IMPACT OF ALLOY AND GEOMETRY ON VLA POSITIVE GRID DESIGNS

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Abstract

Historically, a true 20-year life vented lead acid (VLA) battery meant a thick positive plate, usually 0.25" or thicker. New materials and improved designs have resulted in a reduction of grid corrosion and associated positive plate growth, making it possible to achieve 20-year life with thinner plates. This paper will share results of life testing and field data to show 20 years of life can be achieved with these new designs.

Introduction

There have been many papers authored regarding positive grid growth in pure lead, calcium lead, and lead antimony batteries over the decades with most of the recent publications primarily focused upon valve-regulated batteries (VRLA). It proves much more difficult to find recent papers for VLA positive grid corrosion and cell life. The most frequently cited VLA corrosion research papers are now over 50 years old!

Early work by Willihnganz (1) on lead-calcium batteries had established a threshold of 10% horizontal growth as representative of end of life condition for high calcium (0.07%) content VLA cells based upon field returned batteries and accelerated life testing. Cannone et al (2) established a lower threshold of 4% within their work titled "Positive Grid Design Principles" published in *The Bell System Technical Journal*, September 1970. The 4% horizontal limit was more realistic for this lower calcium (0.05%) plate as the positive active material would begin to lose contact with the grid wires beyond this value and still provide ample time for battery replacement before capacity failure occurred. The early research by Landers (3-5), Willihnganz (1), and Cannone et al (2) regarding positive grid corrosion, life, and design are still finding relevance in today's VLA products and are the foundations of the present designs and operating parameters.

VLA cell life has been universally accepted as a direct function of the time to failure of the positive plate (grid). IEEE 535, "IEEE Standard for Qualification of Class 1E Vented Lead Acid Storage Batteries for Nuclear Power Generating Stations," specifically includes an aging procedure requirement to age the cell, "…to the predominant aging failure mode which is based on the failure of the positive plates." IEEE 535 and IEEE 450, "IEEE Recommended Practice for Maintenance, Testing, and Replacement of Vented Lead-Acid Batteries for Stationary Applications," establish end of life of a VLA battery to be when it can no longer deliver 80% of its manufacturer's rating.

The historic perception has been the thicker the plate…the longer the life. While the basis of this argument has merit, there is more to a long-life grid than just thickness. The growth of the positive grid is critically dependent upon several factors including: grid alloy, grid wire geometry, and grain size of casting (process). Lead calcium plates grow (corrode) in length and width over the course of their life due to surface and intergranular corrosion (grain boundary).

The positive plate is cathodic during discharge so that electrons are accepted to bring about a chemical reduction. On charging an anodic reaction or oxidation occurs and the electrons leave the plate. The negative plate functions as an anode during discharge and a cathode during charge with corresponding electron exchange and chemical oxidation or reduction. Since the plates are maintained under a constant float charge condition for virtually their entire service life, it is the oxidation of the positive plate that is a major determinant of battery life.

Since those early studies on higher calcium VLA life, significant advancements in grid alloys have been made which have resulted in more corrosion resistant grids. The alloy advancements, in combination with grid geometry changes, have resulted in positive plates exhibiting significantly less growth at the end of the traditional 20-year design life.

Alloy & Grid Geometry Improvements

Much of the early research and grid growth projections were based upon binary, high calcium content alloys. The Malley & Williamson (6) paper on high temperature VRLA products included data detailing reduced plate growth on grids cast with calcium-tin alloys. Data presented in the Results section will show similar growth and conclusion for VLA batteries.

The positive grid continuously corrodes (grows) over its life. Battery designs often address this phenomenon by suspending the positive plates to allow for vertical growth and allowing separator overlap on sides of plates for horizontal growth. Since the positive plates are supported by the negative plates, the positive grid does not need to provide structural support (loading) but rather resistance against excessive grid growth and the forces applied during pasting. This is accomplished by dividing the grid up into quadrants (subdividing grid into smaller grid sections) to limit total grid growth; reference Figure 1. The larger horizontal and vertical bars act to restrict overall grid growth thus allowing active material to maintain contact with grid wires for a longer period. The more intermediate members provide more restraint on positive plate growth resulting in a longer life cell.

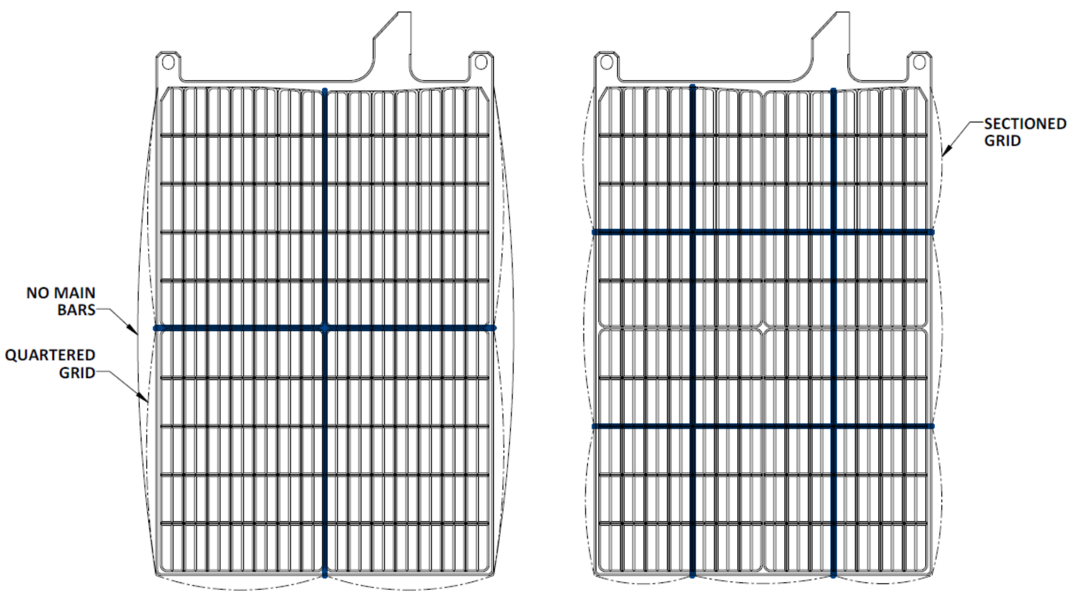

Figure 1: Positive Grid Construction, Main Wires

Wire geometry is selected to provide large surface area contact between active material and grid wires. The number of wires, active material pellet size, wire shape, wire size, and wire placement are all contributing factors that must be balanced for the design of a long-life grid. The embedding of the internal grid wires within the positive active material also aids in reduction of grid wire surface oxidation corrosion.

The original 20-year telecom/utility lead calcium VLA batteries were first introduced with roughly 0.25”-0.27” thick positive plates. Many of these models are still offered today while later battery models were introduced with thicker (0.31”) positive plates. There were various reasons why positive grid thicknesses were increased to 0.31” over forty years ago including competitive pressures from the introduction of Bell Labs’ Round cell which was introduced with a 30-year warranty (later increased to a 40-year) and economic pressures. Lead was one of the cheapest raw materials used in the battery so utilizing thicker grids reduced the number of plates and separators used within a battery. The changes to utilize thicker grids were never about achieving a 20-year life as the 0.25” plate designs were already achieving this. The positive grid is universally accepted as the most important component in a well-designed lead acid battery as it typically determines performance and life for VLA float batteries.

Experimental

Positive grid growth data was collected from various VLA product models over several years. The battery data set includes cells received back from the field (naturally aged nuclear cells) and standard production cells supplied for lab testing. Some of the naturally aged cells were returned from the field after 17 years of service and then maintained on float potential in controlled battery lab environment (77°F) for an additional eight years.

Accelerated thermal aging per IEEE 535 at 160°F/71°C, using ten (10) test days per equivalent year, was conducted to age the standard production cells produced with Ca-Sn-Al lead. Thermal aging was conducted in an insulated, steel environmental chamber heated by forced air and controlled with microprocessor controllers. The environmental chambers were maintained within +5/-2°F (+3°C to -1°C). The cells were maintained under float conditions with positive plate polarizations maintained between 50-100mV for the duration of the thermal aging period. All cells were intermittently capacity tested throughout the thermal aging period to insure integrity of cells. Prior to the disassembly of cells to measure positive grid growth, all cells were subjected to a final capacity test.

For the capacity retention over life data acquisition, cell testing was reviewed on over sixty cells conducted as part of routine life testing of VLA products. After conducting baseline capacity test, thermally aging was conducted per IEEE 535 as detailed above. The cells were removed from the environmental chambers every three equivalent years of life (30 days), cooled, floated for 72 hours, and then capacity tested prior to being placed back into thermal chamber. This process was repeated until the cells fell below 80% of rated capacity. For conservatism, and to reflect the intent of IEEE 450 defining battery end of life as being 80% of rated capacity, the data presented in the results section were normalized against ***initial*** (baseline) capacity so as to not take advantage of any overperforming (under rated) batteries.

Results & Discussion

Figure 2 illustrates the impact a specially engineered alloy can make on positive grid growth. The data presented was from timed dissections of batteries and not related to battery capacity failures; all batteries dissected were still above 90% of initial capacity. As previously presented within this paper, early end of life grid growth limits were established at 10% (Willihnganz) and later reduced to 4% (Cannone). The horizontal and vertical growth percentages from virtually identical grids (size, thickness, number of wires) cast from different alloys (0.03%Ca-Pb & Ca-Sn-Al) are presented in Figure 2 highlighting the impact of the alloy change only. At twenty years' life, both alloys resulted in positive grid growth less than 1.5%. Comparing the common 22-year life intercept, the Ca-Sn-Al alloy demonstrates significantly less horizontal and vertical grid growth than the 0.03%b Ca-Pb. Both alloys are exhibiting growth significantly less than the accepted 4% level at their defined end of life.

The naturally aged cells (0.03% Ca-Pb) all maintained greater than 100% of their rated capacity while the thermally aged cells exhibited a maximum capacity loss of 8% over 32 years' equivalent life.

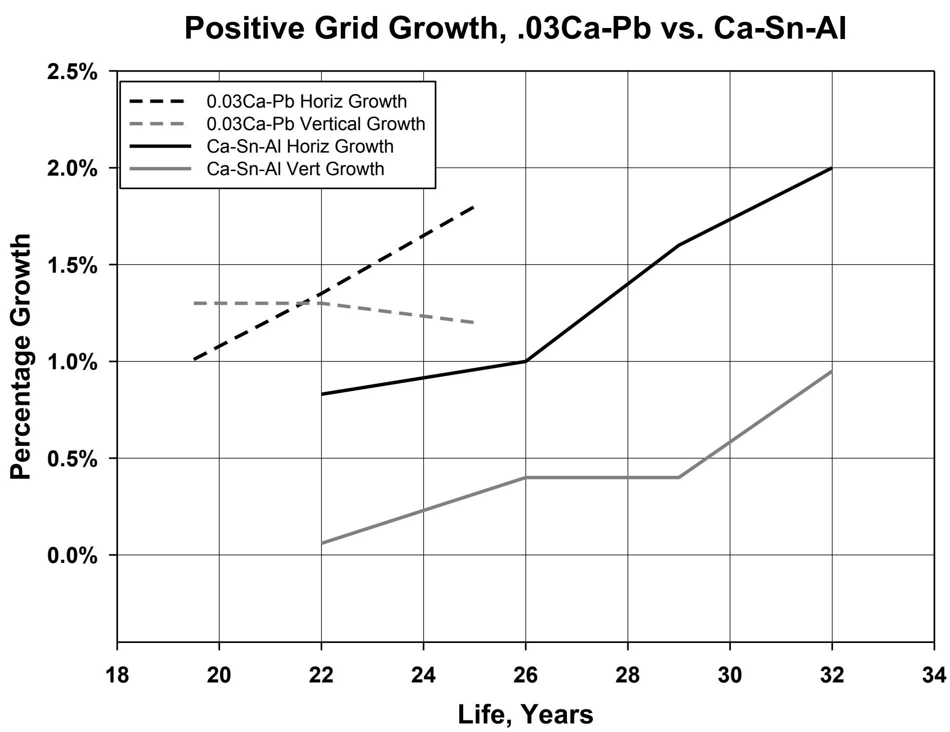

Figure 2: Positive Grid Growth for Different Alloys

Similar growth studies were carried out on cells built with thinner (0.21") positive plates cast from the Ca-Sn-Al alloy and the overall growth percentages are very similar to the 50% thicker (0.3") plates presented in Figure 2. Unfortunately, this data was only captured at the 21-year life point with the horizontal growth averaging 1.2% and the vertical growth at less than 0.4%. The similarities in growth percentages between 0.21" and 0.3" grids are not entirely unexpected as many of the internal wires of the grid designs are of similar size/shape regardless of the outside frame thickness.

Accelerated life testing using the thermal aging factors of IEEE 535 were conducted over several years on various models of VLA float batteries. The batteries included models from UPS, Utility, and Telecom product offerings and were of various positive plate sizes and thicknesses. The capacity retention data presented in Figure 3 is representative of over 60 cells. Regardless of the market application, or the size/thickness of positive plates, all models demonstrated similar capacity retention characteristics. The capacity retention data presented in Figure 3 has been normalized to **initial** capacity results versus rated capacity to comply with the intent of IEEE 450's (20% capacity loss) definition for end of life (80% capacity).

Average results plotted by positive plate thickness are presented in Figure 3 and life values beyond 25 years have been truncated. Cells assembled with positive plates thicknesses between 0.21" and 0.31" all maintained greater than 90% of initial capacity over their warranted 20-year life. To improve the readability of Figure 3, positive grid thicknesses less than 0.21" were removed. However, thermal aging experiments on UPS batteries with grid thicknesses as thin as 0.17" have also successfully achieved over 20-year life.

Generally, VLA float batteries experience very little capacity loss over their 20-year design life if maintained in a controlled environment. The data presented here shows life extending beyond 20 years and some of that conservatism is built into VLA products to address the uniqueness of every individual site installation. Not all installations can maintain 77°F room temperatures, control machine vibrations, service batteries monthly, limit outages, etc.

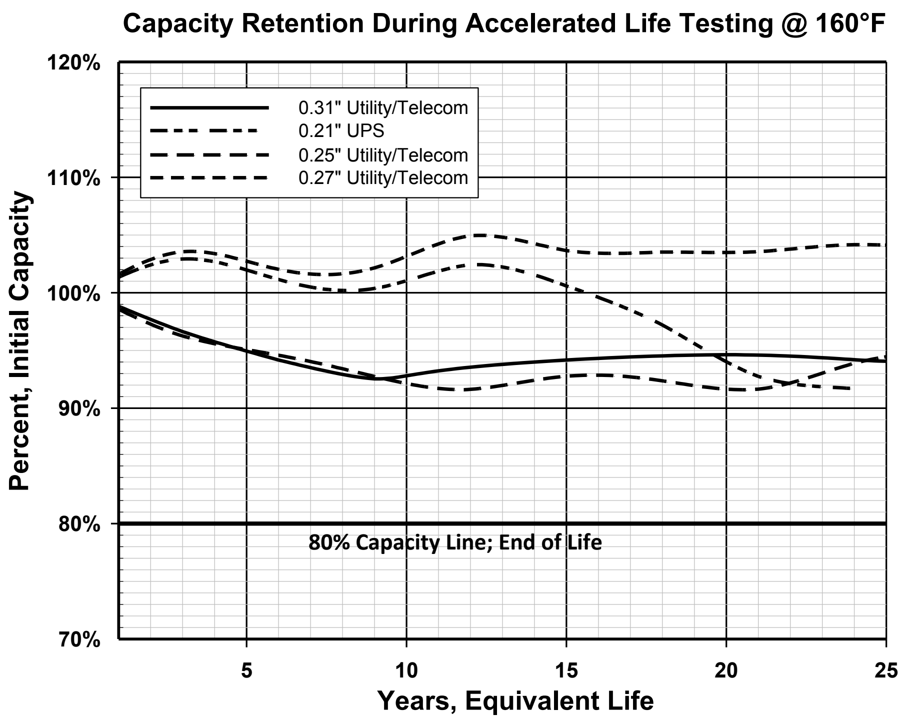

Figure 3: Capacity Retention Over Life

Conclusion

Traditional, time tested, vented lead acid batteries are still alive and well. Market challenges from VRLA and other technologies are having an impact on VLA sales, but for mission critical applications VLA is still the technology of choice. Development work on improving designs to meet changing market demands continues. The long-standing assumptions that a 20-year life of a VLA battery is governed by a minimum thickness positive plate needs to be revisited. Advancements in grid alloy and grid geometry are minimizing the effects of corrosion on the positive grid and resulting in thinner positive plates mirroring the life and performance characteristics of traditionally much thicker plates. Batteries will continue to fail for a multitude of reasons (sedimentation, premature capacity loss, post corrosion, shorts, etc.) but excessive growth of the positive plate should not be one of them.

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