ILZRO-Sponsored Field Data Collection and Analysis to Determine Relationships Between Service Conditions and Reliability of VRLA Batteries in Stationary Applications

*Paula A. Taylor[a], Patrick T. Moseley[b], Paul C. Butler[c]

[a]Energetics, Incorporated, 7164 Gateway Drive, Columbia, MD, 21046 USA

[b]International Lead Zinc Research Organization, PO Box 12036, Research Triangle Park, NC, 27709 USA

[c] Sandia National Laboratories, PO Box 5800, MS 0613, Albuquerque, NM 87185-0613 USA

Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy under contract DE-AC04-94AL85000.

Abstract

Although valve-regulated lead-acid (VRLA) batteries have served in stationary applications for more than a decade, proprietary concerns of battery manufacturers and users and varying approaches to record-keeping have made the data available on performance and life relatively sparse and inconsistent. Such incomplete data are particularly detrimental to understanding the cause or causes of premature capacity loss (PCL) reported in VRLA batteries after as little as two years of service.

The International Lead Zinc Research Organization (ILZRO), in cooperation with Sandia National Laboratories, has initiated a multi-phase project to characterize relationships between batteries, service conditions, and failure modes; establish the degree of correlation between specific operating procedures and PCL; identify operating procedures that mitigate PCL; identify best-fits between the operating requirements of specific applications and the capabilities of

*Paula A. Taylor, Energetics, Incorporated, 7164 Gateway Drive, Columbia, MD 21046, USA; telephone: (410) 290-0370, facsimile: (410) 290-0377

DISCLAIMER

specific VRLA technologies; and recommend combinations of battery design, manufacturing processes, and operating conditions that enhance VRLA performance and reliability. In the first phase of this project, ILZRO has contracted with Energetics, Incorporated to identify and survey manufacturers and users of VRLA batteries for stationary applications (including electric utilities, telecommunications companies, and government facilities); the confidential survey is collecting service conditions of specific applications and performance records for specific VRLA technologies. From the data collected, Energetics is constructing a database of the service histories and analyzing the data to determine trends in performance for particular technologies in specific service conditions.

ILZRO plans to make the final report of the analysis and a version of the database (that contains no proprietary information) available to ILZRO members, participants in the survey, and participants in a follow-on workshop for stakeholders in VRLA reliability. This paper, prepared before preliminary conclusions were possible, presents the surveys distributed to manufacturers and end-users; discusses the analytic approach; presents an overview of the responses to the surveys and trends that emerge in the early analysis of the data; and previews the functionality of the database being constructed. The presentation of this paper will include preliminary results and information regarding the follow-on workshop for the study.

1. Background

Although valve-regulated lead-acid (VRLA) batteries have served in stationary applications for more than a decade, proprietary concerns of battery manufacturers and users and varying

approaches to record-keeping have made the data available on performance and life relatively sparse and inconsistent. Such incomplete data are particularly detrimental to understanding the cause or causes of premature capacity loss (PCL) reported in VRLA batteries after as little as two years of service[1, 2]. The International Lead Zinc Research Organization (ILZRO), in cooperation with Sandia National Laboratories, has initiated a multi-phase project to characterize relationships between VRLA batteries, service conditions, and failure modes; establish the degree of correlation between specific operating procedures and PCL; identify operating procedures that mitigate PCL; identify best-fits between the operating requirements of specific applications and the capabilities of specific VRLA technologies; and recommend combinations of battery design, manufacturing processes, and operating conditions that enhance VRLA performance and reliability.

2. Approach

With input from Sandia and ILZRO, Energetics developed survey instruments for VRLA manufacturers and end-users. The surveys are designed to collect the following information pertinent to VRLA cells in stationary applications

- manufacturing processes,
- intended use (as designed),
- expected performance and life,
- actual service conditions, and
- actual performance and life.

Existing relationships, Internet and library literature searches, and supplemental information from battery experts at Rutgers University (working with ILZRO on a separate component of the

VRLA reliability effort) provided information to compile an international list of more than 25 VRLA battery manufacturers that received surveys. Analysts contacted a representative at each manufacturing company before mailing the survey to confirm the company's willingness to participate in the study and willingness to complete a survey. The largest group of surveys were mailed late in June, 1998. Two smaller mailings were issued in July. Manufacturers were asked to respond within a month of receiving the survey with information about three VRLA products:

- highest sales volume VRLA product,
- best-performing product in the field, and
- most problematic product in the field.

As shown in Figures 1 through 4, the survey was in a check-box format to reduce the amount of time needed to respond, and solicited information about the physical and electrical characteristics of the products, expected service and life characteristics of the product, R&D testing conducted on the product, and market information regarding the product. The last page of the survey, not shown in this paper, asks manufacturers to write additional comments.

Figure 1

ILZRO Valve Regulated Lead Acid Battery Survey

PRODUCTS AND MANUFACTURING SITES

How many VRLA cell types do you manufacture?

Which cell do you address in this survey (name or #)?

Where do you manufacture this product?

❑ North America ❑ South America ❑ Asia

❑ West Europe ❑ East Europe ❑ Africa

PHYSICAL CHARACTERISTICS OF CELLS

What are the cell's exterior dimensions (cm)?

Length Width Height

In what medium is the electrolyte suspended?

❑ Absorbed glass mat ❑ Thixotropic gel ❑ Other

Are that any characteristics unique to this electrolyte?

What is the separator material and thickness (mm)?

❑ Polyvinylchloride ❑ Polyethelyne ❑ Other

❑ Porous rubber ❑ Glass cloth

What is the separator saturation (%)?

How much electrolyte is in each cell (ml)?

How much variation from nominal electrolyte volume is allowed (%)?

What is the specific gravity of the electrolyte in a fully charged new cell?

PHYSICAL CHARACTERISTICS (CONT.)

What is the allowable valve opening/reseal variation (%)?

Open: _____ Seal:

What is the Ah of the plates? Positive _____Negative

What is the plate geometry?

Geometry	*Positive plate*	*Negative plate*
Flat	❑	❑
Tubular	❑	❑
Other	❑	❑

What is the nominal stack compression (psi)?

What is the allowable variation in compression (%)?

What elements do the paste alloys contain (wt%)?

Element	*Positive paste*	*Negative paste*
Antimony	❑	❑
Tin	❑	❑
Calcium	❑	❑
Other	❑	❑

What elements do the grids contain (wt%)?

Element	*Positive grids*	*Negative grids*
Antimony	❑	❑
Tin	❑	❑
Calcium	❑	❑
Other	❑	❑

Figure 2

What is the cell case material and thickness (mm)?

❑ Polyvinylchloride ❑ Polypropylene ❑ Poly carbonate

❑ ABS ❑ Polystyrene ❑ Other

What process is used to seal the cover to the

❑ Ultrasonic weld ❑ Asphalt ❑ Hot

❑ Bead mash heat ❑ Epoxy ❑ Other

What are the vent-valve opening/reseal points

Open:

Seal:

PHYSICAL CHARACTERISTICS (CONT.)

How is the post/cover seal made?

❑ Welded ❑ Epoxied ❑ Other

In what orientation are the cells designed to operate?

❑ Plates horizontal ❑ Plates vertical ❑ Either/bo

Please circle the maximum & minimum recommended operating temperatures for this cell (°C).

-80 -70 -60 -50 -40 -30 -20 -10 0 10 20 40 50 60 70 80

Does this cell use/require thermal management?

❑ No ❑ Yes, method

How much space is between cells in a module (cm)?

Vertical space Horizontal space

How much space is between modules in a string (cm)?

Vertical space Horizontal space

What elements do the post/busbars alloys contain (wt%)?

Element	*Positive*	*Negative*
Lead	❑	❑
Copper	❑	❑
Cadmium	❑	❑
Antimony	❑	❑
Silver	❑	❑
Other	❑	❑

PERFORMANCE & LIFE CHARACTERISTICS

For what application(s) is this cell designed?

❑ Float ❑ Deep Cycle ❑ Shallo

Sketch the cell's cycle life vs. depth-of-discharge in ideal temperature, discharge & charge conditions.

3 curves: C/20, C/8, and C/2 discharge rates

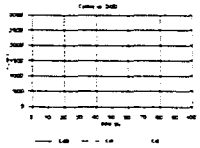


Figure 3

ELECTRICAL CHARACTERISTICS

What is the cell capacity at 77F (Ah)?

What is the cell's internal resistance (mΩ)?

What is the cell's monthly self-discharge rate (%)?

What is the cell's specific energy at the given rates (Wh/kg)?
C/20: C/8: C/2:

If you sell this cell in modules, please indicate module ID, the number of cells per module, voltage of the module, and the nominal capacity for each product.

ID	# cells/volts/Ah	ID	# cells/volt
	___/___/___		___/___/___
	___/___/___		___/___/___
	___/___/___		___/___/___
	___/___/___		___/___/___
	___/___/___		___/___/___

PERFORMANCE & LIFE CHARACTERISTICS

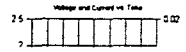
How often should cells receive equalization recharge?
❑ Specified interval _____ ❑ Other indicator

Have customers reported premature cell failures?
❑ No ❑ Yes

❑ float ❑ deep cycle ❑ shallow cycle

Does your company conduct in-house root-cause analysis of cells that fail in service?
❑ Yes

Please sketch the cell's ideal charge characteristics.
4 curves: charge voltage & current and cell voltage vs. time



What is the cell's recommended float voltage and current?
Voltage: _____ Current:

Please circle the float service warrantee (years).

1 2 3 4 5 6 7 8 9 10 15 20

What maintenance procedures do you recommend?

CONTACT AT YOUR COMPANY

Please record your name, address and phone so that we can contact you for clarification if necessary.
Name Addre ss

MARKET AND SALES

How many of these cells are sold each year?

As individual cells In modules

How many individual cells are sold each year?

Float Deep Cycle Shallow Cycle

Figure 4

Does your company out-source root-cause analysis of cells that fail in service?

❑ No ❑ Yes

Analyst

What is most prevalent cause of in-service cell failures?

Float

Shallow Cycle

Deep Cycle

How many cells are sold in modules each year?

Float Deep Cycle Shallow Cycle

How many of these cells are sold each year for the following applications?

Telecom Industrial UPS

Utility substation Motive power

R&D TESTING

How many single cells have been tested in your laboratory to determine and verify cell performance?

Shallow cycle

	Deep Cycle	Float
How many single cells have been tested in your laboratory to determine and verify cell service life? Shallow cycle		
How many units of each type of module product have been tested in your laboratory to determine and verify performance? Shallow cycle		
How many units of each type of module product with this cell have been tested in your laboratory to determine and verify service life? Shallow cycle		

CUSTOMER CONTACTS

Please supply contact information for customers and distributers whom we may contact to gather data on the actual service conditions that this cell experiences.

Name Company/Address Telephone

COMMENTS

Please write any comments you consider important regarding VRLA reliability and performance in stationary applications, especially with respect to charging and charge controls.

To ensure that data collected from end-users would include feed back from end-users with a wide range of experience with VRLA cells in stationary applications, the distribution list for the end-users' survey was compiled from a number of sources: pre-existing relationships and Internet and library searches, customers that manufacturers identified on page 3 of the manufacturers' survey, and a small number who responded to a solicitation posted on an Internet web-page[3] that was registered with major search engines under the keyword, "VRLA." At the time that this document was prepared, more than 20 people had visited the web-site, and the e-mail account for the site had received one inquiry.

As shown in Figures 5 and 6, the end-users' survey requested information about the source of the VRLA product, the operating conditions in which the product served, the monitoring conducted during the service life of the product, and about the performance and length of service life for batteries with the best and worst performance in the end-user's experience. Like the approach with manufacturers, the approach to soliciting participation from end-users included contact previous to mailing to verify their willingness to participate. At the time that this document was prepared, no end-user surveys had been mailed, but analysts intended to request that end-users also complete the survey within one month. The end-user distribution list included electric utilities, telecommunications companies, and government facilities at the time that this manuscript was drafted. The final list will also include others identified in manufacturers' survey responses.

Figure 5

BATTERY IDENTIFICATION

Please provide the manufacturer's name and model number for the valve regulated lead acid (VRLA) product that you will describe below.

Manufacturer _____ Model

What application does the battery serve?

How many volts/amps does the application require?

From whom did you purchase the batteries?
- ❑ Battery manufacturer
- ❑ Original equipment manufacturer
- ❑ Battery vendor/distributer
- ❑ Other

How many have you purchased?

BATTERY OPERATION

Did the manufacturer/vendor provide operating specifications? ❑ Yes ❑ No

FLOAT

What float voltage do you maintain (volts/cell)?

What current do you apply during float (amps)?

BATTERY MONITORING

Which parameters do you monitor, how often?

	Cell	Module	String
°C/°F	❑ _____	❑ _____	❑
Volts	❑ _____	❑ _____	❑
Amps	❑ _____	❑ _____	❑
Other	❑ _____	❑ _____	❑

If you log readings, what format is used?
❑ Print ❑ Electronic

What are the maximum, average, and minimum ambient temperatures in the battery room (°C)?

Max. Temp ____ Avg Temp _____ Min Temp

What % of a year is the temperature at or near the maximum?

Do you use thermal management for this battery? If yes, please specify method

Please sketch the recharge regime (for charge voltage and current and expected cell voltage) or provide details as an attachment.

C Y C L E	How many cycles/year does the battery experience?	Were there any issues of concern related to the operation or performance of this battery?
	Do cycles occur at regular intervals? If yes, what is the interval length? If no, is cycling ❑ Random ❑ Clustered	What is the warranteed service life (years)? What percentage of the batteries at your facility achieved the following service lives? 1/4 warranteed life ____ 3/4 warranteed life 1/2 warranteed life ____ Warranteed life
	What are the maximum, average and minimum depth of discharge that cycles demand (%)? Max. DOD ____ Avg DOD ____ Min DOD What percentage of the cycles are at a maximum, average and minimum depth of discharge? Max ____ Avg ____ Min At what rate does the battery discharge (A)?	Have you ever had a failure analysis performed and, if so, by whom? Yes No ❑ Vendor ❑ Manufacturer ❑ In-house ❑ Consultant What were the root causes (in order of frequency)?

Please provide the following information for the battery in service for the longest amount of time.	
Vendor	Date of purchase
Date of installation	Date of removal from service
Reason for removal from service Please attach copies of operating and monitoring logs	

Please provide the following information for the battery that failed previous to it's warranteed service life (if applicable):	
Vendor	Date of purchase
Date of installation	Date of removal from service
Reason for removal from service Please attach copies of operating and monitoring logs	

ADDITIONAL COMMENTS
Please feel free to add any additional data or comments.

Because information about manufacturing and operation of VRLA cells is often business sensitive, Energetics offered to establish formal non-disclosure agreements with each participant. This action assured participants that the survey responses would be confidential and the data reported in the final results would be an anonymous aggregation of information that protects the proprietary interests of all of its constituents.

From the responses to the survey, analysts are constructing a database of cell characteristics, required and actual service conditions, and service histories. Analysis of the data, on going at the time that this paper was drafted, was focused on identifying performance and service life trends for particular technologies in specific service conditions. The database (that protects all proprietary information) will be available to ILZRO members, participants in the survey, and participants in a follow-on workshop for stakeholders in VRLA reliability. The database constructed for analysis will contain detailed product- and installation-specific information about manufacturing, installation and operating history for the cells in service at sites of interest in this study. This detailed information will be accessible only to the analysts conducting the study. However, the database to be distributed to the public will be a comprehensive, searchable log that contains the following information:

- ❑ contact information for manufacturers and end-users,
- ❑ published specifications for VRLA products,
- ❑ characteristics of installations for families of applications:
  - telecommunications substations and relays,
  - electric utility substations,
  - military security installations,

- building energy efficiency associations,
- public school backup power, and

performance histories for families of VRLA technologies in categories separated by manufacturing characteristics:

- ❑ glass mat vs. gel,
- ❑ vertical vs. horizontal plate orientation,
- ❑ type of plate alloy,
- ❑ type of case and post seals, and other.

The contact information is assembled through a commercially available, dBase-compatible contact management software package, ACT! The remainder of data is contained in a database constructed with dBase-compatible Microsoft Access. This software permits construction of a relational database that permits construction of an analytic tool and a public version that protects proprietary information. The analytic database has capabilities to assist in identification of similarities and disparities between discrete reports of field monitoring data, and to facilitate trending of performance and life of specific VRLA technologies in specific applications.

3. Project Status

The willingness of VRLA battery manufacturers was a key concern at the outset of this project. Because the due date for responses to the manufacturers' survey was after the due date for the manuscript of this paper, the actual response rate of manufacturers will be reported at 6ELBC, but not in this paper. However, preliminary response from the industry suggests that manufacturer participation will be more than adequate. At the Battery Council International

conference in April 1998 in Washington DC, the chairs of two sessions (both who were battery manufacturing company representatives) announced the ILZRO study, and encouraged their colleagues to participate. During preliminary phone calls, more than 25 manufacturers were contacted in the United States, Europe and Asia. All of those contacted agreed to receive the survey; at least a quarter of that population expressed enthusiasm for the project and made a commitment to complete the survey.

End-user response is also expected to be adequate. Before incorporating customers identified by manufacturers, analysts constructed a list of 20 organizations that use VRLA cells in a wide variety of stationary applications. If each VRLA manufacturer identifies one customer, the list will include more than 45 end-users. End-user participants recruited from the Internet web page will increase that number. From this population, analysts expect to have representation of end-users with favorable and unfavorable experience with VRLA products. This cross-section will increase the likelihood of identifying impacts on performance and life for specific combinations of cell design and operating regimes. Trends in this data can be compared with other data compiled for telecommunications applications only[4].

By September 1998, project analysts will have received the manufacturers' responses, and many of the end-users' responses. That data will allow the authors of this paper to present preliminary results at 6ELBC along with an overview of the functionality of the database that will be made available to the public. In addition, the presentation of this paper will include information about ILZRO and Sandia's plans to work together on a follow-on workshop and on subsequent phases of VRLA-reliability research. Participants at 6ELBC will have an opportunity to request inclusion

on the distribution list for the final report of this analysis and the public version of the database. At present, the distribution list includes ILZRO members, participants in the survey, and participants in the follow-on workshop for stakeholders in VRLA reliability.

Acknowledgements

Sandia National Laboratories would like to acknowledge and thank Dr. Christine E. Platt of the U. S. Department of Energy's Office of Utility Technologies for the support and funding of this work. We also gratefully acknowledge all of the contributing organization who participated in this project and contributed to its success. These organizations include the International Lead Zinc Research Organization, and Energetics, Incorporated.

References

[1] Pederson, George A., "An Expert Management System for VRLA Batteries in Remote Telecommunications Centers," *Proceedings of the Sixteenth International Telecommunications Energy Conference*, INTELEC'94, Vancouver, British Columbia, Canada, 1994, pp. 491-496.

[2] Poulin, J, Heron, R. and Mailloux, D., "The Use of Ratiometric Measurements to Determine Battery Status," *Proceedings of the Sixteenth International Telecommunications Energy Conference*, INTELEC'94, Vancouver, British Columbia, Canada, 1994, pp. 497-504.

[3] www.geoworld.com/ResearchTriangle/Thinktank/3729

[4] Feder, David O., "Performance Measurement and Reliability of VRLA Batteries," *Proceedings of the Seventeenth International Telecommunications Energy Conference*, INTELEC'95, the Hague, The Netherlands, 1995, pp. 22-28.