Reliability Of Valve-Regulated Lead-Acid Batteries For Stationary Applications

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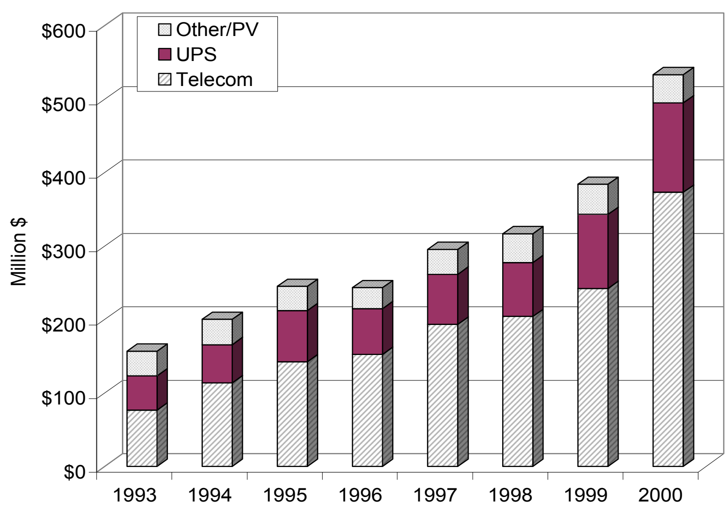
Background and Purpose

Valve-regulated lead-acid (VRLA) batteries have been commercially available for more than 20 years. They have been enthusiastically embraced by users of uninterruptible power supplies (UPS) because of the anticipated reduction in installation and operating costs, smaller footprint, increased installation flexibility, and fewer environmental concerns. Yet UPS applications now account for less than 23% of VRLA annual sales, which have grown from $157 million in 1993 to $534 million in 2000 [1]. Telecommunications demand for emergency back-up power is responsible for recent growth in VRLA sales, and accounts for 70% of sales in 2000 (see Figure 1).

Figure 1. VRLA Battery Annual Sales 1993-2000



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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 VRLA battery temperature and charging sensitivities, manufacturing quality control, or compatibility issues with particular applications. Proprietary concerns and inadequate data acquisition systems have limited the amount of performance and life-cycle data that is publicly available. This has hindered the ability to evaluate premature capacity loss, which has been reported for VRLA batteries in some cases after as few as two years of service [2].

The U.S. Department of Energy, Sandia National Laboratories (Sandia), International Lead Zinc Research Organization (ILZRO), and the Advanced Lead-Acid Battery Consortium (ALABC) have sponsored a multi-phase project to investigate these issues. The focus of this study 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.

Program Phases

This study was carried out in five phases. The first two phases included two confidential surveys, one of manufacturers of VRLA cells for stationary applications and the other of VRLA end users with stationary applications, primarily in the electric utility and telecommunications business sectors [3, 4]. An analysis of the two surveys was performed to characterize the VRLA population and identify parameters of design, manufacturing and operation that may affect VRLA performance and reliability. The fourth phase involved

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conducting four independent workshops to examine the results. The workshops were held for ALABC and ILZRO members and participating manufacturers. Finally, the authors revised the analysis to incorporate the suggestions for improvements.

As of March 2002, 16 utilities and nine telecommunications firms completed end-user surveys. These responses represent over 56,000 installations with over 740,000 cells (see Table 1). 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 average utility respondent represented about a dozen installations. The data presented in this report are analyzed in four categories: Less than or equal to 48 volt (LTE48V), spiral-wound, UPS, and photovoltaic (PV) systems. It should be noted that the LTE48V and spiral-wound categories are both used for telecommunications purposes.

Market Comparison

Battery Council International (BCI) conducts annual market assessments of U.S. lead-acid batteries. The BCI VRLA dollar sales data spanning eight years (1993-2000), identified in Figure 1, were converted to unit sales data (see Table 1). This yields approximately 11 million VRLA cells employed in stationary applications. The total cells identified in our survey represent 7% of the total cells estimated to be in operation in the U.S. This number is significant, when compared to other random sample surveys performed by the U.S. Department of Energy and other government agencies.

Table 1. Surveyed Cells as Percentage of Total VRLA Cells in U.S.

Application	Total Surveyed Cells	Percentage of Total Surveyed Cells	Total Cells in U.S.	Surveyed Cells as a Percentage of Total Cells in U.S.
LTE48V	258,000	63.4%		
Spiral-wound	11,553	34.7%		
Total telecom	269,553	98.1%	8,260,000	8.8%
UPS	11,553	1.6%	2,290,000	0.5%
PV	2,112	0.3%	320,000	0.7%
Total	742,587	100.0%	10,870,000	6.8%

Warranted Life

Many VRLA products were initially marketed as “maintenance-free, 20-year life batteries.” Although these claims are being seriously reconsidered by manufacturers and end users alike, there is still a large misconception in the end-user community that VRLA batteries are only successful if they require no maintenance and last 20 years.

The end-user survey included a question on the length of warranty on batteries. Half of the respondents claimed that their cells held 20-year warranties; however, those respondents only employ a small amount of cells at their installations, thus, accounting for a mere 3% of the total cells identified in the survey. An initial assumption was that the owners/operators of older cell models would report holding 20-year warranties, however, only a third of all surveyed 20-year cells were installed prior to 1990. Most of the 20-year cells were installed between 1990 and 1996, which is when the bulk of the surveyed facilities were installed. No apparent trend exists between the year the cells were installed and the warranty reported by the participating end users. Almost all (96%) of the cells surveyed were reported as holding five, seven, or ten-year warranties, and there are distinctions by application:

- LTE48V predominately hold ten-year warranties
- Spiral-wound all held warranties under eight years
- Majority of UPS held 20-year warranties
- Nearly all PV held five-year warranties

End User Profiles

The LTE48V systems provide stored energy for the communication systems for both the telecom and utility industries. Nearly 50% of all LTE48V surveyed cells were installed between 1980 and 1989, most of the remaining cells were installed between 1990 and 1993 (see Table 2). These cells were predominantly located in outdoor installations. Despite the fact that nearly all of these cells were reported to be installed in temperature control environments, they were exposed to temperatures above 31°C, with 33% of them experiencing maximum ambient temperatures above 40°C. The surveyed end users reported that all of their LTE48V cells were installed in temperature-controlled facilities. Regardless of the maximum ambient temperature, these surveyed cells were primarily floated within the 2.23 to 2.27 voltage window.

Table 2. End User Profiles

Description	LTE48V	Spiral-wound	UPS	PV
Installed 1980 – 1989	50%	100%	2%	0%
Installed 1994 – 1996	3%	0%	41%	72%
Outdoor	71%	65%	7%	11%
Temperature controlled	100%	100%	60%	99%
Max Temperature 20 - 30°C	4%	0%	38%	48%
Floated at 2.23 – 2.27 volts per cell (vpc)	99%	100%	90%	1%

The surveyed spiral-wound cells were all installed prior to 1989. Most cells were installed outdoors where maximum temperatures exceed 40°C. Regardless of their location, these systems were all temperature-controlled and floated between 2.23 and 2.27 volts per cell. These two features may help explain the excellent performance of these cells, well beyond the warranty period.

UPS installations required more cells and higher voltage (rated at or above 125V). Just over 40% of the surveyed cells were installed between 1994 and 1996. These cells were largely installed indoors in temperature-controlled environments. The survey respondents were unable to identify the maximum ambient temperatures 30% of the cells were exposed to. However, just fewer than 40% of the surveyed cells were reported as experiencing maximum ambient temperatures between 20 and 30°C. Nearly all of these cells were floated within the 2.23 and 2.27 voltage window.

All surveyed PV cells were installed after 1994. They were typically installed in controlled environments indoors, with maximum ambient temperatures not exceeding 40°C. However, 99% of all surveyed PV cells were floated above 2.27 vpc, a finding the manufacturers found unusual. It was suggested that perhaps these respondents reported the equalization charge voltage instead of the float voltage, as PV cells are more typically cycled than floated.

Replacement Experience

The VRLA end-user survey was handicapped in seeking the type of information needed to develop a complete picture of cell performance. This was primarily because:

- VRLA cell replacements and unusual experiences were not well documented by the installation operators; rather the survey had to depend on respondent recall, which is both subjective and inexact.
- VRLA cells are typically installed at remote, unmanned locations. If the owner/operator does not have a data acquisition system with remote access or a regular monitoring program to track cell health, he can only venture a guess as to when the cells first failed. Many respondents answered this question as a range, i.e., 1994-1995. Midpoints were used in the database to enable analysis.
- The age at which the first cell was replaced could be derived by the answers provided by the survey respondents. This question was used as a proxy for estimating when cells failed. The age of the second and third cell replacements would also be of great interest and could be incorporated into subsequent survey designs. However, given the number of installations and cells covered by a single respondent, it is unlikely that those questions would be answered accurately.

All surveyed end users were able to provide the year of installation and the year the first cell was replaced. The age of first cell replacement was calculated by subtracting the year the installation experienced its first cell replacement from the year the cells were installed.

Because of the issues identified, certain assumptions were used to estimate the number of cells replaced at the same time. Any monoblock-type[2] installation experiencing a first cell replacement meant that two, three, or six cells were replaced, depending on the monoblock design. For grouped cell[3] configurations, the number of first cells replaced varied by installation size and application:

- One cell is assumed to be replaced in small LTE48V and PV installations
- Two percent of all cells are assumed to be replaced when a larger UPS installation experienced its first cell replacement (this assumption is drawn from documented experience from surveyed end users)

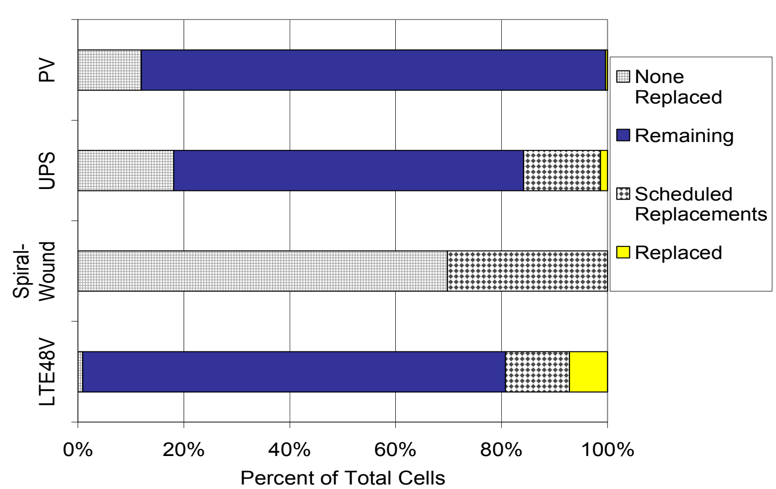
In this manner, the number of first cells replaced was calculated as a percentage of all cells in the installation.

Cell failures within the first year of service are typically due to manufacturer defects usually covered by warranty. The installations experiencing first cell replacement within the first four years of operation are considered premature failures. VRLA manufacturing representatives advised that those cells replaced during their fifth year of service were a result of a pre-determined replacement schedule to ensure system reliability. Consequently, cells replaced after four years of service are regarded as scheduled replacements.

The survey responses indicated that the field performance experienced by the surveyed VRLA batteries was positive as over 186,000 cells operate in surveyed VRLA installations in which no cell has ever been replaced (see Figure 2). These cells represent 25% of all cells surveyed. Thirty-three percent of surveyed cells were replaced due to premature failures and just less than 50% were scheduled replacements.

Of all the surveyed cells, the spiral-wound experienced the best field performance. The surveyed spiral-wound cells were installed in the 1980s. They were extremely successful as 70% of the cells had never been replaced at the time of the survey and they were 20 years old. The remaining 30% were replaced after five years of service, suggesting that they were scheduled replacements. These cells are used in 36,500 installations operated by only two survey respondents.

Figure 2. Surveyed Cells by Application and Replacement Experience



While the surveyed LTE48V cells did not experience the same long life as the spiral-wound cells, their performance still far exceeded previous reports. None of the cells installed in surveyed LTE48V installations experienced failure within the first year of service. Only 19% of the surveyed LTE48V cells were replaced and 63% of those were replaced after four years of life, indicating likely scheduled replacements.

The end users of the surveyed VRLA cells in operation at UPS installations reported favorable experiences. Only 2% of all surveyed UPS cells required replacement. Nearly two-thirds were in service for three-to-four years before needing to be replaced. Only 23 of the surveyed cells in UPS installations failed in their first year of service, suggesting the

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[2] A battery consisting of two or more series-connected cells in a single container. A 12 volt battery is a monoblock consisting of 6 series-connected 2 volt cells.

[3] One or more battery cells connected in series or parallel.

cause was due to manufacturer defect. These account for less than 1% of all installed cells. Almost 20% of the cells replaced were scheduled replacements.

The surveyed cells installed in PV installations performed extremely well as only seven cells required replacement; three of these within the first year of life indicating manufacturer defect. The remaining four cells were replaced within two years of service.

Because VRLA cells are very sensitive to temperature and float voltage, the age at first cell replacement was analyzed against the maximum ambient temperature and float voltage to determine if any trends existed between these operating conditions and time of first cell replacement. Ideally, the analysis should address the percentage of time each year that the maximum temperature prevails in addition to considering the average temperature and minimum temperature. Unfortunately, none of these parameters were consistently provided by the end users, leaving only the maximum temperature to analyze against float voltage.

As it turns out, there were very few failures that could be attributed to improper float voltage and temperature exposures. Two-thirds of all surveyed cells were operated at maximum temperatures below 40°C and nearly all of those were floated between 2.23 and 2.27 vpc. Surprisingly, the survey respondents indicated that no premature cell failures occurred with those cells exposed to maximum ambient temperatures greater than 40°C.

At the time of survey, those cells that were installed between 1980 and 1989 had required very few replacements. In fact, no UPS cells installed within that time frame were replaced and only 3% of all LTE48V cells were replaced. Cells installed between 1990 and 1996, on the other hand, required more replacements – 88% of these cells were located at installations that experienced some cell replacement, nearly all were premature failures.

Summary

The results of this survey effort have indicated a number of findings worthy of note:

- 3% of surveyed cells hold a 20-year warranty
- 99% of surveyed cells floated between 2.23 and 2.27 volts per cell
- 67% of surveyed cells operated at maximum temperatures above 40°C
- 25% of all surveyed cells have never been replaced
- 42% of all surveyed cells operated five or more years before being scheduled for replacement
- 33% of surveyed cells were replaced within the first four years of operation
- Analysis of float voltage did not reveal clear reasons for early cell failure. Indeed for LTE48V cells, the only failures were those within the 2.23 to 2.27 voltage window
- Spiral wound cells experienced a long life even under adverse temperature conditions

While end users do have feelings, anecdotes, and opinions of how their batteries are performing in the field, they do not have actual data representing battery performance as it costs too much. There is a need for an objective data acquisition and analysis study on VRLA field installations.

References

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