

REDUCING THE WATER USAGE IN UPS VENTED LEAD-ACID BATTERIES

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Abstract

While the market share of vented lead-acid (VLA) batteries has declined over the last several years, they are still a significant player in the industry. The safety and reliability of vented lead-acid technology is excellent and proven. Vented lead-acid technology has been proven to be reliable and safe over a long period of time.

One major drawback of VLA batteries is maintenance. Most companies do not have battery expertise nor the workforce to allocate to battery maintenance. While many battery maintenance tasks can be minimized or eliminated through proper product selection, installation, acceptance, and monitoring, watering is still a manual operation. In addition, as opposed to other standby applications, water usage is typically higher in UPS applications.

This paper documents a field experiment utilizing VLA UPS batteries to compare water usage through lowering the float voltage and/or replacing the flame arrestors with recombination vents.

Introduction

Lead-acid batteries have a long history of safety and reliability. The first lead-acid battery was developed in 1860 [1] and has been the dominant battery chemistry in the standby stationary market for over 100 years and still holds a considerable market share. In the last 20 years the Valve-regulated lead-acid (VRLA) has come to dominate the market share over the traditional Vented lead-acid (VLA) due to the perceived reduction in maintenance and the ability to pack more energy into a smaller footprint. However, the VLA is still considered the most reliable lead-acid product and is the only class 1E approved safety battery for nuclear power plants in the US.

Besides footprint, the major drawback to VLA batteries is the requirement to add water on a periodic basis. Many of the other maintenance tasks can be minimized using monitors and/or experienced-based practices. While there may be some unique solutions to automate watering tasks, for most users it requires manual labor. While adding water to batteries generally sounds like a trivial task, it should not be done without understanding the safety aspects of working with a battery on a live system. This includes chemical, arc flash, shock, and thermal hazards. It can also include hazards associated with using ladders to reach cells that are on multi-level racks. Further complicating the use of ladders is using them with PPE that may be required for the other hazards. In addition to the safety hazards, ensuring that the proper water is used is critical to the operation and life of VLA batteries.

Due to efficiency and staff reductions, many users do not have trained staff to work around batteries. This leads to subcontracting and in some cases, there may be multiple levels of subcontracting. To date, there is no nationally recognized body that can certify that an individual or an organization is fully qualified to perform this work and to do it safely with proper PPE. Because this work is often awarded to the lowest bidder, the chances of getting someone who isn't fully qualified is significant. A simple activity like watering can turn into a disaster if the wrong water is used or a person is injured.

Some users have gone to VRLA batteries or other technologies such as lithium-ion simply based on the need to add water periodically, even if reliability and/or safety are degraded.

The reason periodic water additions are required is because water is converted into hydrogen and oxygen during the float charging process. Recombination vents are replacements for the standard flame arrestor vents. A catalyst is embedded in the recombination vents which recombines a high percentage of hydrogen and oxygen back into water vapor, thereby reducing water usage and hydrogen generation. A recombinant vent (left) is shown with a standard flame arrestor (right) is Figure 1.



Figure 1 recombinant vent vs. flame arrestor

The use of catalysts has been studied and used in VRLA batteries for some time [2]. In fact, Thomas Edison [3] was granted a patent in 1912 for recombining hydrogen and oxygen, see Figure 2. Catalysts installed in VRLA batteries have been used for more than 20 years to reduce water loss, among other things. Since VRLA batteries are not designed for water additions, a method to reduce water loss is essential.

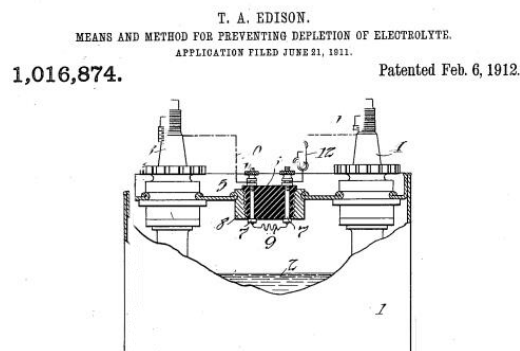


Figure 2 Edison Patent of 1912

There has also been some usage of catalysts in VLA batteries, but this has been mostly outside the US.

Higher water usage is also a result of floating lead-acid batteries at a higher voltage. VLA batteries used in UPS applications are typically 1.250 gravity and they are typically floated at 2.25 volts (average) per cell. This voltage is about 150 millivolts over open circuit and is on the high end of a typical manufacturer’s recommendation. Higher voltages will typically cause higher float currents. A higher current will generate more hydrogen (and subsequent water loss) through electrolysis and the higher polarization on the negative plate will also generate higher amounts of hydrogen. In addition, higher polarizations on the positive plate will cause increased corrosion and plate growth which will shorten the life of the battery.

This research and paper will investigate and report on the relative usage of water through the use of recombiner vents and/or lowering the float voltage.

Experiment set-up

Four in-service 240 cell VLA UPS strings are being utilized for this study. These strings are the same make/model, have been manufactured in the same general time frame, installed in the same time frame and have all been initialized and acceptance tested in accordance with IEEE recommended practices and the manufacturer’s recommendation.

These batteries are UPS type vented cells and were manufactured in October 2020 and June 2021. All strings were performance tested as part of the commissioning process.

These batteries have a nominal specific gravity of 1.250 and have been floating at 2.25 V/cell (540V overall). The Installation and Operation manual for these cells allows voltages from 2.21 to 2.30 for 1.250 sp.gr. cells.

One string is used as the control String A1). Recombiners have not been installed on this control string and the voltage remained at 2.25 volts per cell. Two strings have recombiners installed on every cell, with one of these strings having a reduction in float voltage. The remaining string has a reduced float voltage with no recombiners. See Table 1 for a summary of the configurations.

Table 1 String Summary

String Designation	Average voltage per cell	Recombinant Caps installed?
A1	2.25	No
A2	2.25	Yes
B1	2.22	No
B2	2.22	Yes

Prior to all the strings being watered to the high line, data was obtained from every cell/string (voltage, current, reference electrode, etc.). The site is visited monthly to inspect and obtain select measurements. Additional measurements will be taken on a semi-annual basis, and a full capacity test will take place after one year.

This is an on-going study, and this paper is a snapshot of the results at a point in time. Further updates will be presented in another paper.

Test and Measurements procedures

Float voltage:

The cell and overall voltage are measured with a calibrated Fluke 289.

Float current:

String float current is challenging because the currents are relatively low, but the interconnecting cables and connectors are very large. Therefore, a larger clamp is needed which corresponds to lower resolutions at current values below one amp, which are typical for float currents. Additionally, with most UPS systems, there is a significant amount of noise on the bus.

To get an accurate float current reading, a Hioki CT6846-05 AC/DC Clamp is used which is then connected to a Hioki CT9557 Sensor Unit. The measurements are recorded from a Fluke 289 DMM attached to the output of the sensor unit. The clamp is demagnetized and zeroed within $\pm 0.010\text{mV}$ prior to being locked into place for each reading. The clamp is locked around the inter-cell straps connecting cell #1 to cell #2 for the positive reading and cell# 239 to cell #240 for the negative reading. The current is measured for 15 seconds using the DMM's Min/Max mode and the minimum, average and maximum are recorded.

Plate polarizations:

The procedure for determining the positive and negative polarizations [4] is to immerse a reference electrode in the electrolyte. The voltage is then measured between the reference electrode and the positive post. A second measurement is taken between the reference electrode and the negative post.

The raw reference electrode readings are not meaningful by themselves. These readings are relative voltages dependent on the material of the electrode. However, open circuit voltages of the positive and negative plates relative to the reference electrode can be calculated given the specific gravity and the temperature of the cell. The individual plate polarizations can then be calculated by taking the difference between the measured reading and the calculated open circuit value.

Mercury-mercurous sulfate reference electrodes were used and the equations are documented in [4].

Water usage determination.

At the start of the experiment, all cells were filled to the top line. A measurement guide (with mm marks) was placed on 25 cells per string and is shown in figures 3 and 4.

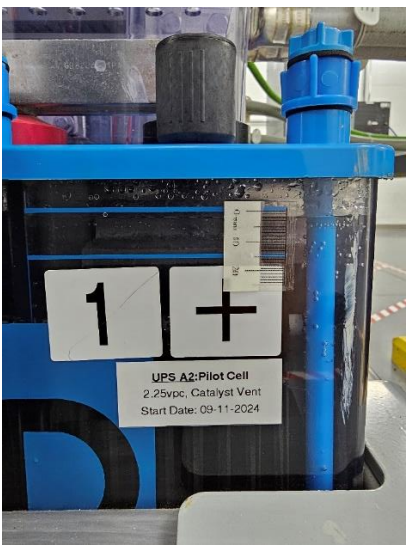


Figure 3 Measurement guide for electrolyte levels

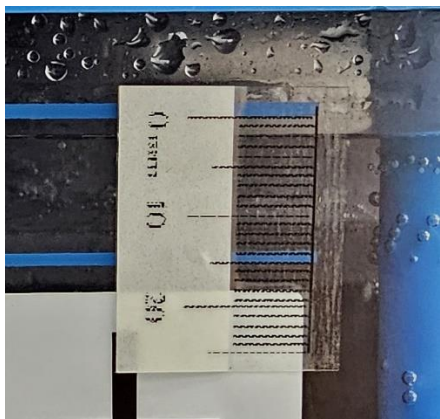


Figure 4 Measurement guide close-up

Performance testing

All performance testing was and will be performed in accordance with IEEE 450[5]. Calculations were made in accordance with the rate adjusted method.

Issues and potential issues

The project was initiated in September 2024. Recombiners were installed on 480 cells (2 strings of 240 cells). A few days later the site's operations personnel discovered electrolyte on the tops of the cells. This was a major concern and resulted in the team reconvening on site to determine the issue.

The project was almost halted due to the electrolyte overflow on a critical site. Immediate steps were taken to clean up the electrolyte and determine the cause.

The recombiner vents have a pressure vent that opens at 0.07 psi. While this is a small amount of back pressure, the relationship between pressure and height of water is 27.708 inches per psi. To convert this from water to electrolyte, you need to divide by the specific gravity. The result is about 1.6 inches of electrolyte rise in the sampling tube. Given that all cells were filled to the high line, this was enough to push the level of electrolyte to the top of the sampling tubes. Although there were caps at the top of the sampling tubes, they did not contain the rising electrolyte. Part of the problem may have been that the caps were not torqued to the specification. There was also evidence that the threading for the caps was sub-optimal; burs were noted on some of the cap threading. Those would prevent the caps from making a perfect seal, despite the rubber O-ring. Whatever the case may be, the result was electrolyte escaping the cell.

It was decided by the team that the sampling tubes would be removed and when the caps were replaced, they were torqued to the manufacturer's specification. These actions solved the problem, but the initial issue caused a lot of work between cleaning and neutralizing the electrolyte overflow and pulling the sampling tubes from 480 cells. Picture of the sample tubes before and after removal are shown in Figures 5 and 6.

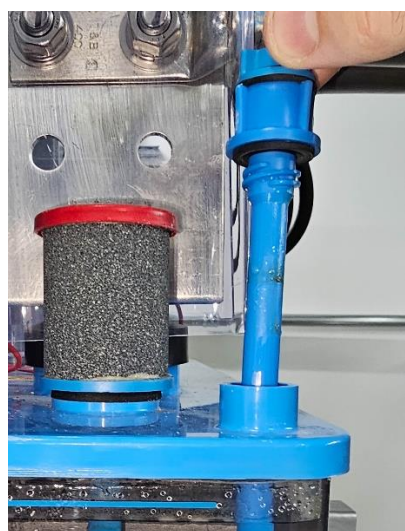


Figure 5 Sample Tube



Figure 6 Sample Tube Removed

Our organization has over 30 years of experience measuring specific gravities and we can find no technical reason that sampling tubes are needed. We realize that some organizations may utilize them in their maintenance practices, but it should be discontinued because there is little or no value in their use. Removal of the sampling tubes will allow all VLA battery manufacturers to remove the tubes completely which would eliminate another source of leaks and probably save the manufacturer and users some money. Sampling tubes are uncommon in Europe.

There are recombination caps that have no pressure vent and therefore provide no backpressure. These were not tested as part of this project but if the performance is like what is reported herein, they would be preferable given the potential to cause electrolyte overflow as discussed above. Published data comparing recombinant vents with a pressure vent vs. without a pressure vent was sought but not found in the process of compiling this paper.

There are other potential issues associated with the recombinant vents. One is the service life. While there is no indication that the recombinant vents will not last the life of the cells, the recombinant vent model used for this project is relatively new and there is no simple way to determine life without experiencing it. It has been reported [6] that there are instances of recombinant vents being in service for 20 years or more.

Reliability of recombinant vents is also not known. As with service life, for any particular model, time will tell. No issues have been found to date

In both service life and reliability, there are several failure modes to consider. A failure of a recombinant vent to recombine gases would be the most basic failure mode. While this failure mode could be the result of poor design, it could also be due to a handling or installation issue.

Another possible failure could be if the recombinant vent would not allow any gas to vent, which would cause a pressure buildup in the cells. The design of the recombinant vent used in this experiment opens at 0.07 psi and it seems unlikely that this valve would stick close and cause enough back pressure to damage the cell. The user should understand the design of the particular recombinant vent being utilized to ensure that this is not a possible failure mode.

Catalysts from VRLA cells have been poisoned [7] from hydrogen sulfide. While this issue has been solved in VRLA cells, it remains to be seen if it is an issue with VLA recombinant vents.

If the catalyst material would somehow drop into a cell, this could cause the cell to fail. While this may be unlikely, physical damage from handling or installation could cause this to occur.

The recombination of hydrogen and oxygen into water vapor is an exothermic reaction and heating does occur. Under normal conditions, the heating is not a concern as shown in figure 7. Under abnormal conditions, excessive heating can occur [8] and has shown to cause irreversible damage to in some models.



Figure 7 Nominal heating under normal conditions

Good design and testing practices should help eliminate these potential failure mechanisms but it is important for users to understand and manage the risks associated with these devices. Careful product selection is key.

Initial installation of the UPS system and battery acceptance (performance) testing

The UPS system was installed and tested in 2021. The batteries were initialized in strict compliance with the manufacturer's instructions. The battery acceptance tests were performed a few months later in accordance with IEEE 450[5]. The battery was subjected to the constant power load at approximately the 30-minute manufacturers rate to 1.67 volts per cell (Vpc). The test ended when the UPS shut down trip point was reached which was approximately 1.67 Vpc average. The capacity was determined using the rate-adjusted method to 1.75 Vpc. The capacities of the four strings are shown below in table 2.

Table 2 Battery Performance Data

String	Tested capacity	Temperature corrected
A1	101%	106%
A2	104%	106%
B1	102%	104%
B2	103%	104%

In addition to the overall battery performance, the capacity of every cell was also calculated. There are no cells with a capacity of less than 100%.

Individual cell voltages, specific gravity, intercell connection resistance and cell temperatures were also measured and recorded with no anomalies noted.

Results to date

The project is ongoing, and the final results will likely be reported in a future paper.

The main objective of this project was to limit the water loss of a vented lead-acid UPS battery. Figure 8 is a summary of the water usage over the first nine months of the project. The water loss is recorded for every 10th cell and then averaged to obtain the string average as shown in Figure 8.

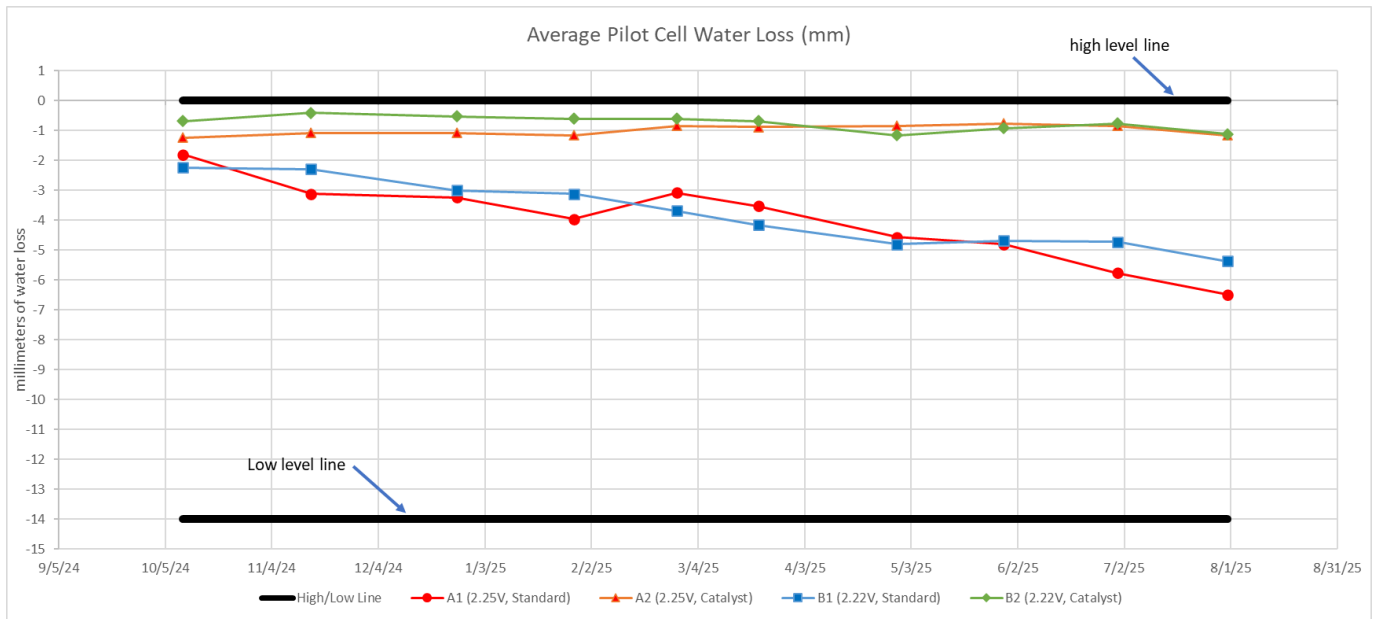


Figure 8 Average Pilot Cell Water Loss (mm)

While Figure 8 only shows the designated pilot cells for every string, the other cells in the string are routinely checked for any significant deviations from the pilot cells, and none have been found to date.

The data clearly show that little or no water loss has occurred in strings where the recombiners are used. There was an initial drop of about 1 mm but that was most likely a combination of some settling and loss from the initial overflow and removal of the sampling tubes. It is difficult to extrapolate the time until water replenishment is needed (at about -15 mm), the data seems to indicate that 1 mm water loss per year would not be an unreasonable assumption. This rate of loss may increase as the cell ages and float current increases. However, a ten-year-or-longer interval might be possible given the results to date.

On the other hand, lowering the voltage to 2.22 volts per cell average has no effect on the water loss. Water loss correlates with the use of the recombiners and is not dependent on the float voltage.

A secondary objective was to determine if a lower float voltage was beneficial to the life of the cell. While it is difficult to determine the increase in life of a cell after nine months, plate polarizations can be measured and compared to the research and an estimate of increased life can be made.

Research[9, 10] has shown that amount of positive plate polarization can significantly affect battery life. The amount of negative plate polarizations does not affect life so as long as they are not depolarized. A low or high positive plate polarization can reduce life significantly, see figure 9. The total polarization of the cell is the voltage applied above the open circuit voltage. For 1.250 specific gravity cells, the open circuit voltage is approximately 2.10 volts and therefore the total polarization is 150 millivolts for cells charged at 2.25 volts and 120 millivolts for cell charged at 2.22 volts. The total cell polarization is divided between the positive and the negative plates.

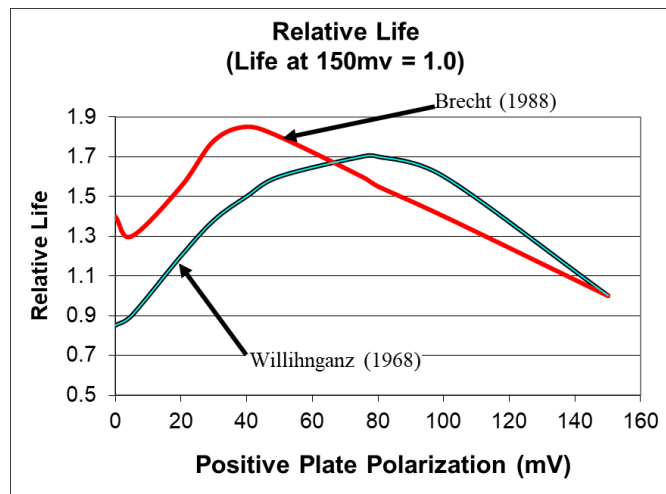


Figure 9 Relative life vs Positive Plate Polarization[9]

The plate polarizations were measured and calculated at the six-month inspection. A summary of the data is shown in Table 3.

Table 3 Differences in Plate Polarizations

String Designation	Float voltage	Pos polarization (avg mV)	Neg polarization (avg mV)
A1	2.25	122	36
A2 (catalyst)	2.25	118	35
B1	2.22	127	-2
B2 (catalyst)	2.22	124	3

This data indicates that the differences between 2.25 and 2.22 (30 millivolts) are distributed mostly to the negative plate. The positive plate polarization is mostly unaffected which would indicate that there would be no difference in service life.

However, this data seems to be inconsistent with what would be expected for a reduced float voltage. There were some questions as to whether there was an issue with the probe or the calculations. To this end, additional reference electrode testing was performed at the battery manufacturer's laboratory with different probes under controlled conditions and the results are shown in Table 4.

Table 4 Lab plate polarizations

Probe type	Float voltage	Pos polarization (avg mV)	Neg polarization (avg mV)
1.210 probe	2.25	127.24	17.64
1.250 probe (TPI)	2.25	134.04	10.44
1.210 probe	2.22	99.24	16.64
1.250 probe (TPI)	2.22	106.04	11.44

String float current is also important to the discussion of plate polarizations. As was mentioned earlier in this paper, measuring float current on these batteries is challenging between the large amount of noise and the large conductors. Figure 10 is the measured string float current over time. While there are some variabilities with the data, the string current for 2.22 strings (B1, B2) were about 64 millivolts lower than the 2.25 strings (A1, A2) on average. Assuming the Tafel curve for the positive plates has a constant slope, one would expect that the positive plate polarizations would be decreasing at the lower float voltage, consistent with the lab data.

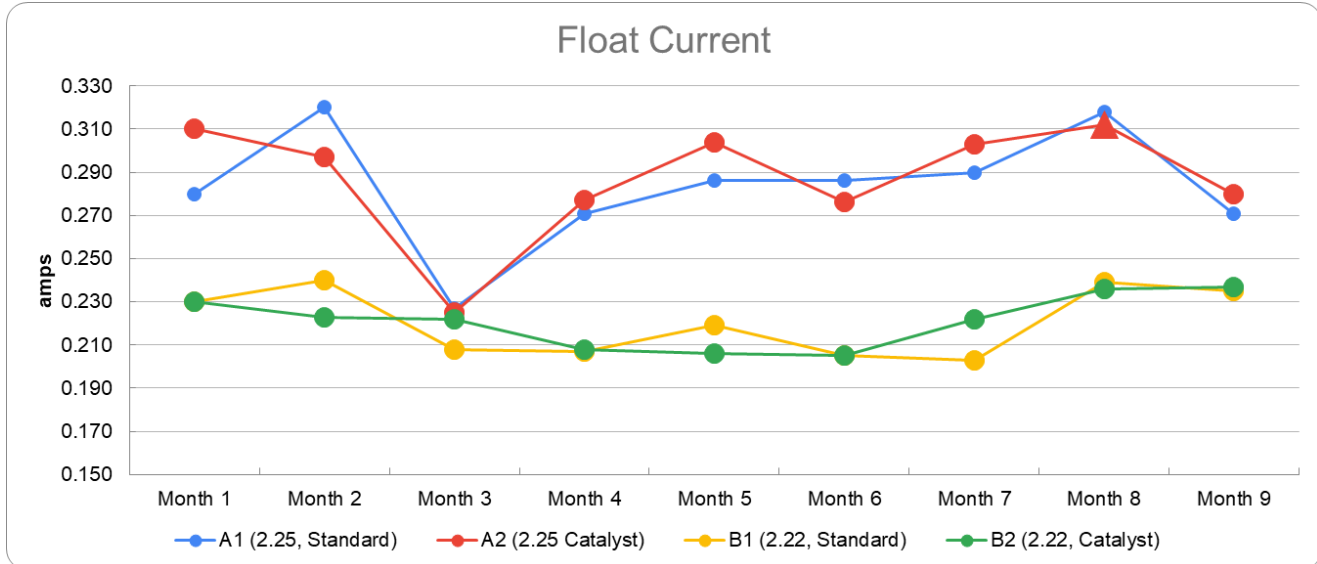


Figure 10 String Float Current

The data from the lab suggests that the lower positive polarization will increase the life up to 30%. More investigation needs to be done in this area to make a definitive conclusion.

Summary

Four in-service 240 cell UPS VLA batteries were utilized to evaluate recombination vents and the effect of reduced float voltages. At the point of publication of this paper, the data is encouraging on the recombination vents. While it is too early to extrapolate the data, it seems possible that the interval between watering may be 10 years or longer. It is also possible that the battery may never need watering again before it is replaced at the end of life.

Recombination vents have the potential to make VLA batteries essentially maintenance free (visual inspections are still needed). This not only will save significant manpower, but it could also eliminate any potential cell issues due to contaminants in the water. Risks to personnel, such as exposure to electrolyte, are also reduced or eliminated.

A reduction in hydrogen evolution is an added benefit. This was not evaluated as part of this study. Users will still have to consider an overcharge situation where the recombination vents would be less efficient, but a proper analysis could determine that reduced ventilation may be in order.

The rate of water loss is not affected by the reduction of float voltages from 2.25 vpc to 2.22 vpc. However, it is possible that the life of the cells can be extended by the lower float voltage. More time and analysis are needed to reach a conclusion and will be reported in a future paper.

Other than the initial problem with electrolyte leaking through the sampling tubes, no other detrimental effects of the recombinant vents have been found at this point in the project.

Users should be cautioned that recombinant vents are not all created equal and potential problems do exist. Due diligence is required in a vendor/product selection process and the battery manufacturer should be consulted as well.

Finally, the battery community should come together and agree that sampling tubes are not needed, and the battery manufacturers should be encouraged to remove sampling tubes from their design.

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