The History of the VRLA Special Recovery Process

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Abstract

It has taken us decades to get to this point, but this generation is very environmentally conscious of its responsibilities to be good stewards of our planet, and understands that even small acts of conservation and thinking green can benefit both ourselves through profitability and everyone on the earth through carbon footprint thinking. By utilizing the actions described in the Special Recovery Process either in a proactive or a reactive method is as green as one can get, as it minimizes the carbon footprint of that specific battery.

With that being said, this paper is going to detail the history of the actions that have been taken over the past 20+ years to recover 2 volt VRLA (Valve-Regulated Lead-Acid) cells from PCL (premature capacity loss), which has led up to the present day "Special Recovery Process" as described in the IEEE 1188a2014 (1) document, and how modifications to that process can be applied in a proactive means as well as a reactive means. This is going to be journey through time and actions from 1994 up until today.

Introduction

The recovering of lost battery capacity or capability, or the maximizing of the useful lives of all types of rechargeable batteries, has been a standard practice for at a very long time. In fact, Thomas Edison's maintenance manual from the 1920's for his Nickel-Iron batteries explained exactly how to drain and replace the electrolyte to recover performance (2) with those cells. This same general procedure of electrolyte replacement is still in use today with some slight variations with Nickel-Cadmium cells. Also, as everyone reading this surely understands, when a VLA (vented lead-acid) battery fails to perform as expected during its normal design life, but which is not visually falling apart, the very first step recommended by every battery manufacturer is to perform an equalize charge and then to retest. Or when the electrolyte level declines to the alert level in the cell (low line), water is added to the cells in order to both keep the plates covered and to maintain the proper SG (specific gravity) for the particular cell design and capability. This recoverable failing early in the VLA battery's designed life could also be called PCL (premature capacity loss), as it is with VRLA (valve-regulated lead-acid) cells. Equalizing and maintaining the correct electrolyte levels is a standard practice. Sometimes, when a VLA battery has been undercharged or not properly recharged after a discharge, the plates become sulfated, and it requires aggressive charging or even discharging and recharging to fully recover the cells, which again is a normal industry practice and recommended by all manufacturers when applicable.

However, not as well known is the fact that VRLA batteries that fail due to PCL causes, as explained in IEEE 1188a2014, can also be improved or recovered. The IEEE 1188a2014 explains in detail the primary causes of PCL in VRLA cells, as well as the various steps that may be used to recover from those causes. Prior to the creation of IEEE 1188a2014, the recommendation in IEEE 1188-2005 was to replace the battery if it failed its capacity test. There was no allowance for or recommendation of any kind as to any possible means for recovering the battery. The IEEE Stationary Battery Committee, 1188 Working Group realized that there were processes being used that could recover many of these battery strings and created an amendment to IEEE 1188-2010. That is where IEEE 1188a2014 came from.

This paper will cover the evolution and progress that has occurred over the past 20+ years, starting with the initial attempts at recovery by just adding water to these cells. Those original procedures might best be compared to triage in combat, where the goal is to help the patient (cells) survive but real repairs come later. Then we will cover the subsequent years. where the root cause of a majority of the PCL failures was discovered, lessons learned along the way, changes made to the process, and ending with the present day procedures that can result in long term recovery. We would be remiss if we did not acknowledge that every manufacturer also has learned lessons along the way, and substantial improvement has occurred in their understanding of the issues that affect or impact these cells. They all have improved their manufacturing processes, and there is no comparing the performance and normal life of the present day 2 volt VRLA cells to those made 20 years ago.

With that being said, every manufacturer will agree that off gassing to a point that creates dry-out is a kiss of death. Also, all will acknowledge that if the negative plates become discharged or sulfated, for whatever reason, the capacity or capability of the cells will be reduced.

In The Beginning of Large Format VRLA Batteries in Telecom Applications

Back in the mid 90's, when 2 volt VRLA batteries were first really making inroads into the telecom market, there were substantial early capacity loss failures and thermal runaway issues. The major player in the market at that time was GNB, with their Absolyte 1 battery models that they introduced in 1982, and, because they were the first and had the largest share of the market, they were the recipients of the majority of the problems at that time.

During the 1994 – 1995 time frame, BR&T (Battery Research and Testing Inc.) was contracted to perform on-going capacity testing for United Telephone in Florida as part of a before-and-after process for sites where GNB was performing their FAR (Feld Adjustment Repair) program. For those not familiar with the FAR program, it was a process of adding water to cells as a means to compensate for a lack of plate to mat to plate compression in cells, due to a manufacturing procedure that, when those cells were manufactured, did not including banding of the plates to maintain ionic contact between the AGM and the plates. That overlook of the need for banding was corrected. The GNB program entailed adding the same amount of water to each cell of a specific model. As a side experiment during this testing program, BR&T began the initial process of adding differing amounts of water to cells within the same string. How much water BR&T put into each cell was based upon the differing internal ohmic values measured for the particular cell as part of the inspection process.

Both of these procedures resulted in immediate improvement in the internal ohmic values as well as in the capacity. Of noticeable difference was that, by varying the amounts of water added to each cell, BR&T was able to bring all of the cells in the string into a closer grouping as far as the resulting ohmic readings and capacity were concerned. This was just the beginning of our "education" on this process; we all had so much more to learn to get to where we are now, with the technology and process.

GNB's position at that time was that the PCL was the result of the lack of compression, and BR&T's position was that it was dry-out caused. In hindsight, it was both. And, sadly, as documented by papers at Battcon 1997 (3, 4), the improvements were relatively short lived, as within 2 to 3 years the impedance values started to increase again and follow-up capacity testing in 1996 – 1997 showed the recurring capacity decline. No one in the industry at that time understood the real root cause of the PCL issue.

Just in case anyone thinks this was just a US problem, it was not. PCL was occurring around the world with all manufacturers' products, and there was substantial research and effort going into trying to understand what was causing this early failure from all the manufacturers and all the major users. There were over 50 papers presented at Intelec conferences between 1982 and 2002 on VRLA batteries plus their failure modes. Dr. Feder's Intelec 1995 paper (5) reported on the results of capacity tests on over 24,000 cells from sites around the globe. He was just one of the many hundreds of people that were trying to solve the issue of what is now referred to as PCL, as it was really a multi-headed monster that, at that time, had many causes. Also, at Intelec 1995 was the first time that the ability of these 20 year design cells to last 20 years without drying out to the point that they would not be functional (6) was openly presented and challenged.

Some of the History of Issues

Manufacturing and in service issues

In the beginning, all manufacturers struggled with various design, application, manufacturing, and user caused issues, along with just a lack of any real long term experiences with the technology. This was a plain old lead and acid battery, which we all understood, or so we all thought. Every manufacturer that is still around today worked diligently to understand this technology in order to build a better product, and they have succeeded.

Today's manufacturers now have the benefit of a longer performance history and technical data accumulation that was not possible 20 years ago, and, based upon that experience, ongoing improvements have been made, and continue to be made.

Some of the issues that caused problems years ago that have improved or changed are as follows.

- Dissimilar metals that caused internal parts failure
- Failure to maintain plate to mat compression
- AGM issues
- Jar to cover and post seal issues
- Lack of understanding of importance of material purity
- Off gassing issues resulting in dry-out, as well as long term saturation issues
- Recombination issues, negative polarization issues, undercharging, sulfation, and discharge
- Positive over polarization issues resulting in overcharging and accelerated grid growth
- Quality control importance
- Thermal run-away (AKA thermal walk away by Curtis Ashton)
- Manufacturing process issues
- Improvements with monitoring devices and data interpretation
- User education on application restrictions

There were many more, but the above list gives an indication of the breadth of issues involved.

The discovery of the root cause of the majority of PCL failures

Research led by Will Jones of Philadelphia Scientific eventually led to the realization of the root cause of PCL. Will's discovery was that the recombination process was too efficient and that too much oxygen was getting to the negative plates and causing them to become underpolarized. The underpolarization of the negative plates lead to overpolarization of the positive plates, which caused many of the related symptoms that have become associated with VRLA failure, such as: dry-out, increasing float current, positive plate corrosion/growth, early cell failure, premature capacity loss and even thermal runaway.

Will Jones' discovery led Philadelphia Scientific to develop and introduced their catalyst for VRLA cells in 1998, which helped maintain the proper polarization of a VRLA cell's negative plates by simply scavenging some of the oxygen present in the cell, converting it back to water, and preventing it from reaching and depolarizing the negative plate. This simple, non-intuitive action reduced the overpolarization of the positive plates, which, in turn, reduced the required float current and, thereby, the excessive off gassing that leads to dry-out. The decreased float current, normally half of what a non-catalyst equipped cell would draw, also led to reduced positive plate corrosion/growth and reduced the risk of thermal runaway. The causes of the need for and the benefits of a catalyst in the head space were first explained at Intelec 1996 (7), with follow-up papers in subsequent years at various conferences (8, 9, 10) and even a section added to Dr. Dietrich Berndt's book on Maintenance Free Batteries (11). Over the years, there have been numerous other papers presented at various conferences by a variety of authors that acknowledge that the predominant cause of PCL at their respective time was negative plate discharge and dry-out caused.

Ongoing issues causing PCL

Above, we explained that there were many differing issues that the manufacturers had to work through, and that all have made substantial improvements to their products, as well as to the education of the users in the applications of those products. How can it be that today we still find batteries that suffer from PCL?

1. It is still possible that there can be negative polarization issues, and this issue can be addressed by the introduction of a catalyst into the head space to help with this. High rate charging can also help to correct this issue in many applications, but must be used judiciously so as to not aggravate or cause a problem.

2. There is only so much electrolyte put into a cell, and there will always be some amount of off gassing and, over time, in order for the cell to remain saturated, water needs to be added. Even with a catalyst in the head space, there will still be some off gassing, although at a lower rate than the same cell that does not have a catalyst in the head space. Of note is that in applications that have a higher than normal ambient temperature, the catalysts will provide a maximum benefit by minimizing the off gassing. It must be remembered that dry-out is a kiss of death for any cell. Maintaining proper saturation is critical to maximizing life and capability.

3. It must be understood there not all VRLA PCL is the result of dry-out. As with any technology, there will always be new issues that arise and are not presently understood. As Dr. David Feder told me many times, "We do not know what we do not know." How true that is, because until we encounter and solve a new problem, we have no idea what that new problem or solution will be.

Field corrective actions both reactive and proactive

As stated in the beginning of this paper, the very first actions taken to recover cells from PCL entailed the addition of water to the individual cells, nothing more. The end result was improved ohmics and capacity. GNB attributed the need for their FAR program to a lack of compression, but, as is well understood, the problem with PCL has continued across all manufacturers even after all cells were banded, so the root cause was not lack of compression. However, lack of compression did aggravate the PCL problem.

As was discovered by the research done by Jones and Feder, and others, the primary root cause of PCL was negative plate polarization issues. While it is correct that, in theory, a perfectly built battery with the purest of materials might never need the benefit of a catalyst to help prevent the discharge of the negatives in normal charging, the reality is that it is very difficult to build the perfect battery every time, and a catalyst can benefit any cell. An additional benefit of a catalyst is in an application that is in a high temperature environment, as the catalyst aids in the recombination of gasses, and the water is returned to the cell to help maintain proper saturation.

After our initial attempts to recover batteries by just adding water, and learning that those actions alone would not provide a long term solution, we next coupled the resaturation process with the installation of a Philadelphia Scientific catalyst equipped vent assembly, and this provided a longer term solution. However, we observed that sometimes there would be differing amounts of improvement in differing strings, even though they were the same date codes and models. We then realized that because the negative plates in differing strings could be at different amounts of discharge and sulfation, that aggressive charging could be required to recover the negatives as much as possible.

Because we had named our original process the IOVR™ process, which simply stands for **I**nternal **O**hmic **V**alue **R**ecovery, as that is what is very observable quickly, in order to differentiate that initial process from the addition of this high rate charge, we named this revision the IOVR+™ process.

As listed in the IEEE 1188a2014 document, these actions are shown being used in a reactive manner. In other words, they are undertaken after a problem has been discovered. However, they also can be used in a proactive manner, in order to prevent or delay the loss of capacity or capability or life.

Is the ability to recover 2 Volt AGM VRLA cells application specific?

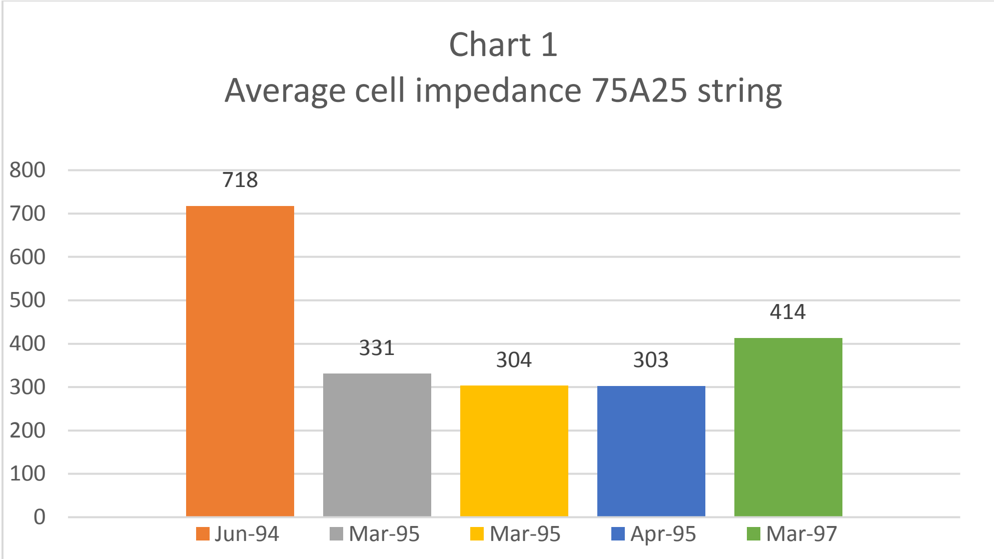
The utilization of the process is not application specific, as it can be performed on structurally intact cells in any type of service, from UPS, with their high short rate loads, to telecom, with longer duration lower rated loads, as well as utility applications whose batteries can have both a higher than normal inrush or short term loads, and then lower loads for a longer duration. There have been user presented papers at previous conferences that have documented how individual users have saved their companies millions (yes millions) of dollars by taking either reactive or proactive actions (12 & 13) in both UPS and telecom applications. Paper 12 shows that batteries can even be recovered following a thermal runaway event.

Case Studies

The following are three examples of the attempts at both reactive and proactive actions. All the batteries in this example were at least six years old when originally tested.

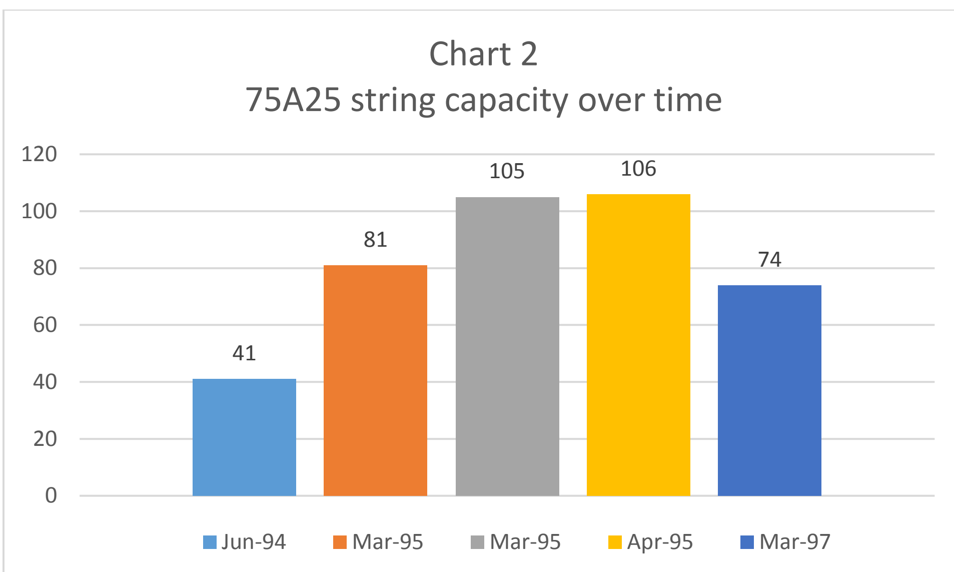
Example 1 Battcon 1997 results reactive actions with short term benefits only.

The following is the average cell impedance in the 75A25 string over time. June 1994 was the as-found average, followed by March 1995, which showed substantial improvement following GNB's initial FAR process. Following that initial improvement and the first load test following that first watering, the customer had GNB return to the site within and inject additional water. As can be seen, this lowered the impedances even further. Also, as can be seen by two years later, when we returned for the last follow-up load test, the internal ohmic values were increasing. As will be seen in the next graph, the capacity was decaying also. This confirms that water alone was not the answer to this PCL.

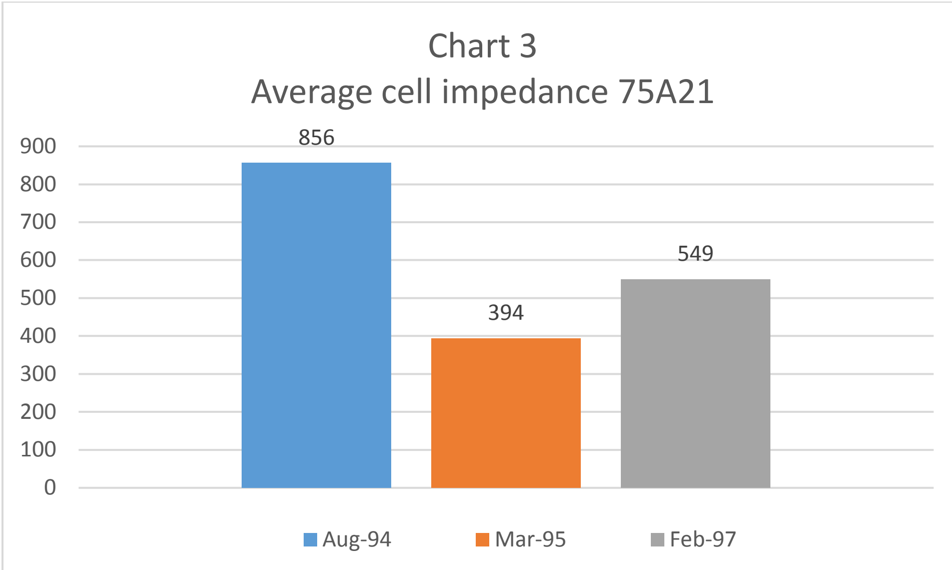


The following graph shows the capacity changes over time from the initial as-found capacity of 41%, followed by the first load test following the initial watering by GNB under their FAR program, then following additional watering an increase to 105%. Within one week, we again load tested the string and the result was 106%. We believe the increase was due to the repeated discharging and recharging. However, as can be seen by two years later, the capacity was declining, which confirms that the PCL was not due to just loss of water or lack of compression.

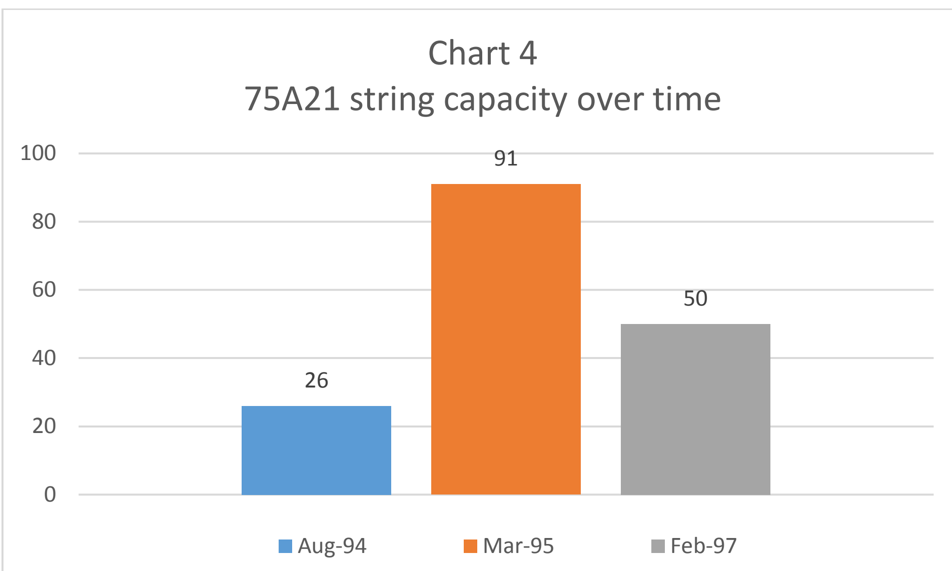
It is important to remember or understand that these efforts were before the root cause of most PCL was understood, and before a high rate charge to recover the negative polarization and catalysts added to maintain that recovery were included in the process.



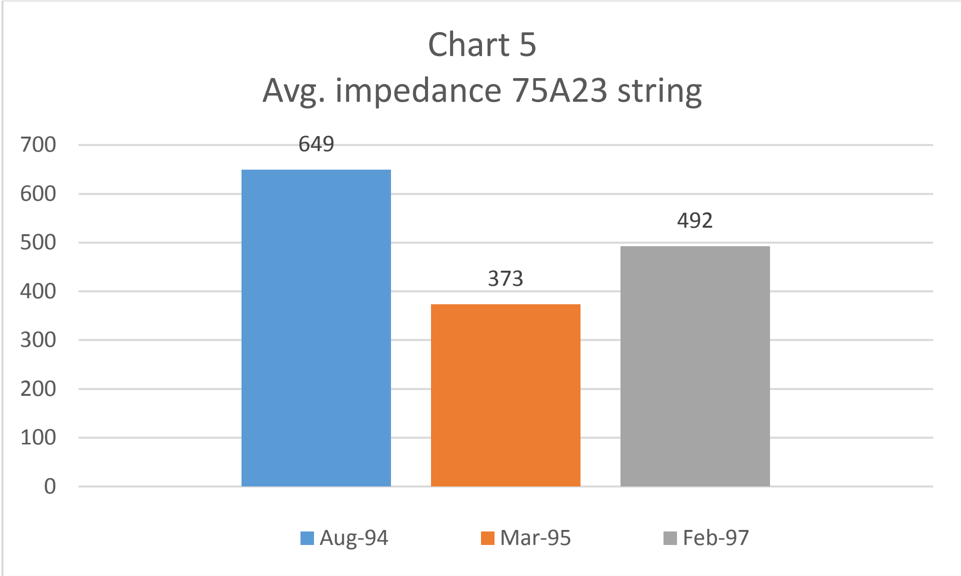
This graph shows the changes over time also with a substantial improvement immediately following the water additions, and also the decay as time increases. Again, water alone, while important, was not the cause of the PCL.



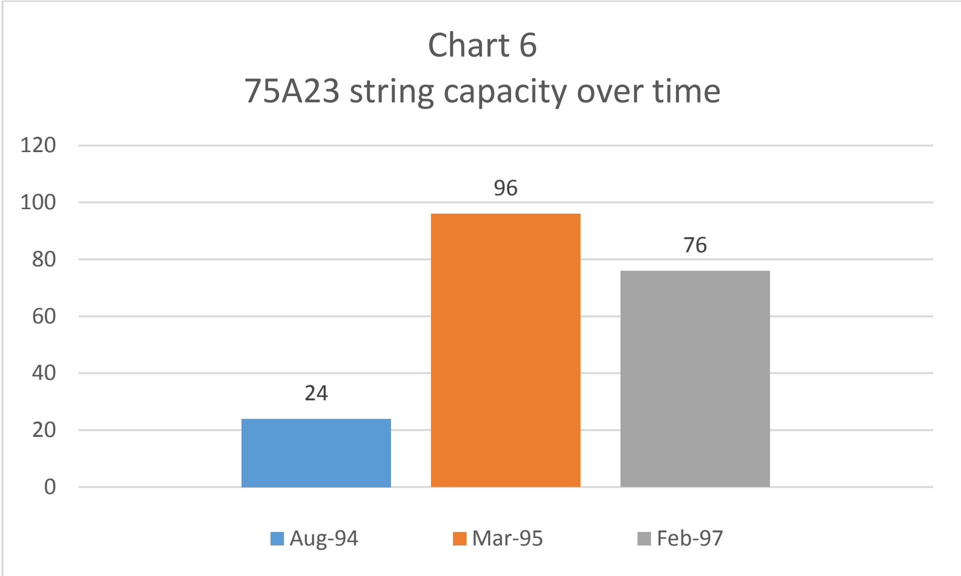
The following chart shows the improvement in capacity as the result of the rehydration alone but, as can be seen, the decline in capacity returned, which confirms that the root cause of the PCL was not dry-out only.



And last but not least, from the 1997 report, as can be seen with the 75A23 string, there was immediate improvement in the impedance values, but in a relatively short time they again started to increase.



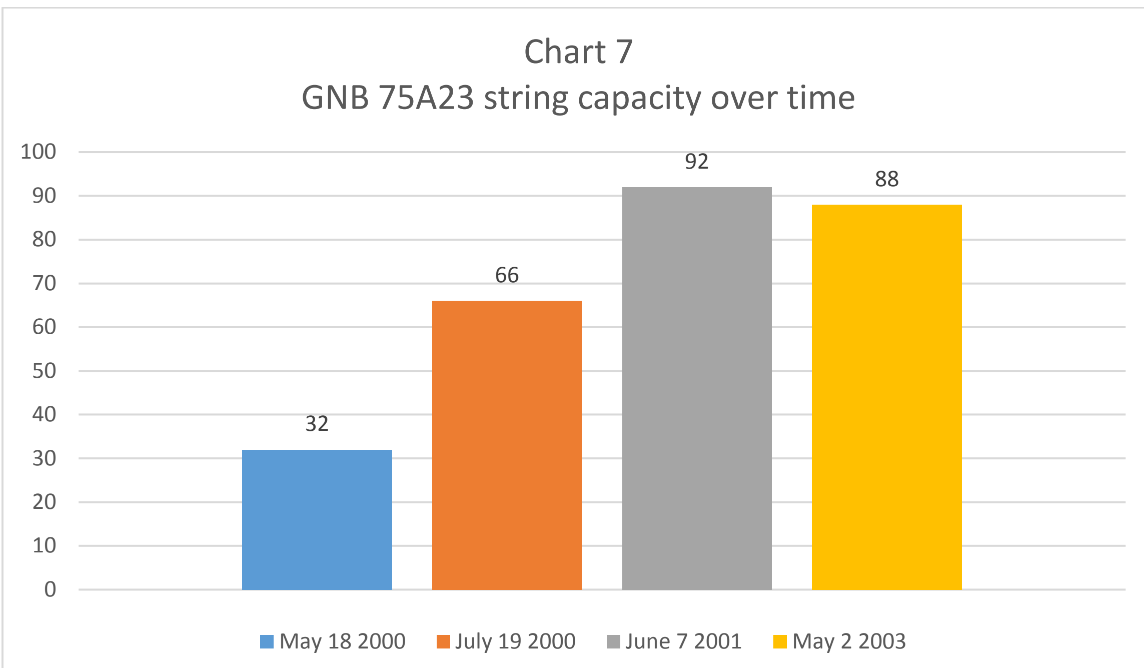
This string reaffirms that water alone was a substantial benefit, but it was not the solution to long term recovery.



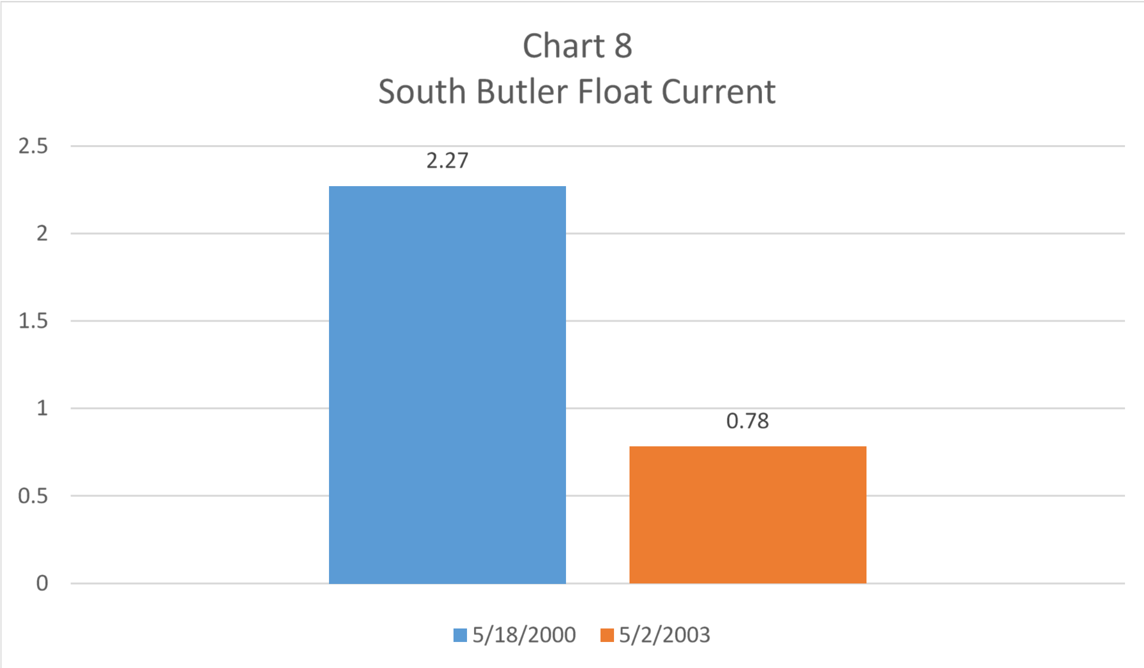
Example 2 South Butler Microwave site reactive actions with long term improvements.

This example shows the results over time of this March 1992 manufactured battery. Of note is that the 5/18/2000 and 5/2/2003 tests were performed by that customer's normally used battery testing company (TPI) and not by BR&T. We understand that the 2003 test by TPI was to prove or disprove the longevity of the recovery process or to confirm/verify the improvements that the BR&T capacity tests recorded. The 7/19/2000 and 6/7/2001 capacity tests were performed by BR&T. The 7/19/2000 test was performed within seven days of the performance of the IOVR+™ process. Immediately following the 7/19/2000 test and before we performed the recharge of the string, we performed some cell adjustment work to the lowest capacity cells in the string. This string was a 24 volt microwave string.

This battery was mounted vertically, and there was very advanced positive plate growth as will be seen in the picture below, but, still, the improvements were quite substantial. Even though the positives had grown this much, and the plastic was severely stretched around each positive post, all the cells were structurally intact, which allowed us to proceed with the process. Also of note is that the company performing the initial and final load tests recorded the float current on 5/18/2000 as 2.27 amps and then on 5/2/2003 it was 0.78 amp, which is just another indicator of a successful improvement to the cells. Our performance of the Special Recovery Process was successful in lowering the required float current with this battery and increasing the capacity and run time even with this very advanced state of positive plate growth battery.

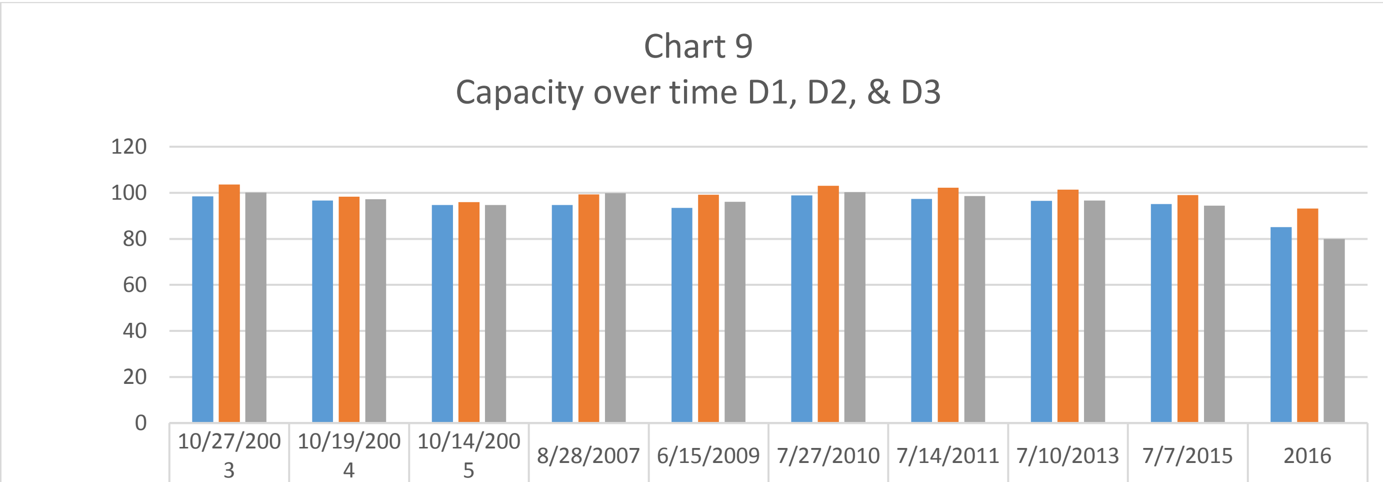


The following chart shows that, once the cells were properly saturated and the plates properly charged, the float current required to maintain the cells in a properly charged state was able to return to approximately where it should be for an 825 AH string of that age, at that time.



The following picture shows just how much growth had occurred with the positives by their being continually overpolarized for many years. That a battery in this condition was able to make the amount of recovery that it did is a testament to the ruggedness of the product and their ability to be abused but still be able to recover capacity. As all should understand, there is no way to make the grids shrink back to their original dimensions, so the life of this battery was severely compromised upon our arrival, but it did recover and was still reliably supporting that site three years later. We never returned to this site, but understand that the battery supported the site until it was shut down within two years after the final load test by TPI.

Example three: Three 1,400 AH 120 cell strings proactive actions with long term results.
These three strings were manufactured in September 2002, and installed in October of 2002. The first load test was performed in October 2003. Catalysts were not installed until 2005 following the load tests then. Initial rehydration occurred during summer of 2009, with subsequent as-needed adjustments to specific cells.



	10/27/2003	10/19/2004	10/14/2005	8/28/2007	6/15/2009	7/27/2010	7/14/2011	7/10/2013	7/7/2015	2016
String D1	98.4	96.7	94.7	94.7	93.4	98.8	97.3	96.5	95.1	85.1
String D2	103.6	98.3	95.9	99.3	99.1	103	102.2	101.3	99	93.1
String D3	100.1	97.2	94.7	99.8	96.1	100.2	98.6	96.7	94.4	79.9

Additional information on VRLA batteries uniqueness and abilities
A generally unknown attribute of the 2 volt AGM VRLA cells is that they have the ability to be left off charge for extended periods of time (multiple years) and then be able to be recovered back into usable battery strings. This unique ability was first reported by Robert Szasz from AT&T Canada at Intelec 2002 (14). He reported on how during an AT&T acquisition of another telecom company, it was discovered in a warehouse that there were 40 strings of batteries from two different manufacturers that had sat off charge for up to four years. He also reported how a decision was made to see if there was any value in recovering the battery strings, and how they worked with the two manufacturers, and the results of the project. He also delivered a follow-up paper nine years later at Battcon 2011 (15) that reported on the continued usage of the battery strings at 14 years of age. This same type of a result was reported on at Battcon 2014 (16) and it covered cells that had been found in a non-climate controlled warehouse here in Florida and not far from where we are right now. Those cells were three and a half years old upon discovery and never been charged while in storage, yet they also recovered to perfectly usable cells. Of note is that these cells were from a different manufacturer than the two reported by Robert Szasz. This would seem to indicate that the AGM cells have a common ability for this no matter which manufacturer’s product it is. This may be a stretch to accept, but there were three completely different manufacturers and the difference in manufacturing dates from the two studies is over ten years, and all were able to be recovered into useful cells. While not a part of the discussion of this paper, could this ability lend itself to intermittent charging?

Another study is not so well known due, to the fact that it was an EPRI funded project and not released to the general public. The project was undertaken to determine if naturally aged VRLA batteries could perform as designed following a seismic test. This project has nothing to do with the special recovery process being explained in this paper but is added here just to provide additional information for those unaware of some of the history of VRLA batteries. The project investigated the ability of naturally aged VRLA batteries of approximately ten years of age being able to meet the capacity test requirements as listed in IEEE 535-2006 for qualification for safety related batteries at nuclear plants. The research project required two different manufacturers' products in order to see if the generic design was applicable. This study was in response to the Fukushima disaster and a general desire to be able to provide as much reserve time as possible within the confines of existing Class 1E battery rooms. Because of the energy density available with 2 volt VRLA batteries, it is possible to install 2 to 3 times the amount of reserve time by using VRLA technology in a VLA battery room. The general results of this were reported at Battcon 2013 (17). Although both systems passed the testing requested of us, the concept was not pursued any further that this author is aware of.

Review and Summation

There have been substantial changes to the process of attempting to recover 2 volt AGM VRLA cells from PCL from 1994 up until today, and the transition went from just adding water in varying amounts to the cells, which turned out to be a short term improvement, then on to the inclusion of a Philadelphia Scientific catalyst equipped vent, and then to the inclusion of very high rate charging. We now are at last able to gain the maximum amount of recovery possible and maintain it for extended periods.

However, everyone needs to understand that there is no “one size – fits all procedure”, and not all PCL is the result of dry-out, as negative underpolarization issues are continually in play, as could be unique manufacturing or processing issues. It also needs to be understood that incorrectly performing the Special Recovery Process can also cause problems as well as fix them. It may be hard to accept that there are varying levels of capabilities with battery service organizations, but just as with surgeons, they are not all the same or have the same capabilities. A botched operation can cause damage as well as cure it, just as a botched attempt at the Special Recovery Process can yield less than desirable results.

While the IEEE 1188a2014 explains the general procedure for using the Special Recovery Process in a reactive manner, it must also be understood that the same actions can be used in a proactive manner to prevent PCL from occurring. It only seems to make sense to use preventive actions when applicable, rather than wait until some sort of failure occurs and then to react to that.

What has been very interesting to learn along the way, over the past 20 years, is just how misunderstood these cells were, and how they have a tremendous ability to recover from substantial neglect or abuse and, as they are still physically intact, be returned to reliable and useful battery strings. It also acknowledges that a tested capacity of less than 80% with 2 volt VRLA cells does not necessarily mean that the battery needs to be replaced, or that its degradation rate is increasing or will increase. Instead, you need to determine if your battery just requires corrective actions, or really is at end of life.

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