# VRLA BATTERIES: AGM vs. GELLED ELECTROLYTE REVISITED

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**Introduction**

VRLA cells used in stationary battery applications have now been installed for approximately 30 years. They are found in telecommunications central offices, wireline remotes, wireless cell sites and mobile switching centers as well as CATV head-ends and neighborhood nodes, to name a few areas of use. They are commonly used in off-grid photovoltaic installations as well as traction or motive power applications. Recently, new interest has arisen on the possibility of using VRLA cells in lieu of VLA cells in certain critical applications where VRLA cells have not previously been permitted or qualified in the past[1].

This interest has been brought about in large part due to the pressure to reduce maintenance costs while balancing regulatory requirements imposed by government agencies, e.g. NERC in the electric utility space and the NRC in the nuclear power generation arena, among others.

The main failure mechanism for a VLA wet cell has long been recognized as accelerated positive plate corrosion that leads to a reduction in the capacity of the string to below 80% of its rated discharge capability. The nuclear industry and the NRC recognize this fact and use it as the basis to qualify batteries for use in Class 1E safety related areas within a nuclear power generation station.

It is also a known fact that the VRLA cell introduces other failure mechanisms into the equation. One of the major failure mechanisms with VRLA cells used primarily in North America is premature loss of the electrolyte within the cell, or accelerated water loss. This often results in a dryout condition within the cell which can lead to thermal runaway in extreme events if not detected prior to the event. Some believe that dryout is the chief cause of failure within the VRLA[2]. Thus, the track record for reliability and longevity of service life with the VRLA has proven not to be as desirable for critical applications up until now.

In 2006 and 2007 Wieland Rusch gave papers at Battcon that provided a technical analysis of the Vented Lead Acid (VLA) battery vs. the Valve Regulated Lead Acid (VRLA) cell, and looked at certain aspects of the Gelled Electrolyte when compared to the AGM (Absorbed Glass Mat) topology.

BAE Batterien has considerable experience with the gelled electrolyte VRLA in many installations in Europe and North America, and has conducted accelerated life testing of its gelled-electrolyte VRLA cells. It also has results of in-field testing done on these cells which show reliable performance over several years.

Based on this experience, it believes that with a careful understanding of the application to be served as well as carefully analyzing the performance characteristics of the gelled-electrolyte battery, gelled electrolyte cells are capable of service life comparable to a VLA cell.

In light of this information, we also believe that a renewed look at the gelled electrolyte VRLA battery is warranted.

This paper, then, explores again the practical relationship and differences of the gelled-electrolyte cell with those of an AGM cell and to some degree with the VLA cell, and offers its conclusions based on this knowledge.

But first, let’s review the chief characteristics of the three types of cells – well, actually the four types of lead-acid cells – we have in play for stationary applications in North America:

1. VLA – Lead Calcium cells

   It is understood that there are many types of grid alloys used for VLA cells starting with pure lead cells. An evolution of grid alloys in North America has led to a significant share of users that specify lead calcium alloyed cells. The lead calcium cell was developed by the Bell labs in 1935 and has served as a successful cell type for steady float-charge type applications.

2. VLA – Lead Selenium cells

   Lead selenium cells have been the predominant cell type used in Europe and other parts of the world for many decades. They contain a low amount of antimony, but merge many of the advantages of lead antimony with lead calcium while diminishing the negative antimony migration effect that can shorten the life of a pure antimony cell. Their evolution path and apparent advantages have been presented in several papers, so we will not go into detail with them here today.

3. VRLA – Absorbed Glass Mat cells

   The VRLA AGM cell was introduced to the stationary battery community in North America in 1982 with the advent of the Absolyte battery. It was designed to provide a replacement for VLA lead calcium cells. It offered footprint and supposed maintenance benefits, and the telecom industry which was expanding by leaps and bounds due to the introduction of wireless and the effects of deregulation, took great advantage of this new battery.

4. VRLA – Gelled Electrolyte cells

   The gelled electrolyte is not new to users in North America. Actually some of the original VRLA cells were of gelled construction. However, due to the growth of the AGM cell in the US market, most US manufacturers stopped offering the gel.

   The gelled electrolyte cell was actually first introduced in the late 1950's when small lead-acid batteries were made using a silica gel ($SiO_2$)[3]. BAE actually introduced its VRLA in 1997[4]. Today, the gel is used in many parts of the world for stationary battery applications.

**Basics of VRLA Technology**

Not to oversimplify or appear to be too repetitive, but as most who work with batteries on a regular basis know, in a vented lead acid (VLA) flooded cell, during float and discharge, oxygen gas is released from the cell and the hydrogen ions move in the electrolyte to the negative plate. There it is reduced to hydrogen gas. Some of the oxygen gas does find its way to the negative plate where it can be recombined with the hydrogen gas and reform into water. But both the oxygen and the hydrogen gasses not recombined are released and leave the cell via the openings in the flame arrestor. This action results in a slow water loss, but eventually these cells have to be refilled with distilled or ionic water. Of course, one of the advantages of a VLA cell is that this event can be monitored and controlled, assuring that the cells remain filled with the correct amount of electrolyte, contributing to their extended service life.

With valve-regulated lead-acid (VRLA) cells, there are actually two distinct actions: [1] a liquid one in which the hydrogen ions are transported via the electrolyte and [2] a gaseous one. Both play an important role in the performance of the VRLA cell.

In the gaseous phase, oxygen gas migrates to the negative plate where it is reduced to oxygen ions ($O^2$). In the meantime, hydrogen protons ($H^+$) are being transported in the electrolyte to the negative plate as well. At the negative plate the oxygen and hydrogen combine again to form water. Known as the internal oxygen cycle, this process is called recombination of the electrolyte and defines the principle of VRLA methodology. It is based on the principle that "the oxygen evolution rate at the positive electrode and the oxygen-reduction rate at the negative electrode balance each other."[5]

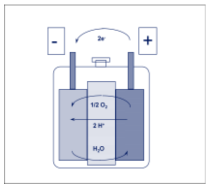

Fig 1: Oxygen Cycle in VRLA Lead-Acid Batteries

In the valve regulated cell, the water is diffused back into the mat or gel. However, it is important to note that the internal oxygen cycle generates water from the oxygen and the hydrogen protons, not the hydrogen gas. This is important because it shows that hydrogen gas is not removed by the internal oxygen cycle.[6] Dr. Rusch points out that while this is true, 5-10% of the hydrogen ions are still reduced to a gaseous state, and this small amount of hydrogen is released through the pressure sensitive release valves.[7]

In the VRLA process, the electrolyte is mobilized in one of two ways, depending upon the type of VRLA being considered.

1. The Absorbed Glass Mat (AGM) VRLA utilizes a microporous felt known as a glass mat to immobilize the electrolyte. The electrolyte then fills the smaller pores of the mat by capillary action, but a good portion of the larger pores remain unfilled. Specific gravity also plays a role here, but we'll deal with that in a moment.

2. The Gelled Electrolyte (GEL) forms by the addition of silica dioxide ($SiO_2$) to the sulfuric acid ($SO_4$) and water ($H_2O$). In this type, the gel shrinks which open crevices that run through the electrolyte. Void space is available around the electrodes, allowing fast transport of the oxygen gas.

Obviously, the question we need to ask and answer today is: what are the differences between these two forms of VRLA cells, and what are the resulting pluses and minuses of each in today's context?

**Major Concerns w/ VRLA Cells**

Over the 30 years that VRLA's have been in service in North America, scores of papers have been written and presented regarding the many issues associated with the VRLA. Battcon was actually started as a user-based forum to address the major issues that were haunting users as the VRLA cells did not live up to their expectations or manufacturer's claims, and Infobatt was also started to address these issues as well as battery monitoring.

And as these papers attest, the emphasis has been on the AGM technology since the major majority of VRLA cells installed in North America are AGM cells.

In all fairness, it is important to point out that there have been advances made in the AGM arena in recent years, but still there is an open question as to how long cells will remain in service at full capacity, even under environmentally controlled conditions.

It is rare if a VRLA AGM battery remains in service at tested >80% capacity for longer than 12 years at constant float at 25°C. I know - there may be some isolated cases where cells have made the 15 year mark or longer, but the general consensus is that if we can get 12 years out of a VRLA (AGM) at float at 25°C, we consider ourselves fortunate. Now some may claim that they can get much longer life out of the AGM cell, but we really don't have a lot of evidence yet that says that is true.

In switchgear or UPS applications, getting to the 10-year mark with tested capacity is unlikely, while 5-7 years is more common with larger 20-year 2V cells. The mono-block 12V types are lucky to get 3-5 years, although I'm sure there are some instances where longer life may be achieved. The difficulty again resides in the limited capacity testing data available from actual installations.

However, it is important to point out, as Al Williamson from C&D did in a 2008 Battcon paper, "High temperatures offer a very challenging environment for any electrochemical system. VRLA products, however, are susceptible to deterioration at high temperatures."[8]

It is a proven fact that batteries placed in high temperature or unmaintained environments are subjected to a set of conditions that will significantly shorten the service life of the battery in question.

So what are the significant causes for concern? And are there recognizable differing results for AGM vs. GEL cells? There are 6 areas that I'd like to open for discussion today:

1. Water Loss and Resulting Dryout
2. Increased Float Current and Internal Resistance
3. Loss of Compression
4. Discharging of the Negative Electrode – PCL 3
5. Thermal Runaway
6. True Cost of Ownership

Let's take a brief look at each of these:

## Water Loss and Resulting Dryout

A major factor in the significance of water loss and potential dryout of the cell rests in the difference in the nature of the two technologies. As Dr. Berndt points out again in his work on VRLA batteries, "One characteristic of both methods of electrolyte immobilization is that, during service, the slight water loss leads to an increase of the gas channels. . . . The result of this is a slight increase in the float-charging current during the operational life of the batteries. This is a system characteristic, and is completely normal."[9]

However, this loss of water not only increases the float current, which is normal, but can also increase the internal resistance of the AGM cell while the effect on the GEL cell is not as evident. As we all know, an increase of the internal resistance of a cell results in a decrease in capacity and has a detrimental effect on its life. How can this be?

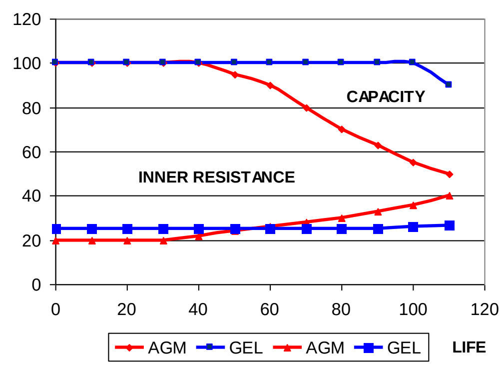


Figure 2: Effect of Internal Resistance on AGM vs. GEL

A lot has to do with the pore structure of the two types of cells.

The AGM fiber glass mat is made of a set of glass fibers in a paper-like arrangement. The fibers are generally 1 to 4 mm thick, each fiber measuring approximately 0.5 µm to 10µm in diameter. The hydrophilic nature of the fiber permits the diluted sulphuric acid to bond on the glass fibers.

Unfortunately, smaller pores in the fiber fill first, while many of the larger pores in the construction do not fill until the mat is completely or 100% saturated. These larger pores, if left unsaturated, are left open. And even the filled ones will open first as dry-out or water loss begins.

Since the AGM is the separator between cells, many manufacturers use an organic binder to provide stability, especially with thinner separators. This is necessary to provide mechanical stability and prevent damage that could lead to short circuits within the cell; nevertheless, it reduces the number of small pores.[10]

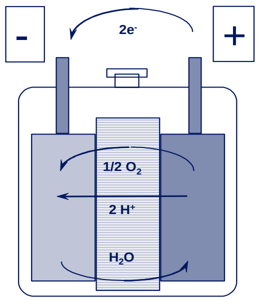


Figure 3: VRLA Recombination AGM

A second effect with the AGM structure is that during float charging or cell discharging the emerging concentrated acid has a tendency to drop down to the bottom of the mat due to the force of gravity. In fact, that is one of the reasons that AGM cells are restricted to about 300mm in height.

On the other hand, the pore structure of the GEL cell is totally different. As H. Tuphorn points out in J. Power Sources 31, 1990, pg 57, "the sulphuric acid bound by the gel, behaves in the same way as in a felt with a pore structure one order of magnitude finer than that of the microglass mat separators."

The GEL cell we have tested is made of pyrogenic silica, a very finely dispersed silicone dioxide ($SiO_2$). Sometimes called a "fumed silica," it is an exceptionally pure form of silicon dioxide. Particles measure from 0.007 to 0.05µm and link together by a "combination of fusion and hydrogen bonding to form chain-like aggregates with high surface areas."[11]

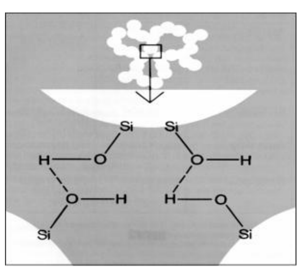


Fig 4: Pyrogenic (Fumed) Silica w/ Hydrogen bridge linked between particles

What is critical to know at this point is that the water and sulphuric acid become trapped in this structure. These chains only have a diameter of 10nm (0.01µm). Therefore, the GEL which is formed out of a liquid homogenous action fills all the gaps between the separator and the plates. This is true for both tubular and flat plates. As the slow water loss occurs within the GEL cell, the GEL forms cracks that permit the oxygen recombination.

This order of magnitude difference in the pore sizes between the GEL and the AGM play a large role in the consequential action of major water loss and dryout. The table below shows the Morphological Differences of the AGM and the GEL:

| Morphological Differences between AGM and GEL | | |
|---|---|---|
| **Description** | **GEL** | **AGM** |
| Diameter of $SiO_2$ Fibers | 0.01µm | 1.0µm |
| Pore size of the active mass | pos. 0.1mm; neg. 0.3µm | pos. 0.1µm; neg. 0.3µm |
| Rigid microporous separator | Yes | N o |
| Plate thickness tolerance | Not critical | Critical |
| Plate contact | SOL/GEL fills all cracks | Elastic properties are essential but limited |

Table 1: Differences between AGM and GEL; Table used by Permission[12]

**Loss of Compression**

In October 1995 Dr. David Feder, a well respected engineer from the Bell Labs and co-developer of the round-cell, presented findings that reported a significant 64% failure rate on greater than 24,000 cells from a database he had collected representing 9 manufacturers of VRLA AGM cells.[13]

Even though the database represented nine different manufacturers, GNB had the dominant market share of large stationary VRLA users in North America at the time. In the year before the paper was given at Intelec, GNB had been receiving reports that a number of their Absolyte II batteries installed in the field were suffering unexplained premature capacity loss.

While not addressing other problems associated with manufacturing or application related problems like lack of maintenance, hostile temperature conditions, etc., they analyzed cells not only made by GNB but the other manufacturers as well and discovered that a problem existed that was common to VRLA AGM technology, and it had its roots in compression loss. [14]

The problem was that the glass mat separator material had shrunk below the dry specification value by some 20% to 40%. They also found that by adding a measured amount of water the AGM glass mat would expand enough to restore capacity for some measure of time. They were careful to point out that "the field adjustment does not correct other problems – such as manufacturing defects or application related issues."[15]

It needs to be noted that since this study was done, additional work has been done in this area by Battery Research and Testing and others, and they have expanded the scope beyond loss of compression to advocate a three step approach to deal with this and the water-loss issue. Some manufacturers have adopted some of the practices recommended by Battery Research and Testing or added catalysts as an internal design step on their own.[16]

GNB, Battery Research and Testing, and others continue to investigate ways to improve the AGM separator, as separator shrinkage does result in loss of contact with the plates and produces the following problems:

1. Gaps in the ionic continuity between the positive and negative plates which results in increased internal resistance. This obviously is a major concern.

2. These gaps cause electrically isolated areas which inhibit the transport of the hydrogen ions and oxygen gas. This results in diminished discharge rates and capacities.

3. Active materials located in isolated pockets self-discharge and lack the capability of efficiently recharging.[17]

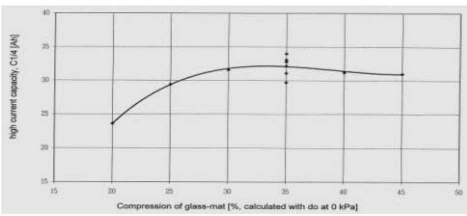


Figure 5: Graph showing measurements of Compression points calculated as a % of high current capacity

To expand on the compression issue, two points need to be emphasized here: [1] compression loss can be attributed to water loss, either through shrinkage of the absorbed glass mat as discussed above, or [2] also through excessive water loss through the jar container. While this latter phenomenon may not be consequential in all cases, there is something to be said for the selection of the jar container for both accounts.

A paper presented by Frank Vaccoro at the 1989 Intelec conference in Florence observed that water loss becomes more critical in unfavorable conditions, i.e. hostile environments, e.g., high temperature and low humidity.[18]

While polycarbonate does have the ability to retain water inside the jar (a lower permeability), ABS and SAN provide the most rigid containers (E-modulus rating), and hence are the main containers used by BAE and other European manufacturers. These offer the best resistance against bulging which can cause loss of electrolyte contact with the plates.

It is also worth noting that loss of oxygen gas through the container walls also results in additional loss of water, and ABS shows some of the strongest retention against that occurrence.[19]

The good news is that for the gelled electrolyte VRLA, the electrolyte is captured and contained in the GEL. This effectively ensures that all gaps are filled from top to bottom of the plate structure, and there is solid continuity between the plates and the gel and the separator regardless of the thickness or thinness of the plates. Use of SAN or ABS jars ensures that the E-module rigidity of the jar container itself is solid. Therefore, compression is not an issue for a properly made GEL cell using pyrogenic silica as its foundation. In fact, in this context it can be said that GEL batteries have similar stable characteristics to the VLA battery until the end of operational life.[20]

**Discharging of the Negative Electrode**

In the VLA flooded cell the grid of the negative plate does not encounter corrosion as long as the battery is properly charged and remains on float – lead is stable and does not corrode. However, a serious corrosion attack can occur, and is frequently observed at the lug/strap burning area of the cell in the VRLA battery. The chief reason this occurs is that the protecting negative potential in reference to the electrolyte decreases due to the continuous oxygen reduction encountered at the negative plate. Remember, this oxygen reduction is what permits the reformation of water as part of the internal oxygen cycle.[21]

This results in the risk of low polarization of the negative electrode. In Figure 5 we see a diagram that illustrates the polarization risk factors for the various types of lead-acid batteries.

BASIC LAW OF FLOAT CHARGE –
POSITIVE AND NEGATIVE ELECTORDES NEED EQUIVALENT POLARISATION

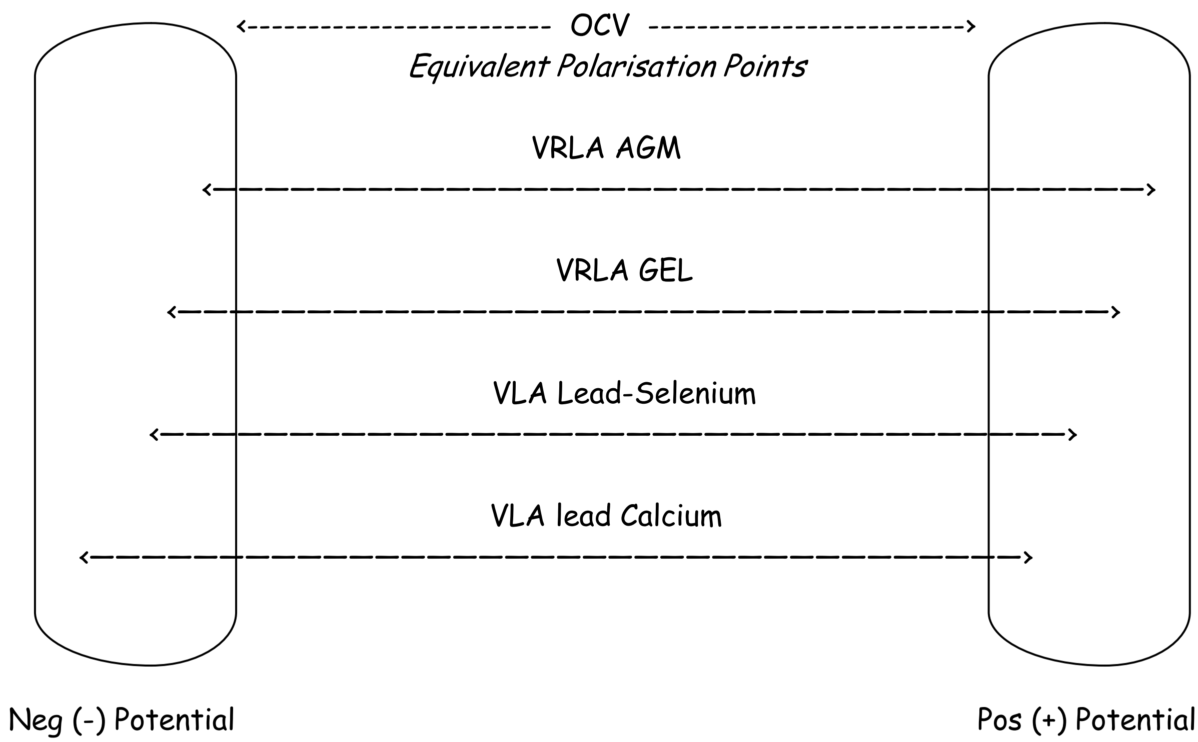


Figure 6: Positive & Negative Polarization Schematic

Commonly known as PLC 3 (Premature Loss of Capacity 3), it cannot be avoided with any cell, but is much more significant with the AGM topology.[22] The reason it is more controllable with the GEL VRLA is due to the fact that the separator used in the GEL cell acts as a barrier to reduce the oxygen recombination. This in turn reduces the polarization of the negative electrode and limits the buildup of sulphation on the negative plate.

**Thermal Runaway**

The events occurring due to thermal runaway have been documented so many times in North American VRLA installations it is not necessary to spend a lot of time on this. I would like to point out, however, that BAE has conducted several tests, including the artificial aging of similar capacity AGM and GEL cells. These cells were aged until 10% of the water content was lost in both cells. The results of that test showed that the AGM cells rose up to 100°C after 5 hours, while the temperature of the GEL cells remained below 50°C even after 28 hours in the test box.[23]

The fact that the GEL and the microporous separator act somewhat similar to the VLA in this case inhibits the likelihood of thermal runaway with a gelled electrolyte. Fortunately, we have not seen any instances of this in our installations to date.

**True Cost of Ownership**

It is true that the initial cost of a GEL electrolyte battery can be a bit more expensive than an AGM equivalent. This is due to the additional price of racking as well as the cost involved in the manufacturing processes, the separator and the GEL itself. However, let's take two examples and see what the true cost of ownership is for a comparable system.

***48VDC String – 1000Ah battery***

Let's assume for sake of argument that 24 cells of a VRLA AGM could be acquired for $20,000. Let's assume for sake of comparison that the GEL VRLA's would cost 15% more, or $23,000. Now let's say that the AGM batteries would last 7 years before reaching the end of their service life with 80% capacity remaining. Now I know some will argue that they can get longer life than 7 years, especially if we add water, use a catalyst, and do heavy recharging of the cell to blow sulphation off the negative plate. But, we'll use the assumption that no cells are replaced or go bad during this seven year period.

Now let's assume, based on the track record we've experienced to date, that a VRLA GEL tubular plate OPzV still shows >80% capacity, but is recommended for replacement due to its proximity to end of life and budget dollars are available.

| Characteristics | GEL Electrolyte VRLA | AGM VRLA |
|---|---|---|
| Initial Cost | $ 23,000.00 | $ 20,000.00 |
| Replacement at 7 years | $ 0.00 | $ 20,800.00 |
| Replacement at 14 years | $ 0.00 | $ 21,632.00 |
| Replacement at 17.5 years | $ 25,374.00 | $ 11,248.00 |
| Total Cost of Ownership at 17.5 years | $ 48,374.00 | $ 73,680.00 |

Table 2: Cost Comparison for a 24 cell (48VDC) application

This assumes an inflation rate of 4% every 7 years, 2% over the last 3.5 year period. We assumed a 50% cost of equipment proration for the last 3.5 years for the AGM. We also did not include any replacement cell costs, warranty replacement labor costs, or additional labor costs associated with mid-stream rehydration activity if part of the process.

Note that there is a cost of ownership savings in dollars of $25,306.00 not including use of money or other factors that would increase the actual savings over time. This nets nearly a 35% savings in dollars just based on the assumptions above. Add in a 1 or 2% cell replacement cost for the AGM's, labor for interim-life analysis and remedial work, and the savings could approach 50% in some cases. And that does not take into account the exposure to risk of critical load associated with the shorter life of the AGM cell.

### *240 cell 480VDC String – 1000Ah battery*

Now let's take a high-end UPS data center application where the uptime reliability is considered "mission critical." Let's assume that we're talking a similar Ah range, but 240 cells instead of 24. For sake of argument, let's say that the AGM's will last 5-6 years and the GEL cells will last 12 years.

Using the same inflation and replacement factor assumptions we used for the 48VDC scenario above, let's see what the true savings could be for the larger installation.

| Characteristics | GEL Electrolyte VRLA | AGM VRLA |
|---|---|---|
| Initial Cost | $ 198,000.00 | $ 169,000.00 |
| Replacement at 6 years | $ 0.00 | $ 175,760.00 |
| Replacement at 12 years | $ 213,840.00 | $ 182,790.00 |
| Total Cost of Ownership at 12 years | $ 411,840.00 | $ 527,550.00 |

Table 3: Cost Comparison for a 240 cell UPS application

This results in a $115,710.00 cost savings over the 12 year period, or 22% more money for use on other investment or infrastructure improvements. And just suppose that the GEL cell could last out to 18 years. Now hold on, I'm not saying that it will, at least not until we have empirical data that shows that it can.

My purpose here is not to pinpoint exact numbers or timeframes, but to provide a comparison given potential parameters that we know can exist based upon past experienced conditions.

**Test Results w/ VRLA Gelled Electrolyte cells**

We do have test data on a few VRLA installations used in UPS data centers we have in place in Canada. Unfortunately, these cells have only been installed for 3 years. Nevertheless, they all show the capacity to be over 100% for all 2,256 cells installed.

These are the actual test results on 12 strings of OPzV and OGiV cells:

| *Equipment Designation* | *Battery Type* | *No of Cells* | *Rated Capacity* | *Years Installed* | *Test Parameter* | *Actual Test Duration* | *Type of Test* |
|---|---|---|---|---|---|---|---|
| ***C1- String 1*** | 6V 10 OGiV 250 | 192 | 136% | 3.00 | 11 min | 15 min | Capacity |
| ***C1- String 2*** | 6V 10 OGiV 250 | 192 | 136% | 3.00 | 11 min | 15 min | Capacity |
| ***C1- String 3*** | 6V 10 OGiV 250 | 192 | 127% | 3.00 | 11 min | 14 min | Capacity |
| ***C1- String 4*** | 6V 10 OGiV 250 | 192 | 136% | 3.00 | 11 min | 15 min | Capacity |
| ***C2- String 1*** | 6V 10 OGiV 250 | 192 | 127% | 2.75 | 11 min | 14 min | Capacity |
| ***C2- String 2*** | 6V 10 OGiV 250 | 192 | 118% | 2.75 | 11 min | 13 min | Capacity |
| ***C2- String 3*** | 6V 10 OGiV 250 | 192 | 109% | 2.75 | 11 min | 12 min | Capacity |
| ***C2- String 4*** | 6V 10 OGiV 250 | 192 | 118% | 3.00 | 11 min | 13 min | Capacity |
| ***D1- String 1*** | 6V 10 OGiV 250 | 192 | 127% | 3.00 | 11 min | 14 min | Capacity |
| ***D1- String 2*** | 6V 10 OGiV 250 | 192 | 136% | 3.00 | 11 min | 15 min | Capacity |
| ***D1- String 3*** | 6V 10 OGiV 250 | 192 | 127% | 3.00 | 11 min | 14 min | Capacity |
| ***B1*** | 12V 3 OPzV 150 | 144 | 100%+ | 9.25 | 360 min | 360 min | Performance |

**Conclusion**

There is so much more I'd like to cover, but then I'd be writing a book. But, my book would not be a classic, or even come close. I owe a great deal of gratitude to Dr. Wieland Rusch who has acted as our technical liaison from the factory in Berlin and mentored me for much of what I have learned over the past six years. And, as those of you who have worked in the battery industry know, either as a user, a supplier or a manufacturer – we never stop learning.

There is no such thing as the perfect battery. And there are so many variables that account for specific performance behavior. However, all battery cells are not created equal. There are applications where available footprint, power density, and situations where the battery is considered more of short term solution. In those situations the AGM can play a valid role and has a place.

However, we believe that there is a significant role that the VRLA gelled electrolyte can play for those application areas where reliability is considered critical, where service life needs to be optimized to its full capability similar to the VLA, and where cost of ownership savings are considered a valuable asset to be enjoyed.

Thank you very much.

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