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# Avoid catastrophic failure events

Inside

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## Detecting internal post-seal failures due to nodular corrosion in VLA cells

The issue of internal positive post seal failures, which has been a problem issue with a number of battery manufacturers over the years, and which was understood to have been addressed and resolved quite some time ago, is now appearing again. Pete DeMar reports on his findings at three power-plant systems and explains how to detect and avoid the issue.

This paper is primarily going to report on a sixty-cell VLA (vented lead-acid) stationary battery that failed horribly when called upon during a unit trip. The battery had what would be considered a quality, quarterly, preventative-maintenance (PM) program, which included battery capacity testing. The overall cost from that failure at the power plant resulted in a loss exceeding $8 million. This is not considered to be 'chump change' in anyone's book.

At the time of the failure (5/26/19) the battery, from a major quality battery manufacturer, was only four years and seven months old. The battery had passed a battery capacity test 14 months prior to the failure. ***How can this happen?***

We will explain this incident in detail and explain how, by performing an annual nodular corrosion detection inspection, you will be able to detect the issue early enough to prevent a catastrophe. Hopefully you can benefit from this lesson at a substantially reduced cost than this plant incurred.

Also covered will be the report on observations at two additional power plants. At one

plant we discovered two battery systems, that respectively have 81% and 75% of their internal positive post seals failing, and not a single failing seal was observable by looking inward from the side of the jar.

All were only discovered through the use of a borescope. Both of these battery systems were less than six years old when this issue was discovered. These cells were from a different manufacturer than those from the above plant, and also are from a well-known international manufacturer. These were discovered in January 2020. This date is provided so that you can realise that you could also have batteries that have this issue.

Because you do not *know* that you have this issue, does not mean that you do not have it. If you are not performing internal post seal inspections, where you are specifically looking for issues caused by nodular corrosion, you really have no idea of their condition.

Nodular corrosion must not be confused with creep corrosion which is when you observe a changing of the colour (darkening) of the positive post/pillar. This is an oxidation layer and is normally not a concern, as long as it does not cause a degradation of the post-to-connection hardware resistance connection, or corrosion of the hardware. Before I go into explaining why this paper and why right now, it is important for all to understand that the problem of nodular corrosion has been around for, I would guess, more than forty years.

At the 1988 Intelec Conference in San Diego, William Brecht and Sudhan Misra presented a paper[1] on the development of a new type of post seal by C&D. The seal was being developed specifically to combat the issue of nodular corrosion of the positive posts, which was being experienced by all manufacturers, all with differing post seal designs. Their paper does an excellent job of explaining just how and why this occurs. In addition, they clearly state that this can be a minor issue, or it can lead to a cell failing open. This is exactly what occurred in the events that led to the writing of this paper.

Nodular corrosion can lead to catastrophic failure if left unaddressed, but it is easy to identify before it develops to where it becomes a danger. All

*Fig 1: Initial picture received of the battery*

you need to do is to perform a proper nodular corrosion detection inspection, which will be explained here.

In May 2019 our company was contacted by an insurance carrier for a power plant in South America that recently had a battery failure during a unit trip event. The battery failure on one of their units had resulted in severe damage to the turbine-generator. This was due to the failure of the battery to provide power to the lube oil pumps and other DC-supported equipment that, when called upon, is required to provide a safe, orderly, and damage-free shutdown of the generator. Those of you that are from a power plant, or that understand how power plants operate, will understand that this is not a good thing. In fact, it is a very bad thing. The failure had occurred the previous month, and they were contacting us because, from all the information they had, this battery was in perfect condition when it failed open.

The insurance carrier recommended to the plant that they bring in outside expertise, with experience in this type of an issue, to determine why this occurred. Their concern was that since this was totally unexpected, then once the unit was rebuilt and placed back into service, what assurance was there that this could not occur again. Because of this concern they contacted our company to perform a root-cause analysis of why this occurred, and to determine if they had any other at-risk cells.

We had not dealt with this plant previously so we had no information on their systems. Upon our agreeing to assist them, we then started requesting information, plus lots of pictures. We requested, and received, every inspection report all the way back to when the battery was installed in 2014, which also included the capacity test that was performed on March 20, 2018. This was just 14 months prior to the catastrophic failure. ***How could this occur?*** As you will see, the problem was hiding in plain sight.

Upon reviewing the inspection reports, there was nothing really unusual as compared to any other typical quarterly or annual inspection reports that we have reviewed from those that are following the IEEE 450 standard and the manufacturer's recommendations.

In addition, from looking at the numerous pictures provided to us, there was nothing unusual observed. As can be seen in ***Fig 1***, the battery and battery room was spotless.

The only item that was able to be observed was cell 46 had a burn mark on the inside of the jar, but nothing else was unusual. The cell was intact and showed no outward signs of a problem. Cell 46 is the cell that went open circuit when the plant transferred to battery power, which resulted in the loss of all DC support to the system.

It needs to be noted that with some battery string layouts it is impossible to see into the post seal areas from outside of the cells, because of the way the cells are arranged on the racks. This may be due to the racks being stepped, or placed against a wall, or a number of conditions. Because of these issues it is critically important that a thorough internal inspection be made with a borescope. Skip this part of the inspection at your own peril.

### Background

As stated earlier the issue of nodular corrosion and the threat it imposes has been known about for a long time. A number of years ago internal positive post seal failures, with the resultant damage to the positive post/pillar and often the covers, were not that unusual. The manufacturers that were experiencing those issues addressed them over time and, even though there are still some occasional issues, it has not been as common as it was 20+ years ago. Up until now, it appears. We have observed more cases of this issue across the various post-seal designs in the past 12 months than in the previous 10 years.

Just as it was many years ago, the only way to discover the issue, when it is still at the point where it does not pose a catastrophic risk, is by looking for it. Obviously, anyone can see part of the results of the issue after it has progressed substantially, and the covers have started to crack.

Although cracked covers are a maintenance and safety concern, the real danger to your support system lies beneath the cover, between the internal and external positive post seals, as that is where the post is being attacked. The need is to find the problem when it is early enough to replace the unit/s before they no will longer support the loads, without failing open under load.

As everyone reading this understands, a high resistance conduction path (think the post itself not the connection point outside the cell) will, depending upon its conductivity still carry some pretty substantial current.

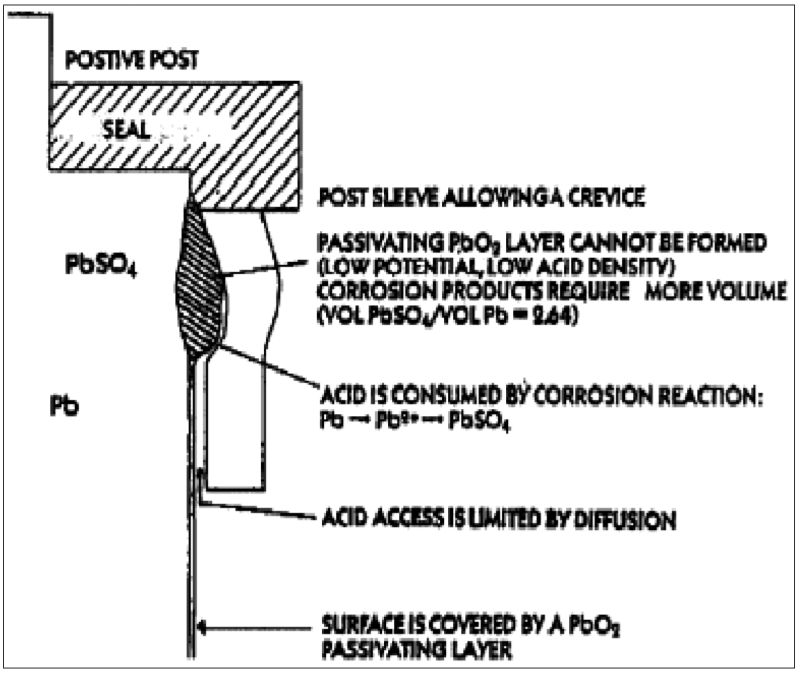


*Fig 2: Drawing of nodular corrosion typical location from the INFOBAT 2004 presentation by (3) Jose Marrero of Southern Nuclear*

Of course there will be an increase in the voltage drop along its length as compared to a post that is not degraded. However these same posts, that have advanced degradation due to nodular corrosion, can fail open with unpleasant results when called upon to pass two, three, or more times current than occurs during a constant current discharge test. Such as when a power plant trips and the lube-oil pumps, jacking pumps, and other instantaneous loads call for power.

***Fig 2*** illustrates how the post becomes deformed when nodular corrosion has occurred (a drawing like this is also in the paper by Brecht & Misra).They also included numerous pictures in that paper that showed cells from multiple battery manufacturers that utilised differing post-seal technologies, and each picture showed the internal positive post -seal failures due to nodular corrosion.

### The investigation

As stated above, the first action was to review all possible data we could get our hands on and see if it pointed us in any direction. There were also numerous phone calls and e-mails.

What we learned was, based upon the inspection reports, discharge test report, and pictures, there was nothing obviously wrong with the battery. Plus, the cell that failed open (cell 46) was still intact and, with the exception of a burn mark on the inside of the jar, appeared to be normal. ***How can this be? Why wasn't cell 46 blown apart?***

Based upon information provided by the plant, the battery failed open within the first seconds of the unit trip, which, as all that understand power plant loads know, is when the inrush loads far exceed the steady-state loads. With the understanding of the reported condition of cell 46, and this information on when the string failed open, it made sense that cell 46 is where we needed to start looking.

Because of the condition of the cover of cell 46 (it looked perfect) in the pictures we received, the prime suspect became the internal positive-post seal. To determine if our idea of the root cause was correct, we next dispatched ourselves to this plant in South America for the on-site portion of this project.

**Battery capacity test**

The battery-testing company had run the discharge test at the manufacturer's published three-hour rate, and the battery passed the test. They did have to pause the test and bypass two cells, but neither of those were cell 46, which is the one that opened.

While a standard, constant-current, one-rate, discharge test is sufficient for many batteries that have a steady state load, it will not cover every eventuality. We believe that with any battery that will have a higher value inrush in the very beginning of the load on the battery, (even if it is for parts of seconds) that inrush should always be included in the test. In other words, run a modified performance test as explained in the (2) IEEE 450-2010 Standard. The amount of capacity that is removed within that first 1-minute (or less) load, will not impact the battery capacity calculation in any meaningful way.

Also, by duplicating that inrush load, you will both verify that the string voltage will maintain a voltage that is required for your equipment, plus it will prove that your battery will hold together for that inrush load. Then, obviously, you follow up with a rate that meets or exceeds the rest of your loads and which can be used to actually plot a capacity. Credit needs to be given to Tim Bolgeo for coming up with the idea of a modified performance test. Prior to his conceptualising the idea of the joining of a service test (which proves that the battery will do what it is designed to do) and a performance test (which is to prove capacity as compared to a manufacturers spec sheet), some plants had to run two tests to gather all of that information. Thus, the modified performance test was created and is very beneficial to all users that have multiple stepped loads.

It should be recommended for anyone that has a system that requires the application of a substantially larger initial battery load than the normal steady state load to use a modified performance test that includes those loads. If the site in this paper had been testing using the modified performance test, they would at least have had the battery fail open when the battery was out of service, with much less expensive results.

**On-site visit**

Upon arrival at the plant and after site- safety orientation, we were very fortunate to have the supervisor of electrical maintenance, (who spoke fluent English) assigned to us as our support person. I cannot express

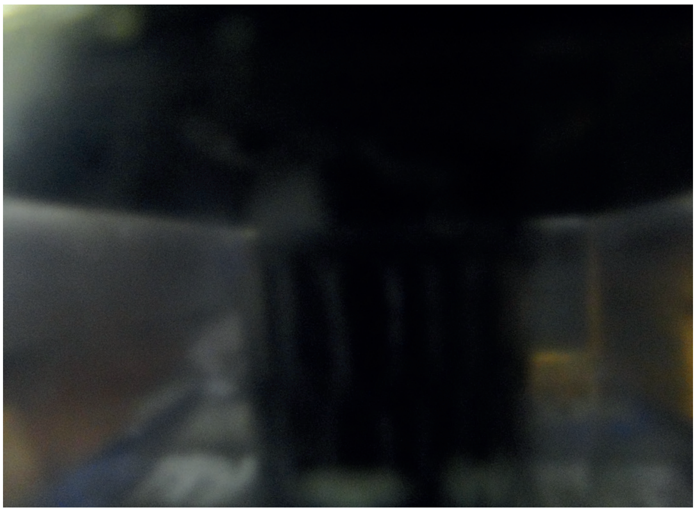

*Fig 3: This was the first cell that we observed the rupturing of the internal positive post seal, and yes this is often how difficult it can be to see under normal conditions*


*Fig 4: The brighter the light used, the easier it becomes to see some of the post seal faults*

how very much we appreciated having him work with us.

We had quite a bit of test equipment with us as, even though we believed that the issue was directly related to an internal positive post seal failure, we also wanted to perform a complete inspection of all of the cells to include internal ohmic readings. Please understand that we had an idea of what we thought was going to be discovered, but an idea is worth very little without proof of what you are thinking.

While Andres was setting up a table for our computer and bringing other equipment, I decided to start looking for the visual indicator of what we suspected. This initial action was performed with just my flashlight as I was going to be inspecting the inside of the cells from outside of the jar at this point. ***Fig 1*** shows the battery and ,as can be seen, it is quite elevated which makes it physically easier to see inside the cells than when you have to crawl around on your hands and knees to see under the covers in all of the cells.

I started with cell # 1 which was the most positive cell and followed the flow of the cells. As I had not seen anything by the time I reached cell 30, I began to question our original thoughts as to the cause of the failure. Even before I started looking into cell 1, I had tried to look inside cell 46. Unfortunately, due to the condition of that jar, with the burn marks on the inside, I could not see anything clearly enough to feel comfortable in our thoughts. If I grabbed the positive post it would move just a little but that was the extent of the external indicators. (We later learned that the loose post was the result of their removing the cable from cell 45–46 to bypass that cell).

I continued to look and was growing more doubtful of our theory as I passed cell 45. However, when I got to cell 51: there it was- a severely degraded internal positive post seal. I showed Andres what it looked like and where to look for it. He started looking and found another cell with a seal in the same condition. We both continued to look from the outside of the cells and actually were double-checking each other, but those two cells were the only ones detectable from the outside of the cell. Andres and I then broke out our borescopes and commenced checking the seals from inside the cells. Again, we were double- checking each other. It is very easy to find this issue when it is well advanced, but a bit more difficult to catch in the earliest stages. The clues are sometimes very subtle. ***Fig 3*** shows cell 51, and, as can be observed, the problem was quite advanced. ***Fig 4*** is the same post with brighter illumination. Through the use of the boroscopes we were able to locate an additional three cells that would otherwise not have been detectable. ***(Figs 5 &6)***. ***Figs 3***, ***4***, ***5***, & ***6*** are pictures taken during our on-site inspections.

*Fig 5: While this cracking is difficult to see, this is what was actually observed. A majority of the cracks that we typically observe are more vertically oriented but, as can be seen, can also be horizontally oriented*

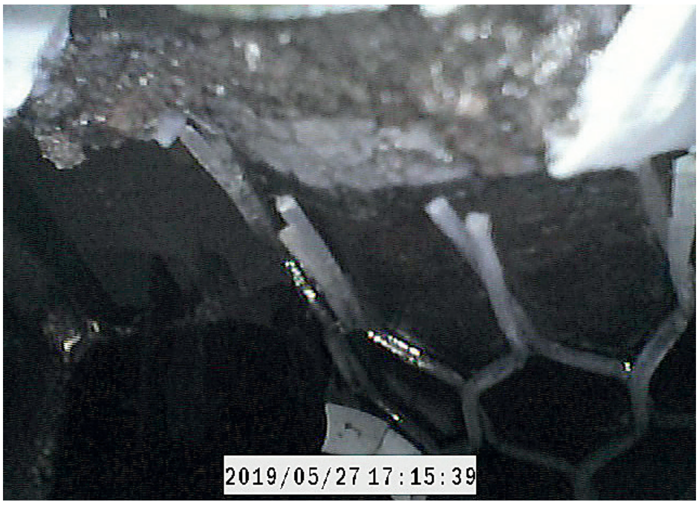


*Fig 6: Borescope pic - this post seal fault was not observable from outside the cell*

*Fig 7: Cell 53 post condition on initial cut away of cover*


*Fig 8: Condition of cell 53 post once the post-seal material was removed*

We also measured and recorded the internal ohmic values of the 59 cells that were in the string. Two of the cells that we discovered with rupturing internal post seals did show internal ohmic values that were outside of the normal values for that model cell, but were not at a point where they would indicate that they needed any further action. That these issues were not detectable by the use of two different internal ohmic measurement techniques, has to lead to questioning whether or not the PRC-005 allowance for internal ohmic measurements as a substitute for battery capacity testing is at all adequate. Yes, this battery had passed a capacity test, but that test had not included the inrush loads.

Because of this incident, it would seem to make sense that anyone that has a system that requires a substantially larger initial battery load (inrush), than the normal steady state load, should use a Type 1 Modified Performance Test that includes those loads. In this authors opinion, if the site in this paper had been testing using the modified performance test, they would at least have had the battery fail open when the battery was out of service. A much less costly option.

Obviously, if there had been Nodular Corrosion Detection Inspections performed, the problem would have been observed well in advance of the post getting to the point where it would fail open under load.

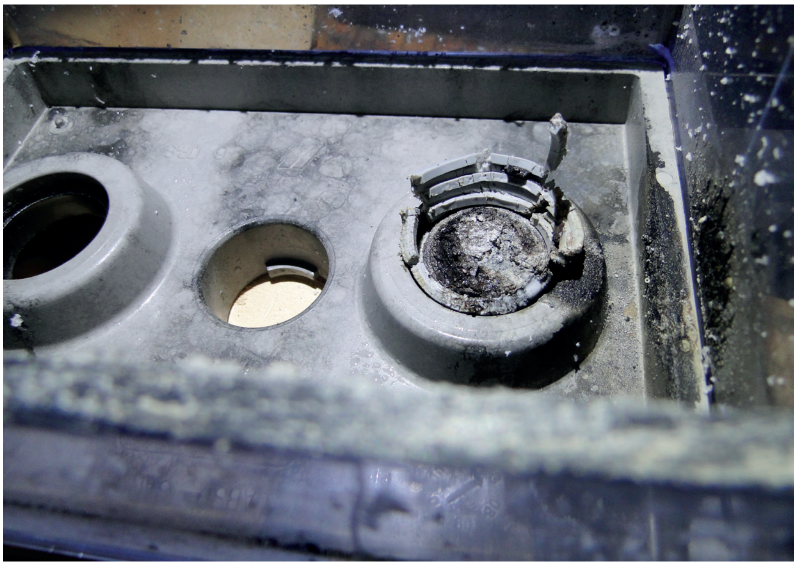

*Fig 9: This is the cover from cell 46. It is easy to see the burn marks on the cover and the side of the jar plus to see that the upper portion of the post is still within its location in the cover. That this cell did not explode when the post melted apart indicates that at the time of the event, that there must have been a very low concentration of hydrogen in the head space, so no fuel was available to ignite (4). The post simply melted apart.*

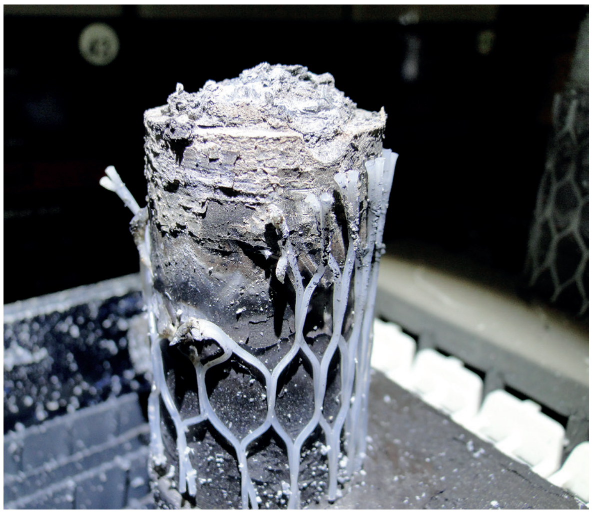

*Fig 10: Cell 46 post*

I consider that the decay in cell 46 could not have been acceptable just 14 months prior and rapidly deteriorated to the point where it would now fail open.

It is also my opinion that in IEEE Standard 450-2010, that in Annex E "Visual Inspection of Battery Installations" a line should be added to e) that states that a "Nodular Corrosion Detection Inspection" be included, in order to draw attention to the importance of this issue.

**Cell dissections**

Upon completion of our on-site inspections, we had accomplished our required task of identifying all at-risk cells within the battery string that had the same failure condition as that which caused the failure. As will be seen in the following pictures, taken during our dissections of the six cells identified, some were quite advanced and some were just barely beginning to exhibit the failure.

We requested that the five cells that we had identified, and the one (cell 46) that had opened, be replaced and sent to our facility in Oswego, NY for further analysis to include dissections. ***Figs 7 – 10*** show some of our observations.

**Additional sites discovered since January 1, 2020 with nodular corrosion issues**

***Figs 11-15*** are from two different locations, with two different manufacturers. The internal post seal designs are different from the design used in the main body of this report. As can clearly be observed, they are also degrading and, as such, can easily be detected, if checked.

As shown in ***Fig 11***, once the nodular corrosion has advanced to some point that is specific to the cell design and materials, the covers will begin to crack. This is a direct result of the nodular corrosion. Once the cover is cracked the gasses from inside the cell will naturally seek the path of least resistance to escape the cell. These cracks in the cover obviously compromise safety as the cover will no longer have the function of a flame arrestor to prevent any outside ignition source transferring to inside the cell.

**Summary**

Failure of internal positive post seals and the creation of Nodular Corrosion is an ongoing problem that can occur with any type of post seal, and the results can be minor or major, depending upon a variety of issues. However, you do not have to find out if you have this issue the hard way. All you have to do is to actually take the time to perform a proper Nodular Corrosion Detection


*Fig 11: Cover showing results of advanced nodular corrosion*

*Fig 12: Cracked post seal - only observable from inside cell*

*Fig 13: Another post seal crack in same battery as Fig 12 - only observable from inside the cell*

*Fig 14: Different manufacturer different post seal design same issue – notice the unusual bump that is visible below the post seal level*

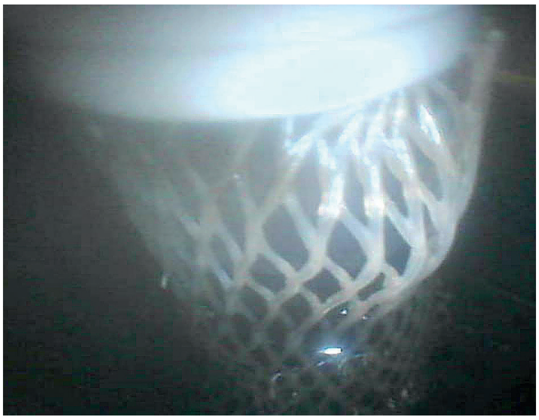

*Fig 15: Unusual bump below the webbing, but no evidence of a post seal failure yet*

Inspection to look for these early indicators, and then to act upon your findings. We recommend that this test be performed,at least once a year, by someone who understands both the importance of this inspection, and how to do it. Remember: all that is required is a flashlight and a borescope.

## References


1. *INTELEC 1988 – William B. Brecht & Sudhan S. Misra - Vulcanised Rubber Post Seal for Lead-Acid Batteries a New Generic Type*
2. *IEEE 450-2010 IEEE Recommended Practice for Maintenance, Testing, and Replacement of Vented Lead-Acid Batteries for Stationary Applications.*
3. *INFOBAT 2004 – Josè A. Marrero of Southern Nuclear – Lead-Acid Stationary Batteries – Types, Failure Mechanisms & Testing.*
4. *Communications with Jim McDowell regarding understanding of how this could occur without rupturing the cell during the melting apart of the post material.*