

REPORT ON THE LONG TERM RESULTS OF BATTERY CAPACITY RECOVERY PROCESSES FOR VRLA CELLS

Peter J. DeMar
Founder
Battery Research and Testing, Inc.

ABSTRACT

It is well understood that premature capacity loss can be recovered through the replacement of the lost water, coupled with the installation of a catalyst. What is not so well understood is the durability of the recovery, nor the importance of the exact procedure itself to the end results.

This paper will track the testing lives of three VRLA battery systems. The strings range from 900 AH to 4,800Ah at their eight hour rate. Two were manufactured in 1993, and one in 1998. Two systems are from telecom sites and one is from a power generation application. All systems were and are in semi temperature controlled applications. One string has maintained its recovered capacity for seven years, and the second string has maintained its recovered capacity for five years. The third system, a 72 cell 4,800Ah string, we divided into three 1,600Ah strings six months ago specifically for this demonstration, so that you can see the differing amounts of recovery gained with the different steps in the IOVR and the IOVR+ recovery process, on the individual strings which came out of a single string.

Shown will be the conditions of each string, the time and testing associated with the initial development of our process, all subsequent testing and the results of that testing. All load tests were run at each string's published discharge rate.

The report will show it is possible to reliably recover and utilize VRLA 2 volt cells that are found to have substantially less than 80% of their published ratings, and for these batteries to maintain these recovered capacities until at least 14 years of age. It also will demonstrate that the IEEE 1188 is in error in Section 8. "Battery Replacement Criteria," when it recommends battery replacement when a battery performs at 80% of its rating, without first recommending any attempts at recovery before replacement.

The only reason we say 14 years of age is that this is the present age of two of these battery strings. We have no doubt that next year we will be able to say 15 years.

This paper is being presented for the sole purpose of educating users of these batteries as to just how they can recover capacity that has been lost prematurely from their 20 year design, 2 volt VRLA battery systems, and what they should expect to see in the way of recovery when the recovery process is properly performed.

INTRODUCTION

As everyone in attendance probably understands, the first of the large 2 volt VRLA cells was introduced to users in the USA by GNB in 1982 with their Absolyte I model cell, which, over the years, has transformed into the Absolyte IIP cells that are still being produced today. Also, over the years, all of the other major manufacturers brought into the market their own specific models of 2 volt VRLA cells. This paper will only deal with the 2 volt AGM VRLA cells that are typically installed in steel trays and mounted horizontally, although the recovery process is pretty much the same if they are mounted vertically. This process will make improvements to any manufacturer's structurally sound product suffering from dryout, underpolarized negatives, and/or sulfated plates. Yes, even gel cells, but with some modifications to the process.

As everyone also understands, the hype of the marketing people so far has pretty much outweighed the actual usable life of these products. Numerous papers have been presented throughout the years by many well respected authors at this and other conferences, such as INTELEC and INFOBATT, that documented the early failure of many tens of thousands of cells from throughout the world. (1)(2)

Among the causes of the failures at that time were any one or more of the following reasons, plus more not understood at that time.

- Leaking covers, or post seals, or jar or cover cracks or failures.
- Sudden failure under load, especially with high rate loads due to internal bus failures.
- Early capacity losses over all ranges.
- Thermal runaway issues.

Of course, there were many early learning curves as the technology was being developed and implemented, just as there is and will be with any new battery technologies being introduced. (For example, the unexpected fires and/or explosions caused by some installed Lithium-Metal-Polymer batteries recently (3)). But, even after all of the manufacturing and design bugs were worked out with the VRLA cells, which pretty much eliminated structural issues, there still today continues to be massive early capacity failure rates in these 20 year design cells. These failures sometimes occur/occurred as early as 3 – 7 years into their expected 20 year life. What was and still today is causing these?

HISTORY OF CAPACITY RECOVERY ATTEMPTS WITH 2 VOLT VRLA CELLS

In the mid 1990s, there was a capacity recovery process where GNB, and BR&T (Battery Research and Testing Inc) were adding water to the Absolyte cells in an attempt to improve the ohmic values and to recover capacity. GNB's procedure was to add a specific amount of water to each cell in the string based upon the model of the cell, and BR&T's procedure was to add varying amounts of water to each cell in the string based upon the ohmic values of the individual cells. Both of these processes almost immediately improved the performance and capacity of the strings.

There was much lively discussion at that time about whether this improvement after water addition was the result of lack of compression between the plates (GNB's position) (4) or dryout of the mats (5) (BR&T's position). Time appears to have shown it was a combination of both, plus some other very important factors that were either not discovered or not understood at that time. Sadly, the tremendous improvements that were gained so quickly with just the addition of the water were of a fleeting benefit, and, within a year or two, the ohmic values would again start to deteriorate, and capacity again would degrade (5). A very important part to the solution of this issue was still unknown.

Prior to and subsequent to that time, there had and has been much research into the causes of the VRLA early life failure modes and development of processes that could assist with the prevention of these early failures and also to extend their useful lives to near or actually to their "design life" of 20 years. One of these was the installation of a catalyst into the head space of the cells, which has shown to help prevent the early demise of these cells when they are installed in new cells, and, when installed in aged cells, they help to restore proper polarization and charging to the negative plates (6)(7)(8)(9)(10).

The information in these papers (and others on the subject) re-invigorated us to further pursue our experiments with the addition of water, but now we included the installation of a catalyst in the head space. We saw much better results than we did with our previous process of just water additions, which led us to the discovery (creation) of the process of coupling the water and catalyst together. This process has been reported on in a number of previous conferences and meetings and has been mimicked or copied by at least three of the major manufacturers and performed on users' batteries by them and others with positive results (12)(13)(14)(15)(16). We eventually named the process the IOVR process (Internal Ohmic Value Recovery), as that is what you first see after performance of the process. The cell's ohmic values improve, which reduces the risk of thermal runaway and improves the capacity or capability. What we missed during all of the excitement with the improvements was the need for a *proper* high rate charge to completely recover all the usable capacity from the plates, even though in some of the papers that got our inquisitive juices going again, the need for high rate charging had been mentioned (9) (11). Sometimes you just cannot see the forest for the trees.

All battery manufacturers' maintenance requirements and other data are based upon the battery being at 25°C, with a very important reason being the required float voltage of the specific model cell. Of course, performance and life are directly affected by variations from this value. Each recommends a specific float voltage for their specific cell models that is based upon a number of factors, with a prime factor being the density of the acid. If they decide to produce another model battery from the same cell but with a lower acid density, they recommend a lower float voltage. The float voltage that is recommended is always so that the value will allow the proper overpotential to be applied to the plates to maintain them in a properly charged state.

With that being said, it is easy to understand that, if a cell off gasses enough that the acid density has risen to some value substantially above its nameplate value and the charging voltage remains the same, then the cell will be undercharged. It is also relatively easy to understand that, if a battery spends its life at an ambient temperature that is enough below the recommended 25°C, and the float voltage is not increased to compensate for this lower temperature (as all manufacturer's recommend), that the plates can be undercharged (17). Add to this scenario that the battery experiences a few power outages that partially discharge it. Couple these discharges with the lower temperature and the improper float voltage for the temperature, and you will end up with plates that do not become recharged and thus become sulfated. Every manufacturer recommends in their installation manuals that a newly installed battery receive a freshen charge, and some even recommend annual equalize charges, with one manufacturer even stating float voltage may not provide sufficient plate polarization to reconvert lead sulfate. They all address sulfation needing special charging. So much for the belief these batteries do not need nor can they benefit from high rate charging. Thankfully, one manufacturer, in their newest installation and maintenance manual, recommends annual equalization charging.

Add into this scenario the well documented fact that the normal electrochemistry occurring inside these cells leads to under-polarized negatives off gassing (dry-out), and overcharging of the positive plates, and it is no wonder these batteries are failing long before their designed end of life, based upon the normal perceived and accepted failure mode of grid corrosion.

WHAT HAVE WE LEARNED SO FAR?

1. Replacement of the water *only* is a short term "band-aid" without other actions being taken and does not recover all available capacity, nor is it a long term solution.
2. The installation of a catalyst *only* in an aged or dried out cell will only recover a certain amount of the lost capacity, even though it will assist in restoring proper potentials to the negative plates.
3. A high rate charge *only* will recover some amount of the lost capacity, and will provide a short term fix for the negative plate potentials, but, without first replacing the lost water, is also a partial fix and does not address the long term problem.
4. *Only* by replacing the water that has been lost, then high rate charging the cells, then adding a catalyst to the head space are we capable of regaining as much of the usable capacity as possible.
5. That the capacity recovered is *sustainable* and not short lived, due to the fact that the cells have been returned to as near as possible to their original designed state, with some improvements.

WHEN IS IT THE RIGHT TIME TO REPLACE THESE BATTERIES?

If you follow the present version of the IEEE 1188 Standard, you will replace the battery as soon as it fails to make 80% of its published rating, which, you will see, appears to be premature with many of these batteries. At this time, the IEEE 1188 states the following, which, as you will see with the batteries in this paper, is throwing away perfectly good batteries.

Battery Replacement Criteria

The recommended practice is to replace a cell/unit or the battery if its capacity, as determined in clause 7.3, is below 80 percent of the manufacturer's rating. The timing of the replacement is a function of the sizing criteria utilized and the capacity margin available, as compared to the load requirements. A capacity of 80 percent shows that the cell/unit/battery rate of deterioration is increasing even if there is ample capacity to meet the load requirements of the dc system. Other factors, such as unsatisfactory service test results (see clause 7.5), or the addition of new load requirements, may require battery replacement. Physical characteristics, such as abnormally high cell/unit temperatures (Annex B), are often determinants for complete battery or individual cell/unit replacements. Reversal of a cell, as described in clause 7.4 (d), is also a good indicator for further investigation into the need for individual cell/unit replacement. Replacement cell/units, if used, should have electrical characteristics compatible with existing cell/units and should be tested prior to installation. Individual replacement cells or units are not usually recommended as the battery nears its end of life.

The story of three battery systems

1. One 24 cell 900Ah string.
Temperature controlled telecom application
Communications quality rectifiers
Birth date 1993
2. One 60 cell 1,400Ah string
Temperature controlled generation control application
Industrial grade battery charger
Birth date 1993
3. Three 24 cell 1,600Ah strings (originally one 4,800 AH string)
Temperature controlled telecom application
Communications quality rectifiers
Birth date 1998

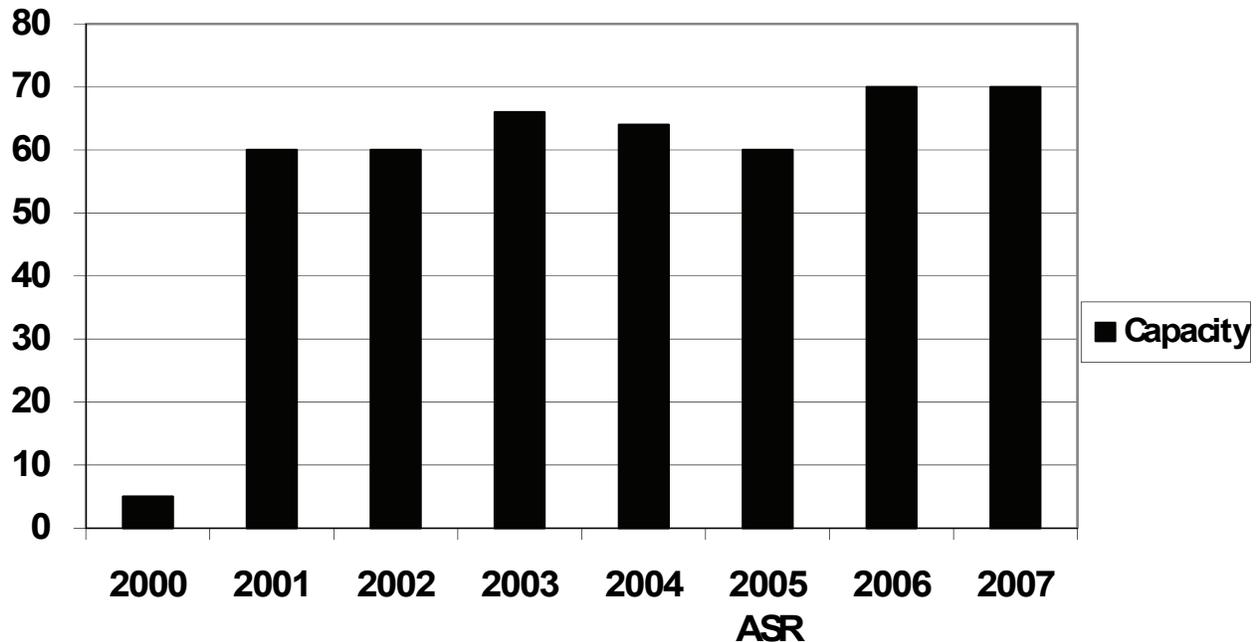
LOAD TESTS AND AS FOUND CAPACITIES

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In October 2000, the first load test was run at the published three hour rate and the battery lasted nine minutes, which equates to 5% of its rating. This was followed by water and catalyst additions, which demonstrated an immediate improvement in the ohmic values. The following load test showed a capacity of 60% (108 minutes). This capacity, although not at 80% (as the IEEE 1188 recommends for time of replacement), was enough to support the site load for over 8 hours, which is what was needed for this customer. As you can see, the following annual load tests show the capacity remained pretty much the same, with no degradation for the next five years. Following the fifth year load test, the customer allowed Andersons Electronics (the company in Canada we have trained in how to perform our process) to add more water to each cell. In the initial stages of this project, the customer required there be only one initial water addition and no fine tuning as time went on. Throughout the development of this process, we have learned each new answer led to yet another question, and we learned the water volumes we thought correct during the initial phase of this research were, in fact, a moving target and difficult to precisely determine.

After this second watering of the cells, the following load test showed an increase in capacity from 60% to 70%, with no other actions taken. In 2006, there was one single drop of electrolyte from around one of the post seals. For this large telecom customer, this is a cause for replacement, even though the battery still had adequate capability to support the loads for over 8 hours (actually 9.8 hours), and, in fact, during the regional blackout of 2003, it supported the site for over 5 hours until a generator was brought to the site. Andersons Electronics took possession of this battery upon its removal from the site and moved it to their shop facility in London, Ontario and placed it on float at 54.0 volts, and continued the test program.

In 2007, it was again load tested and again made 70%, which seems to further contradict the generally accepted belief that, when a battery is less than 80%, it will accelerate in capacity loss, as these cells had been well under 80% for seven years and have stayed right where they were initially recovered to without any further decline. End of life or loss of capacity definitely was not caused by grid corrosion with this battery.

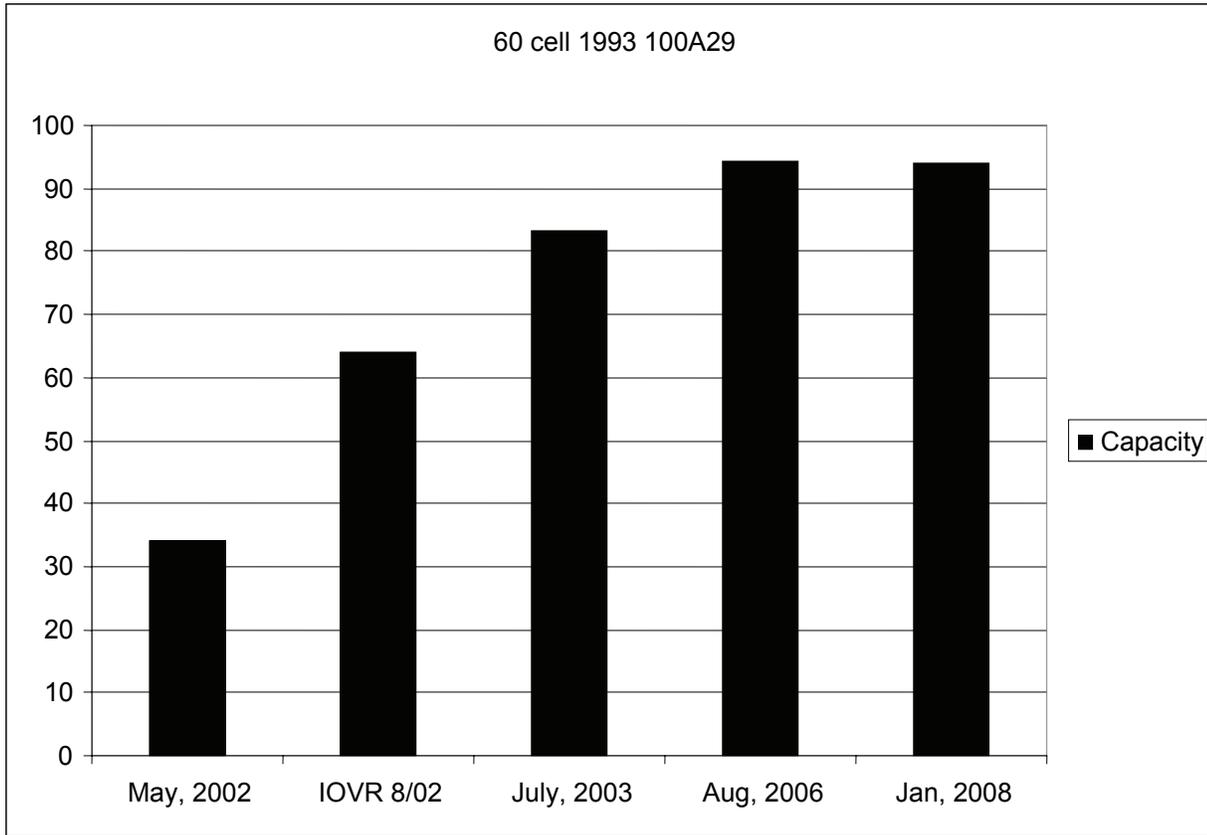


The following 60 cell 1993 100A29 battery was originally part of a 120 cell 100A87 string. It was replaced under warranty with three 120 cell 100A29 strings. We took possession of this battery in May of 2002 and, after configuring it into a number of 60 cell 100A29 strings, performed the initial load test, which produced 34.3% of its rated capacity. Following the performance of our initially developed recovery process, the battery was again load tested and produced 64.1% of its rated capacity. This battery was used in a variety of ways, such as training for performing our process, and in training in the running of load tests, with and without monitoring equipment functioning properly. There is no accurate number to how many load tests there were performed on this battery, nor at the actual rates run, as the training was to familiarize the trainees with a variety of issues involved in load testing, both at short rates (15 minute) and longer ones (up to 8 hours).

In July 2003, in order to prove this battery would support the steady state site loads at a particular nuclear plant during a planned outage, we ran another load test, but with more precision and monitoring and observers than had been during the training load tests. The battery satisfied the requirements of the customer and made 84% of its rating. This discharge test was followed by a high rate recharge. This high rate recharge was in order to restore the battery to a fully charged state as quickly as possible.

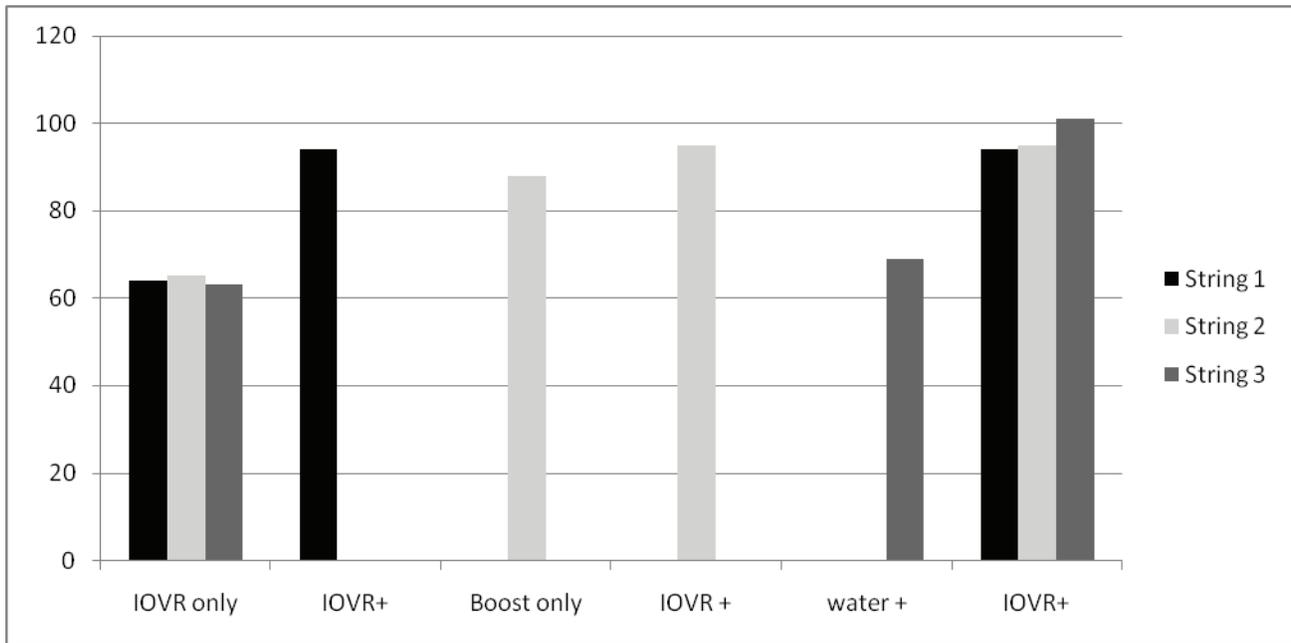
In August 2006, prior to another rental contract at a power plant, we ran yet another closely watched capacity test and the battery now made 94.2%.

In January 2008 we again ran a closely observed load test specifically for this paper and the battery made 93.9%.



And, last but not least, are the reports on a 48 volt 100A99 battery, 1998 birth date that was re-assembled into three 24 cell 100A33 strings. We made three strings out of this one battery, so we could observe the results of each of the separate steps that go into the IOVR+ process. You will see that, following the initial IOVR process, the tested capacities were between 64 and 66 percent for each string.

We then added more water only to string 3, performed a boost charge only on string 2, and performed the complete IOVR+ process on String 1. String 1 recovered to 94% of its rating, String 2 to 88%, and string 3 improved from 66% to 69%. We then performed the additional steps of the IOVR+ process on string 2, and the subsequent load test resulted in 95% of its rating. We then went back to String 3, performed the IOVR+ process and the following capacity test resulted at 100.6% of its rating. We do think that possibly the extra amount of recovery in string 3 is due to the multiple discharge cycles, but that is a question for future research.



NUMBER OF RECOVERED CELLS.

To date, this general process, in its various phases by various companies, including the respective manufacturers, has been performed on over 80,000 cells, with improvements in capacity or run time in all structurally sound cells. Pretty much all of these cells most likely did not have a high rate charge performed, so there is a good potential that there is a substantial amount of capacity still to be recovered from these cells, that can still be recovered if the proper additional steps are performed.

CONCLUSION

Dryout, negative plate underpolarization, and sulfation are the primary present day causes of early failure in 2 volt VRLA cells, not grid corrosion as one would expect. Of course, there are cells that have manufacturing or structural defects, that neither this process nor any other process can recover capacity or capability that was never there, nor able to be utilized. There is no fix for structurally defective cells.

These conditions can all be corrected in structurally sound 2 volt cells through a proper restoration of the water that has been lost, returning the correct over potential to the negative plates, and recovery of the plates to a usable condition through removal of sulfation and correct boost charging, and then adding a catalyst equipped vent assembly into the head space to help maintain the recovery achieved in the cells.

We realize our originally developed process, even though it recovered a substantial amount of capacity or capability, in many cases, left some usable capacity unrecovered because we did not remove all of the sulfates and did not properly recharge the plates. We believe our present version of the process does recover all available usable capacity.

Our tracking of these strings and others on which the IOVR and IOVR+ processes have been performed will continue, and we will report on these results at future conferences.

At this time, it appears there needs to be a change made to the IEEE 1188 standard as it relates to the recommendation as to when to replace a battery. As it is presently worded, this standard is recommending replacement of the battery if it fails its load test, when in most cases all that really needs to happen is for it to be recovered properly to realize its real potential life. As we have shown here, it appears that they neither accelerate their decline when less than 80%, nor are they not recoverable in most cases. We believe the wording in the standard needs to be revised to recommend that, before replacing the battery system, the user first attempt to recover the lost capacity with this process if it has not previously been properly performed. If the process has been properly performed and the battery performs at 80% or less, then it is end of life based upon grid corrosion and it should be replaced. If recovery has not been attempted and it is less than 80%, then most likely you are throwing away a good battery.

I want to offer a special thanks to Robert Anderson of Anderson Electronics for his assistance with testing and documentation for this paper.

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