

Recovering Lost Capacity in 2 Volt VRLA Cells by way of the IOVR™ Rejuvenation Process and the Duration of that Recovered Capacity

Peter J. DeMar
Battery Research and Testing, Inc.
1313 Co. Rt. 1, Oswego, NY 13126 USA
pjd@batteryresearch.com

Abstract - This paper will trace the previous 13 year history of the varying attempts to perform field recovery on 2 volt VRLA cells that are suffering from PCL (Premature Capacity Loss). It is well understood that GNB was the first manufacturer in the USA to bring a large capacity VRLA AGM cell into the US market with their Absolyte I product, which immediately gained acceptance and substantial market share, and was obviously followed by the other US manufacturers into the market place with their own VRLA products. Also as everyone here understands there have been numerous papers at this and at other conferences that at least since 1985 have documented the “early failures” with these cells from all over the world.

The papers that have been presented were all from renowned authors and came from a broad range such as manufacturers, end users, and research facilities. As with any new technology there was a steep learning curve, and it was soon discovered that the VRLA battery was a different animal than the Vented Lead-Acid one that all of the authors knew so well. There were a number of initial problems associated with choice of materials, and manufacturing processes, but these were worked out just as with any new product that is developed. The old saying “time will tell” has had a lot of meaning with this product.

One thing that everyone learned early on was that these cells would suffer PCL (premature capacity loss) from a multitude of reasons, with the initial understanding in the USA being that loss of water from the electrolyte or a lack of compression in the cell was the culprit. The cause or causes of PCL has been the subject of many of the papers presented through the years.

This paper is going to track the development of the IOVR™ (Internal Ohmic Value Recovery) battery capacity recovery process, over the past thirteen years, and just like a child growing up, it will show the initial attempts and shortcomings, then the gaining of a better understanding of the issues, the experiments involved, and the final maturing of the process into the IOVR+™ process. It will track the lives of two fifteen year old batteries that have had various parts of the IOVR and IOVR+ process performed on them, and that have maintained their recovered capacity for up to seven years. It also will show one ten year old system (actually three strings) that we performed differing parts of the IOVR+ process on in order to determine which part of the process caused the greatest amount of recovery.

INTRODUCTION

Ever since 1982 and the introduction of the first large format VRLA battery series into the American market by GNB with their Absolyte brand, there has been an increasing demand for this product type and its usage has garnered a very large share of the stationary market, due to some unique features of the product. Due to this rapid and wide acceptance and demand for product, soon all of the manufacturers had developed and were offering their own models of VRLA cells. Some were gel technology but most were of the AGM design.

While there is an equally large base of the multi cell VRLA batteries (4, 6, & 12 volt), this paper and the IOVR+ battery recovery process that is explained in it applies only to the individual 2 volt VRLA cells that are usually installed in steel trays and mounted horizontally, although the process is the same if they are mounted vertically. All of the batteries that are shown in this paper are of the AGM design, but the process works with GEL type batteries as well, but of course there are some modifications to the process.

With any structurally intact cell that is suffering from PCL caused by dry-out, and/or under polarized negatives, and/or sulfated plates, the IOVR+ will recover capacity and capability.

With VRLA cells, as with many other “new design” products, the reality of their useful life was substantially less than their designed life, which resulted in many early failures when called upon. There were numerous papers presented at previous INTELEC conferences as well as BATTCON and INFOBAT that documented the early failures of tens of thousands of cells from across the world. (1)(2)

In the structural realm of failures were the post seal leaks, jar to cover seal leaks or cracks, as well as cracking of the jars themselves. Also there was the issue of internal negative bus decay and the resultant open failures under load.

Of course the scariest failure of all was the thermal runaway type of failure, because it was so misunderstood, and pretty much still is to this day, by the average user.

And last but not least, a failure that is still with us today is pre-mature capacity loss (PCL). This PCL sometimes occur as early as 3 – 7 years into the expected 20 year life. What was and still is today, causing this PCL (3)?

The element and structural related failures were soon understood and corrected, and it is now much rarer to find the jar to cover leaks, or the negative bus failures which were quite prevalent in the early years of development of this technology. The VRLA technology suffered from the same type of a learning curve as any other new technology. As a comparison one can look at the issues that occurred with the Lithium-Metal-Polymer batteries which recently have made headlines (4), and some of the issues with other Lithium based products. Just as there have been substantial improvements in the VRLA sector, there surely will be more improvements with the Lithium products.

EARLY CAPACITY RECOVERY EFFORTS: ADDING WATER

Back in the mid 1990's both GNB and *Battery Research and Testing* were performing capacity recovery attempts on the Absolyte cells by way of adding water to each cell in the string. GNB believed that the cause of the capacity loss was lack of compression between the plates, and they added the same amount of water to each cell in a string based upon the model design. They also added a manufacturing step where they banded the plates in all new cells being built (5).

Battery Research and Testing's position was that the capacity loss was due to dry-out of the cells, and we added differing amounts of water to each cell in the string based upon the ohmic value of each cell, as compared to a known value that we had determined was correct for that model cell (6). Our initial attempts at this were in the summer of 1994. With either method, the result was an immediate improvement in the ohmic values and the capacity of the string.

It turned out, though, that the improvements which were gained so easily and quickly were of short term, as we learned that within less than 24 months the ohmic values and the capacity would again deteriorate (6). It was obvious that we were missing some very important key to the puzzle.

CATALYST PROVIDES LONGER-TERM BENEFIT

Both before our initial attempts at recovering these cells with the water addition only, and since then, there has been a lot of research into why these VRLA cells were failing so early in life, and every manufacturer was working on how to make them last as long as they were designed to last (20 years). The one finding that now appears to have made the biggest impact in preventing the early failure of these cells, either from being installed in new cells, or when added into aged cells along with replacement of the water that has been lost, is the Catalyst (7 thru 15).

The reason for the benefit is that when installed in new cells, the catalyst helps prevent the under-polarization of the negatives. When installed in aged cells, along with the replacement of the water that has been lost, they restore the proper polarization and charging to the negatives which of course lowers the excessive over-polarization of the positives, which reduces the charge current, and subsequent water loss, and the end result is that the life of the cell is more in line with its design life (16)(17).

The information in these papers (and others on the subject) caused us in 1999 to again start experimenting with recovering these failed cells, but now we added in measurements of the plate potentials of the cells, and verified that there were indeed under-polarized negatives (over-polarized positives) and that following the installation of a catalyst the negative polarization increased and the positive polarization decreased, which resulted in a lowered float current and improved capacities.

We coupled together the same procedure for determining how much water for each cell, along with the installation of a catalyst in each cell. 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 (18 thru 22).

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 cells' ohmic values improve, which results in a reduction of the risk of thermal runaway, and improves the capacity or capability.

HIGH RATE CHARGE REMOVES SULFATES

What was "missed" during all of our excitement with the improvements, was the need for a proper high rate charge to drive off sulfates that had formed on the negatives due to their being under charged, and 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 (16) (23). The old saying that "no one is as blind as he that will not see" is appropriate here. We so missed the obvious.

Every manufacturer's specification sheets and maintenance requirements normally refer to 25°C, with the correct float voltage being referenced to this temperature. Both performance and life are directly affected by variations from this temperature. Each manufacturer also considers the density of the acid in their recommended float voltage. The recommended float voltage range is so that the proper over potential will be applied to the plates in order to keep them in a properly charged state.

I believe that we all 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 under-charged. 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 manufacturers recommend), that the plates can be undercharged (23).

Also if the battery experiences a few power outages which partially discharge it, coupled with the lower temperature, and the improper float voltage for the temperature, then you will end up with plates which do not become recharged and thus become sulfated.

All manufacturers recommend that a newly installed battery receive a freshen charge, and some even recommend annual equalize charges, with one manufacturer even stating that float voltage may not provide sufficient plate polarization to reconvert lead sulfate. Every manufacturer that I am familiar with recommends special charging to remove sulfation. The general understanding that these batteries do not need nor can they benefit from high rate charging is out of touch with the reality of how they operate. Thankfully one manufacturer in their newest installation and maintenance manual recommends annual equalization charging.

When you consider the well-documented fact that the normal electrochemistry occurring inside these cells leads to under-polarized negatives, off gassing (dry-out), and over charging of the positive plates, it is no wonder that these batteries are failing long before their designed end of life, which is based upon the normally perceived and accepted failure mode of grid corrosion. It is no wonder that our original processes did not recover all possible capacity as we were at that time making no attempt to remove the sulfates from the plates, or to fully recharge them, and that to do so we would need to make the cells gas like flooded ones in order to remove the sulfates from the plates (24). Very high voltage charging is required.

LESSONS LEARNED SINCE 1995

1. Water replacement only is a short term “band-aid” and does not recover all available capacity, nor is it a long term solution as it does not address the root cause of the problems.
2. The single action of installing a catalyst in an aged or dried out cell will recover only a certain amount of the lost capacity, even though it will assist in restoring proper potentials to the negative plates.
3. Boost charging at the manufacturer’s recommended voltages may recover some amount of the lost capacity, but usually will not drive off established sulfates. It also does not address the root cause of the problems.

4. Only by replacing the water that has been lost, *then* high rate charging the cells at above 2.40 VPC at standard temperature, and *then* adding a catalyst to the head space are we able to regain and maintain as much of the usable capacity as possible, plus we address the root cause of the pre-mature capacity loss.
5. The capacity recovered by this IOVR+ process is sustainable due to the fact that the cells have been returned as near as possible to their original designed state, with the improvement of a catalyst addition.

WHEN IS THE RIGHT TIME TO REPLACE THESE BATTERIES?

If you follow the current 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. *IEEE 1188 Section 8* currently states the following, which I believe leads to the throwing away of perfectly good and dependable batteries:

8. 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.

AN INITIAL SUCCESS EVALUATION

If the statement that a battery with less than 80% capacity must be rapidly declining was correct, then there is no way that that the following story could have occurred. Why did this battery recover so strongly and last as long as it did? It was one of our first field test successes.

This 24 volt 825 AH battery supports a microwave site in upstate New York. The cells were manufactured in March 1992 and first load tested by a highly qualified independent

battery testing company for the owner on 5/18/2000, with a result of 33% capacity.

Two months later (7/14/2000) we performed our initial IOVR process of adding water and a catalyst to each cell. Five days later (7/19/2000) we returned to the site and performed a load test at the same three hour rate as had been run during the previous load test. The battery now produced a capacity of 66%, up from 33%.

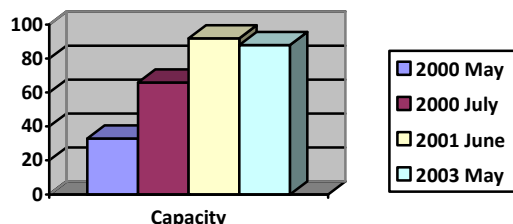
Of key importance to the increase in the amount of recovery was the method in which we recharged the battery. A DC generator was brought to the site and used to recharge this battery rapidly at a high rate in as short a time as possible, to meet the time requirements of their outage window.

We are now firmly convinced that the reason that this battery recovered so well is because of the use of this DC generator to perform the rapid re-charge before we put this battery back on line. We believe that the 60+ volts that the DC generator was set at drove off the sulfates on the discharged negative plates. It is important to note that we were not even thinking about sulfates on the negative plates at this time.

Eleven months later (6/7/2001) we returned to the site and repeated the load test. The float current was now 1.3 amps. The load test delivered a capacity of 92%.

Nearly two years later (5/2/2003), in order to independently verify that the capacity recovery that we had documented in our previous 2 load tests was in fact accurate, the owner again contracted with their independent testing company to return and perform another load test on the battery system. This load test produced a capacity of 88%. In addition to the capacity improvement, they observed that the float current was now at 0.78 amps, which was down from their recorded current on 5/18/2000 of 2.27 amps. We were also impressed that the capacity recovered was still present three years later. This was not a short term recovery. See Table 1.

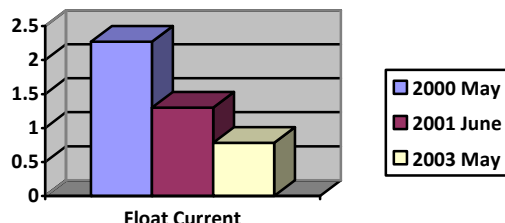
Table 1: Capacity test results for initial success evaluation



What also showed us that we were on the right track was the decrease in the float current. As can be seen from Table 2, there was a steady decline in charge current down to a safe

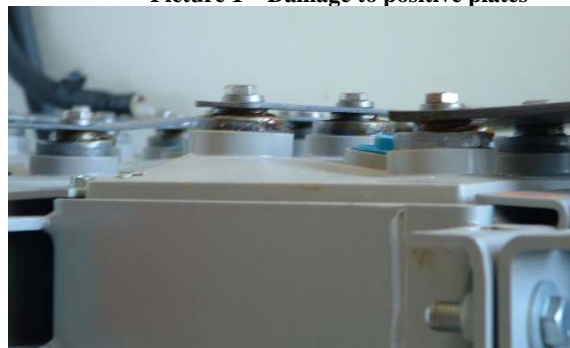
level for the battery size. While still a little higher than one would like for a new and in good condition battery of this size, this is much better than the as-found current. There is no question that the battery was in better shape than when we found it.

Table 2: Charge current for initial success evaluation



As can be seen from Picture 1 below, the positive posts had already severely grown when we first arrived on site, which indicates that the positive plates had been being over-charged for many years before we arrived on 7/14/2000. While we cannot undo the damage done to the positive plates, we can return them to their designed rate of growth. The lowered float current is a key indicator along these lines because float current and grid growth are directly related.

Picture 1 – Damage to positive plates



THREE BATTERY SYSTEM REJUVENATION STORIES

Battery story 1 – does capacity drop rapidly below 80%?

The first story is about a 24 cell 900 AH battery which was seven years old when it was first load tested in October 2000. The battery was a single string at a remote telecom site that was required to provide 8 hours of reserve time for the communications equipment. All load tests on this battery were performed by turning off the rectifiers and adding load to the existing site load. All of the tests were run at the published three hour rate of the battery. The first load test lasted nine minutes which equates to 5% of its rating.

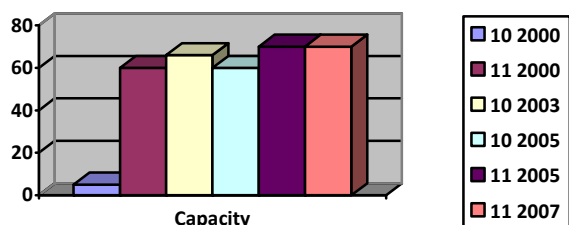
Immediately following the load test, water and catalyst additions were performed which demonstrated an immediate improvement in the ohmic values. The follow up load test showed a capacity of 60% (108 minutes). This capacity, although not at 80% (as the IEEE 1188 recommends for time of replacement) was enough to support the site load for over 8 hours, which is what was needed for this customer.

As can be seen, the following annual load tests show that the capacity remained pretty much the same with no degradation for the next 5 years. After the fifth year load test the customer allowed Andersons Electronics (the company in Canada that we trained in how to perform our process) to add more water to each cell. As part of the original agreement to commence this project the customer required that water only be added once. What we have learned through our ongoing research into this process is that our original calculations did not return enough water to the cells.

The load test that followed this second watering showed an increase in capacity from 60% to 70%, with no other actions taken (we still had not yet realized the need for the high rate charge). One single drop of electrolyte from around one of the post seals was discovered in 2006 and for this customer is cause for replacement. The battery still had adequate capability to support the site load for the required 8 hours (it actually delivered 9.8 hours) and, in fact, during the Regional Black-out of 2003 it supported the site for over 5 hours until a generator was brought to the site. Despite this, however, Andersons Electronics took possession of this battery upon its removal from the site and moved it to their facility in London, Ontario and placed it back on float at 54.0 volts to continue the testing program.

During the fall of 2007 it was again load tested and again it 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. These cells had been well under 80% for seven years and have stayed at the capacity level they were initially recovered to without any further decline. See Figure 3. End of life or loss of capacity definitely was not caused by grid corrosion with this battery. It has to have been from dry-out and negative plate under polarization.

Figure 3 - Rejuvenated cells do not lose capacity rapidly at < 80%



All of the data on this battery has been compiled by Les and Rob Anderson of Andersons Electronics, who have provided immeasurable field support throughout the past seven years of the development of the IOVR and IOVR+ process.

Battery story 2 – from 34% to 94% rated capacity

The second story is about a 60 cell 100A29 battery that was originally part of a 7 year old 120 cell 100A87 string. It had been replaced under warranty with three 120 cell 100A29 strings. We took possession of it in May of 2002. After reconfiguring it into a number of 60 cell 100A29 strings, we performed the initial load test which produced 34.3% of its rated capacity.

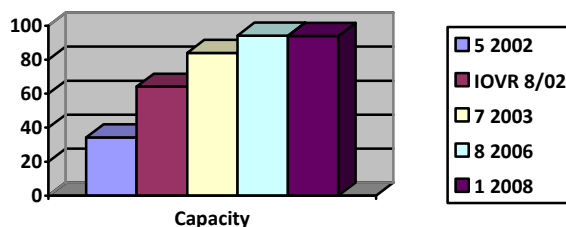
We then performed the IOVR process on the battery and the following load test demonstrated a capacity of 64.1%. This battery was used internally in a variety of ways, such as training on performing the IOVR process, and on the running of load tests, both with and without functioning monitoring equipment. We do not know exactly how many times that load tests were performed on this battery, nor at which rates the load tests were 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 order to prove that this battery would support certain required loads, during an outage at a power plant the battery was again load tested in July 2003. The battery satisfied the requirements of the customer and made 84% of its rating. This discharge test was followed by a very high rate recharge in order to recharge it quickly and to “equalize” all cells.

The same need occurred again in August 2006. Prior to another rental contract at yet another power plant, we ran yet another closely watched capacity test and the battery now made 94.2%. What was happening here?

Again in January 2008 we ran a closely observed load test for this paper and the battery made 93.9%. It appears that we have recovered all possible capacity from this battery, which is now 14 years old. See Figure 4.

Figure 4 - 14-year old battery at 94.2% design capacity



We next shifted our attention to figuring out what was occurring.

Battery Story 3 – impact of each step of the IOVR+ process

The third story is about our desire to determine just which part or parts of the process would impact cell recovery the most. We took a 72 cell 100A99 string and turned it into three 24 cell 100A33 strings, all of which were manufactured in 1998. We wanted to observe the results of each of the separate steps that go into the IOVR+ process.

We varied the steps that we applied to each string as a second step. Each of the strings had already received an initial IOVR process, which yielded capacities that were between 64 and 66 percent for each string.

For the second step, String 1 had a full IOVR+ process performed, String 2 had just a boost charge performed, and String 3 only had water added to it. Both Strings 2 and 3 underwent the full IOVR+ process as a third step. The capacity test results for each string are presented below for each step:

String 1:

- Post initial IOVR capacity = 66%
- IOVR + performed
- Post IOVR + capacity = 94%

String 2:

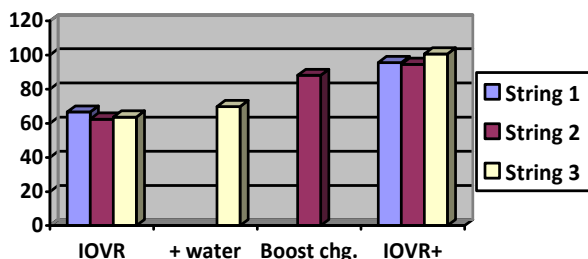
- Post initial IOVR capacity = 64%
- Boost charge only performed
- Post boost charge capacity = 88%
- IOVR+ performed
- Post IOVR+ capacity = 95%

String 3:

- Post initial IOVR capacity = 64%
- Water only added
- Post water addition capacity = 69%
- IOVR+ performed
- Post IOVR+ capacity = 101%

What is clear is that the IOVR+ process produced the best improvements for all three strings. Figure 5 illustrates this.

Figure 5 - Impact on battery capacity of each step in IOVR+ process



During this test we also monitored cell temperature and string float current. The temperature of the three strings dropped significantly after the IOVR+ process was performed, which was due to a decrease in the float current and the resultant internal heat generated by the cell. See Figure 6.

Figure 6 - IOVR+ reduces cell temperature

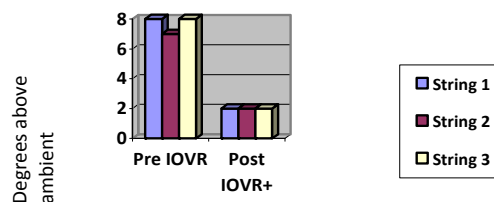
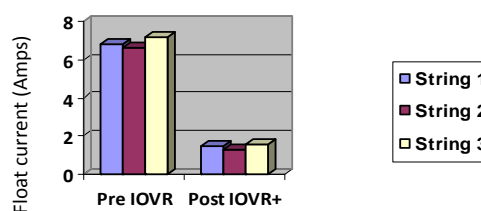


Figure 7 is a graph of float currents, which confirms the decrease in string float current and supports the graph of temperature.

Figure 7 - IOVR+ reduces float current



PROCESS DEMONSTRATED ON >80,000 CELLS SO FAR

To date this general process in its various phases, by various companies including the respective manufacturers has been performed on **more than 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.

WHEN SHOULD THIS PCL BE ADDRESSED?

The sooner in life that conditions that are causing this loss can be addressed, the better the outlook for the life extension. When people ask, “How soon should I do this?”. I answer with, “If today you were informed that you had cancer, how soon would you want to start the cure?”. This is not much different, as the sooner that you correct the issues that are causing the negative plate polarization issues, which affects the float current and the loss of water, and accelerated positive plate growth, the better prognosis for maximum recovery. On the other hand if, as with cancer, you decide to wait a few years before taking action, the less desirable is the outcome of any treatment.

AT WHAT AGE CAN THIS BE PERFORMED?

Typically we are called in to do this when the cells are between 5 and 8 years old and have failed a capacity test, but we also have performed this successfully on 11 year old cells. There is no real age limit, as the recovery depends upon the degree of degradation, and what you want to accomplish. However it is important to note that we highly recommend that catalysts be installed into VRLA cells as early as possible in their life to prevent negative plate self discharge, which will lead to premature capacity loss. There is no better time to install a catalyst than when the cell is being manufactured at the battery plant and before the cell goes into service. The best way to eliminate PCL is to prevent it from ever occurring in the first place.

CONCLUSIONS

We believe that dry-out, negative plate under-polarization, and sulfation are the primary present day causes of early failure in 2 volt VRLA cells, not grid corrosion as one would expect. We also understand that are other PCL causing conditions (24) which may or may not be able to be recovered by this process, and are not addressed in this paper. And of course there are always going to be cells that have manufacturing or structural defects, which neither this process nor any other process can recover capacity or capability, which was never there nor ever able to be utilized. There is not a fix for structurally defective cells.

The PCL causing conditions addressed in this paper can be corrected in all 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 that our originally developed IOVR process, even though it always recovered some amount of capacity or capability, in many cases it left some usable capacity unrecovered. We believe that it did not remove the sulfates on the negative plates that had developed over time while discharged and did not properly recharge the plates. It is our belief that the IOVR+ process does recover all available usable capacity.

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

At this moment in time it appears that 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 that the wording in the standard needs to be revised to recommend that before replacing the battery system that 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 most likely at the 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. Go ahead throw away that money!

It appears that the root cause of the majority of these early capacity failures (PCL) are due to negative plate self discharge, which as we have learned, is quite easy to recover from. Of course the longer one waits to begin the recovery process the more damage that will be done, and the more difficult it will be to recover from.

What also must be understood is that once all available capacity that had been lost to these PCL caused conditions has been recovered, that the future failure of these cells will be from grid corrosion, and it will be time for replacement as there is no correction or cure for that designed-in failure mode.

SPECIAL THANKS

I also would like to extend a personal and heartfelt thank you to a number of special people whose knowledge and encouragement buoyed me to continue with our research into this, even though at times it was pretty frustrating, as there were plenty of naysayers and antagonists from all arenas in this industry throughout this 13 year experience.

There were so many questions that I posed to the following individuals, and at no time did they send me away without some additional knowledge and encouragement. Without their knowledge, experience and patience, I am not sure that we would have persevered to discover this solution.

As Dave Feder once said to me, "Just keep going, as you are on to something." What that "something" was I did not then have a clue.

Thank you to Dr. David Feder, Dr. Dietrich Berndt, Will Jones, Bruce Dick, Harold Vanasse, Jim McDowall, and Frank Vacarro, who sadly has passed on before seeing this research come to fruition. Thanks everyone!!!

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