Can 11 Year Old, Naturally Aged, 2 Volt VRLA Cells Endure a Seismic Event without Suffering Capacity Degradation?

Kenneth F. Barry
Senior Project Manager
EPRI Advanced Nuclear Technology Program
Charlotte, NC 28269

Peter J. DeMar
Founder
Battery Research and Testing
Oswego, NY 13126

Abstract

The paper will summarize the results of an EPRI funded project which was undertaken to determine if naturally aged 2 volt VRLA (Valve Regulated Lead Acid) cells of approximately 10 years of age could meet the capacity test requirements as listed in IEEE 535 2006[1], "The IEEE Standard for Qualification of Class 1E Lead Storage Batteries for Nuclear Power Generating Stations". The primary question was, could these batteries at about 10 years of age of be able to pass a seismic event and then still perform as required.

The Fukushima disaster has demonstrated that having the maximum amount of battery reserve time possible in any Class 1E battery room would be prudent for any operating plant. If 2 volt VRLA batteries could be qualified for Class 1E applications it would be possible to increase the coping time in many existing battery rooms by a factor of 2 or 3 or more, which would allow additional time for implementation of FLEX activities.

This project was not an attempt to formally qualify 2 volt VRLA cells for Class 1E applications, but rather just a very first step into an investigation to determine if they could pass this very important requirement so that they might be utilized in this application. There are many more questions to be answered and procedures and documentation to be created or acquired before this can occur, however this project has answered this initial question. It is also important to understand that IEEE 535 only presently applies for VLA cells; however IEEE 323 can be utilized for qualifying most any piece of equipment, which if I understand it correctly, means that it could be used as the qualification document for VRLA cells.

Introduction

As is well understood in the Nuclear Power Generation industry, all Class 1E batteries in the US are VLA (Vented Lead Acid) batteries and they are either Lead Calcium or Lead Antimony of the suspended flat plate design. There are no other qualified types of batteries that can be used in this application at this time. One only needs to look into the IEEE 535 standard to see the list of battery designs that can attempt to qualify for this very critical application. IEEE 535 2006 lists Lead Calcium and Lead Antimony Pasted plates as the only ones referenced. However, the current PAR revision that is being worked on by the IEEE Stationary Battery Committee has added Lead Selenium Low Antimony Plates to the list of designs that can attempt qualification under this document.

Presently, only VLA batteries are listed in that document as acceptable to be qualified for this very important application. With that single fact in effect, there presently is no means for a VRLA battery to attempt to become qualified for a 1E application under that battery related document. However, one could attempt qualification through IEEE 323 and 344. An interesting fact is that 323 clearly states that the use of a naturally aged test sample is an age conditioning method which avoids the need to identify significant aging mechanisms. There are other requirements such as proof of past history of the sample, but the statement is pretty clear that one could use naturally aged cells, that have documented life records, and eliminate the requirements for accelerated aging.

A few years back, there was an interest in using VRLA batteries in the new Passive Plant design Nuclear Plants, but due to push back from many members of the industry, coupled with the understanding that the IEEE 535 only addressed VLA cells the subject dropped off of the active radar screen. However there still has been a continued interest from some in the industry to be able to utilize these cells if they could become qualified.

In 2008 EPRI funded an assessment of VRLA batteries and qualification issues[2]. This report was an investigation that delved into the history and various failure modes that impacted VRLA batteries, as well as changes and developments or mitigation strategies for specific failure modes. It also was a survey of a number of VRLA battery manufacturers and one independent research and testing representative as to their thoughts on the various unique issues with VRLA batteries and on the applicability of the results of accelerated aging mechanisms to the VRLA cells. In addition they were questioned on their individual thoughts on whether VRLA batteries were applicable for use in the 72 hour designed Passive Plants, as well as their thoughts on any issues that might be important to the utilization of VRLA batteries in a Class 1E application.

However, based upon the Fukushima disaster and resultant report[3], it should be well understood that it would be beneficial to any existing Class 1E battery location to have the maximum amount of battery reserve time possible. If there could be an increase in the amount of Amp Hours of reserve in the same space presently allocated for the battery (battery room) this could be beneficial to almost any plant. However many existing Class 1E battery rooms do not have much free space in their existing battery rooms for increased battery capacity based upon using larger sized VLA cells. If VRLA cells could be qualified for this application, and the floor loading was not an issue, it would be possible to double or triple the amount of battery reserve time possible in any existing battery room.

Of course, with any increase in AH of battery (either VLA or VRLA) there comes an increase in the floor loading. Neither floor loading, nor the need for increased short circuit protection was included or applicable for this study. The one and only objective was to determine if naturally aged 2 volt VRLA cells of approximately 10 years of age would be able to pass a capacity test, followed by a seismic test, and then followed by another capacity test. Nothing more, and nothing less.

VRLA Issues History

As we all well understand, bad news travels much faster and further than good news, and people generally remember bad news longer than they do good news, no matter how good the good news is. This certainly applies to VRLA batteries. After all many of us remember that the original marketing point was that they were “maintenance free”, while what was more of the truth was that they were designed so that normally, over their lifetime, they would not require the addition of water. Like many new products they were introduced to the market before they were fully developed and understood. It happens every day, just think about new electronic gizmos that do not fulfill their hype, or that do not work in this or that situation.

With VRLA batteries, the early years were marked with massive disappointment from around the world. The learning curve was much steeper than most manufacturers understood. There were manufacturing issues, material issues, chemistry issues, and on and on. All manufacturers were suffering through very early life capacity loss issues, and thermal runaway was a common event, and then there were cells that would appear to be fine but which opened up under load. There was a clear lack of understanding of all of the issues that were having an effect on these early designs. Of course, it did not help that there was a massive demand for these products due to their ability to provide a substantial amount more Ah in the same footprint as their VLA counterpart and some companies started providing product long before they fully understood the issues, because they did not want to be left behind. Nor did it help the users that the real maintenance requirements were seldom followed, and there was a lack of tools to properly inspect these cells.

All of the issues that could allow these batteries to fail unexpectedly have been identified, and if the users follow the maintenance and testing regime as listed in the IEEE 1188, there cannot be an unexpected failure, as there will always be an advance warning of a negative change.

Seismic Test Requirement

Because this was intended to be for the passive plant design 72 hour capacity test regime, we utilized the requirements of the ESBWR SSE Design Ground Spectra at Foundation Level from the AP1000 documents as the guide. This requirement was what we provided to Amidyne Group - Nuclear Power Services Facility personnel for their input to their shake table.

It is understood that the seismic requirements vary substantially throughout the country and from plant to plant, but what should be easily understood by all is that all US manufactured 2 volt AGM VRLA cells are fully packed. This means that there is no space for the plates to move around inside of the jar. In addition, all of the jars are individually installed in a steel tray and there is no place for the jars to move around in the tray.

Both of the trays tested at the Amidyne Facility passed their seismic test in that neither tray suffered structural damage. The tray from one manufacturer was a 6 cell tray and the tray from the other was a 4 cell tray. A load was being imposed upon the 6 cell tray during the seismic test as required in IEEE 535, but no load was imposed upon the 4 cell tray at that time. With both trays the voltage was monitored during the shake testing and there was no unusual change during the testing. It is reasonable to imagine that if these cells performed as well following the seismic test as they did before the seismic test, that no degradation occurred during the seismic test. However we want to again state that this was not a formal test at qualification, just a use of the procedures called out in IEEE 535 for the process as a guide to what needed to occur in what order.

Step One

The primary goal was to determine if VRLA cells might be utilized with the Passive Plants so the discharge rate to be applied was the published 72 hour discharge rate. For this we located a battery string that was almost ten years old, which had come from a UPS application at a Telecom company, and had been maintained properly and properly taken care of. This battery was at the time of its selection for this project, being used as a temporary battery system during work on other battery strings.

We then unexpectedly found another battery from a different manufacturer that was almost twelve years old. However, this battery had been severely abused, with little or no maintenance, had experienced a thermal runaway, and been removed from service. It then was used as a training tool, to include discharge testing training and for the previous year before being used for this project, had sat off line. Even though this would not have been our first choice, it did provide us with cells from a different manufacturer to use to test at the eight hour published rate.

These are two different manufacturers, with two different discharge rates, and two entirely different histories, but with surprisingly similar results.

Battery One - The 72 Hour Discharge Test Sample

The trays and cells for this part of the project came from a 60 cell battery that is used as a temporary battery at Battery Research and Testing (BR&T) when they need it to provide protection when they have to take a battery out of service. For ease of testing we used the top four trays (6 cells to a tray with this battery) to make a 48 volt battery (because we have lots of 48 volt discharge test equipment and chargers), and used the top tray (6 cells) to take to the seismic test facility, due to it being the easiest one to remove and the cells in it were a good representation of the average of the 24 cells discharge tested.

The battery was first given an equalize charge then was placed on float for a week and then inspected following the steps in the IEEE 1188 document. Following that the battery was capacity tested at its published 72 hour rate to 1.75 VPC. The starting temperature was 78°F. The test was terminated at 74 hours with an end voltage of 45.81 volts. No, we did not continue the test out to 42 volts (1.75 times 24 cells), as it was not our intent to prove absolute capacity but rather just to find out if there would be any degradation to these aged cells following the seismic test. As can be seen the battery performed at well above 100%. The battery was then placed back on float at 2.25 VPC.

The next step with this battery was to take one tray (6 cells) to Amidyne Group – Nuclear Power Services facility in Newmarket, Ontario for seismic testing on their tri-axial test rig. The seismic requirements tested to were to meet the AP1000 ground level (or below) requirements. The battery passed with no problems.

The final step was to perform another capacity test at the same 72 hour rate as the pre seismic test capacity test. The average cell temperature at the start of the test was 68°F. Again the capacity test was terminated at 74 hours with an end voltage of 45.52 volts, and again the end voltage of 42 volts had not yet been reached.

The discharge test rates in both tests were run at the actual published rate, without rate correction based upon the pre test cell temperatures. The results of the tests were temperature corrected at the end following the IEEE 1188 document correction factors for the "Time Adjusted" method of testing.

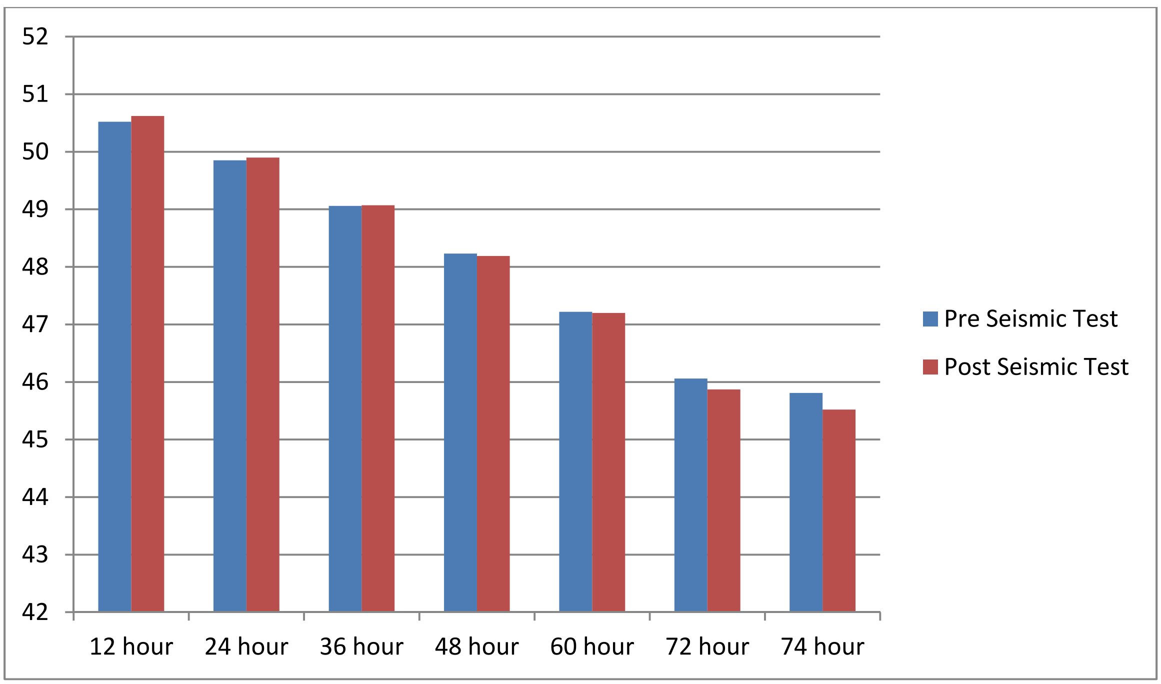

Figure 1 - Seventy two (72) Hour Discharge Test Results

The above chart shows the overall string voltages at various points throughout the capacity tests. The average cell temperature at the start of the pre Seismic test was 78.5°F and at the start of the Post Seismic test was 68.0°F.

Battery Two – The Eight Hour Discharge Test Sample

The trays and cells for this part of the project came from a forgotten battery that was setting in a corner of the shop and had been out of sight and out of mind. This battery had originally been purchased by an educational institution that bought into the "maintenance free" marketing that was originally touted, and put it into a dorm closet to support a telephone system, without climate control, and of course no maintenance. It ended up in a thermal runaway, and was removed from service. BR&T ended up with it and due to its unique layout of being installed in 4 wide trays in a 23" relay rack it was decided that it would make a good training tool as it took up very little space. As a training tool it was used to train technicians in how to perform proper VRLA inspections, and how to hook up and operate different manufacturers discharge test systems, plus how to perform the IOVR and IOVR+ process.

Due to its having sat off charge for over a year it was first inspected to see just what the internal conditions were. That inspection showed some cells that were obviously partially discharged and sulfated so the battery was given a very high rate boost charge. Following that it was then placed on float, re-inspected after some time on float, then capacity tested at its published eight hour rate to 1.75 VPC.

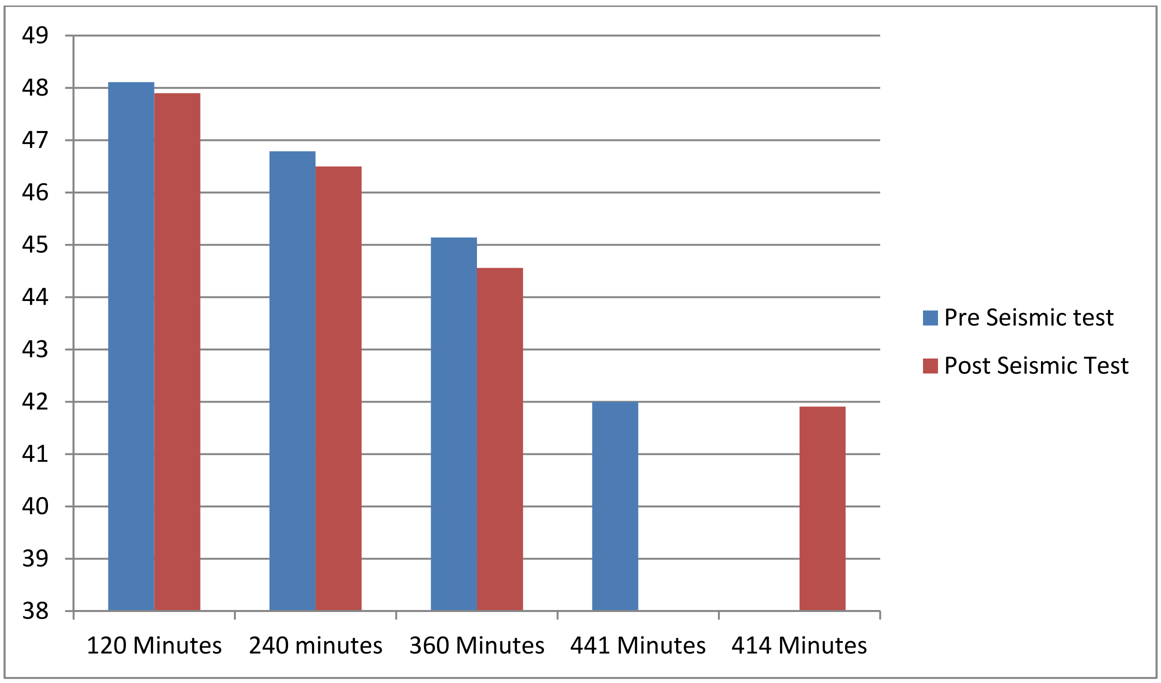

Figure 2 - Eight (8) hour discharge test results

The above chart demonstrates that the overall string voltages tracked each other during both discharge tests. What it does not show is that the average cell temperature was 83°F at the start of the initial discharge test and at the start of the post seismic test was 71°F which accounts for the difference in run time to end voltage.

Again, following the IEEE 1188 temperature correction factors for "Time Adjustment" there was no adjustment to the discharge rate itself based upon the initial temperature, the correction factor used to determine the percent of capacity was applied to the time run, at the end of the test. The calculated capacity was 89.19% for the pre seismic test, and 89.8% for the post seismic test.

An interesting point that should be pointed out with this battery is that cell 24 actually went into reversal during the pre seismic test capacity test but did maintain a positive voltage during the post seismic test capacity test, although at a very low value (0.464) of a volt. This is pointed out due to the fact that it is a common misunderstanding that when a cell reverses polarity during a discharge, that the cell is irreparably damaged. This is not true in all cases. Yes that cell is horribly weak, and may need replacement, but not always.

Summation

This was a very simple and quick investigation to see if there was some unknown inherent issue with VRLA cells that had some reasonable amount of age, which might show up during the pre or post capacity test, or during the seismic test, if someone were to attempt a formal qualification process. The cells that we used were @ 10 years of age from one manufacturer and @ 12 years of age from the other manufacturer. If we could have located older cells, then we would have used them.

Both batteries passed their respective tests with flying colors even though they had lived completely different lives.

That these two different batteries performed as well as they did should make the 2 volt VRLA design cells at least a consideration for a Class 1E application.

It is possible that someone desiring to utilize VRLA cells for a 1E application could follow the requirements of the existing IEEE 323, 344, (and possibly parts of 535) documents and prove that qualification has been met based upon those requirements. If this was to occur then it might be that the IEEE Stationary Battery Committee would then want to create a PAR on IEEE 535 to create a formal document that addressed VRLA cells in addition to the VLA cells, or they may need to create an entirely new document that would be utilized for qualification of VRLA cells. Only time will tell where this concept will end up, or when, but there is a need for a 1E user to have the option to increase the battery reserve time in their applications if they desire to do so, and VRLA batteries if able to be qualified could fill that need.

---

[1] IEEE ANSI/IEEE Standard 535-2006, IEEE Standard for Qualification of Class 1E Lead Storage Batteries for Nuclear Generation Stations.
[2] Valve-Regulated Lead Acid (VRLA) Battery Qualification Assessment. EPRI, Palo Alto, CA: 2009. 1019216
[3] NEI 12-06 Diverse and Flexible Coping Strategies (FLEX) Implementation Guide