the 125 V installations monitored monthly had their first cell replacement within three years. This outcome was worse for 48 V installations; all 21 installations replaced their first cell within three years.

This survey did not ask about proactive maintenance plans, making it near impossible to determine if these failure rates are legitimate. Maintenance procedures for voltage, current, or ohmic measures are not known from this sample. However, questions regarding temperature control were included in the survey, and are examined below.

TEMPERATURE CONTROL AND FIRST CELL REPLACEMENTS

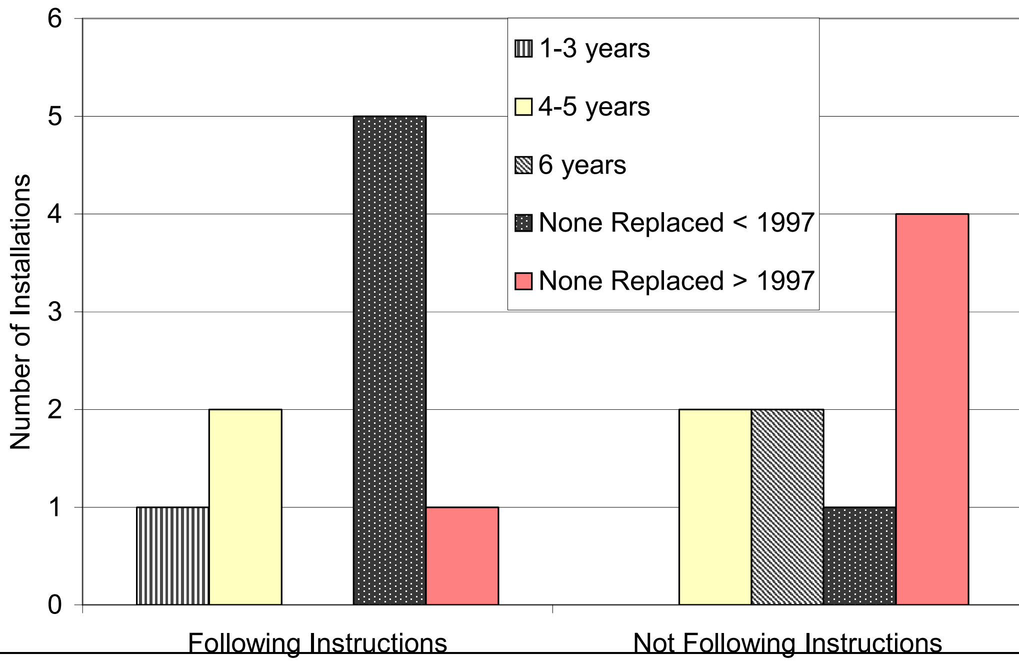
Over half of the utility installations provided some type of temperature control for their facilities, even when not required by the manufacturer. Manufacturers required temperature control for only 18 of the surveyed utility installations (all 125V and 48V). Half of the installations chose not to follow manufacturer's instructions and did not provide any temperature control at the facility.

This analysis sought to answer the following questions:

- If you follow manufacturers' instructions, when is the first cell most likely to fail?
- If you provide temperature control when it's not needed, do cells still fail prematurely?
- If you don't provide temperature control and manufacturers ask for it, does it speed up early cell failures?

Following instructions could not postpone first cell replacements indefinitely (see Figure 1). However, it did result in no replacements for five facilities installed in 1995. The survey results here are inconclusive, but if the end user follows manufacturer's instructions, the first cell will not be replaced until after the fifth year.

Figure 1. Temperature-Control Instructions and the Age of Utility First Cell Replacements



By comparison, most of the utility installations not replacing cells were installed since 1997. These installations could possibly operate for another five years without first cell replacements, but it is too early to tell. Choosing not to follow manufacturer's instructions does carry some risk, but it does not appear to significantly alter the odds of replacing first cells before those following instructions.

Providing fans or air conditioning to control the temperature of the VRLA installations, whether or not required by the manufacturer, does increase the likelihood of not replacing any cells due to premature failure. In fact, utility respondents providing temperature control to 38 installations, even when not required by the manufacturer, have yet to replace their first cell (see Figure 2). Unfortunately, another 56 installations did replace their first cells within the first three years of operation.

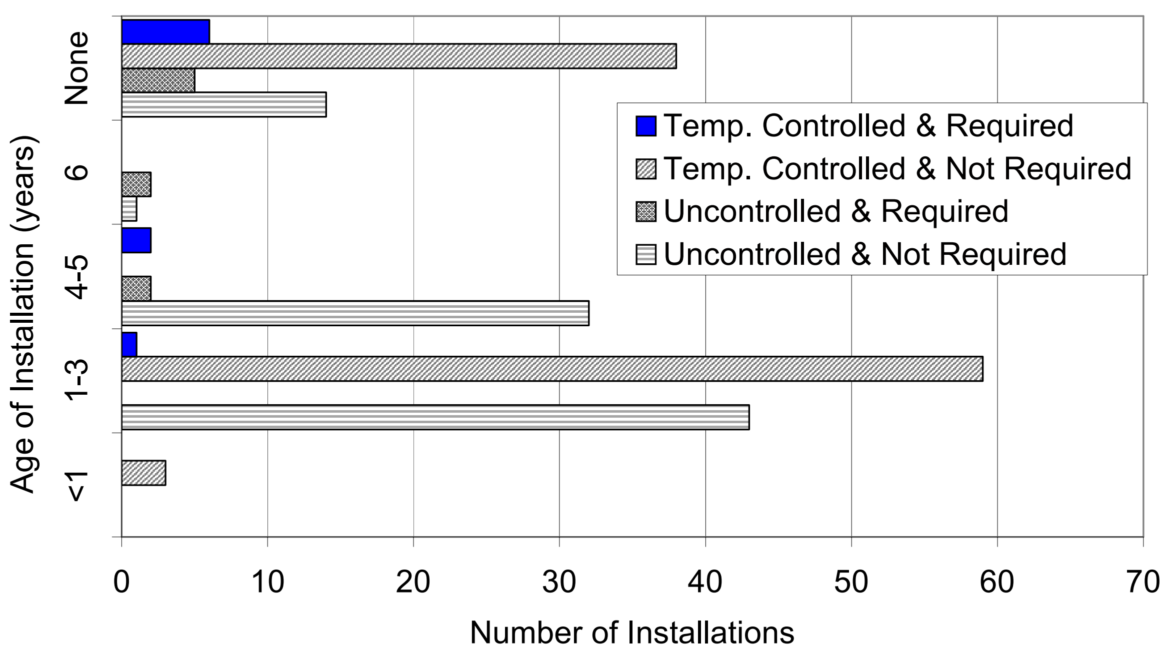
CONCLUSIONS

Even though the surveys are still in the process of being analyzed, a number of important conclusions are worthy of note:

- A significant number of the VRLA cells covered by the surveys are lasting for five or more years: 51% of the 125 V installations and 46% of the 48 V installations.
- There is a large spread in the range of life expectancy for utility VRLA cells, from one to 16 years.
- A vigorous monitoring program does not appear to extend the life of VRLA cells without an equally proactive cell maintenance program. Every installation measured voltage and 81% of the utility installations measured one or two more parameters regularly, with less desirable outcomes. More frequent monitoring appeared to result in first cell replacements within three years.
- Following the manufacturer's instructions on temperature control appears to help delay first cell replacements until after the fifth year.
- Providing fans and air conditioning to control temperature, whether required by the manufacturer or not, does increase the likelihood of not replacing first cells prematurely.

Further analysis of the data and feedback from manufacturers are needed before drawing additional conclusions.

Figure 2. Effect of Temperature Control on the Age of First Cell Replacements



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