HIGH RELIABILITY FLOODED, VRLA, AND FRONT TERMINAL UPS BATTERY DESIGN: PAST, PRESENT, AND FUTURE

Stephen L Vechy
Marketing Director
EnerSys
Reading, PA 19605

ABSTRACT

This paper will discuss the history of lead acid battery technology in Uninterruptible Power System (UPS) applications: How did we get to where we are today; What are the pros and cons of today's UPS battery designs; and What does the future hold for advancements in lead acid designs to meet the changing needs of the UPS marketplace.

Throughout the paper, we will discuss OEM and end user wishes, wants, and concerns with regard to the battery backup systems.

The paper will conclude with a discussion of the recently introduced higher energy density solutions as well as comment on new products in development that will revolutionize the industry.

INTRODUCTION

In the 1970's, major developments were evolving the way businesses gathered and processed data. The advent of the microprocessor and resultant mainframe computer designs led to the development of a whole new power application – Uninterruptible Power Systems. This new application was driven by the need to have high reliability data processing systems running 24 hours a day, 7 days a week without interruption. As our dependence on electronics in all areas of life has grown over the past 30 years, so has the insatiable need for the systems that support these grown exponentially, both in size and increasing necessity for higher and higher reliability – sometimes classified as a level of 9's, for example, Six 9's or 99.9999% uptime.

At the heart of the UPS system is the energy storage device. The most common method for energy storage is the lead acid battery system. A mature technology, lead acid batteries provide a highly reliable, economical means for providing the emergency power needed to support the connected loads in the event of an interruption of the power source (typically the utility grid). Before the UPS application came along, stationary batteries generally fell into two categories: 1) Long duration designs for telecommunications applications which generally needed low power for long periods of time and 2) General purpose designs for electric utility/switchgear applications whose duty cycle typically consists of a high one minute component for breaker tripping and closing, followed by smaller loads for longer periods of time, up to several hours. The UPS application, by contrast, is typically a constant power, high rate discharge generally ranging from 5 to 30 minutes in duration, with 15 minutes being the typical design run time.

An underlying theme that evolves in the UPS market and application is the divergent desires to provide high reliability, with low cost, and small footprint. These forces and the compromises that are selected, over time, have led to the diverse range of products that are available today in the UPS category and are what will drive manufacturers to continue to balance and optimize these forces to better serve the industry.

THE DAWN OF THE LEAD ACID UPS BATTERY DESIGN

Overview

Early UPS systems were designed for centralized, high power applications. It was logical that the flooded switchgear designs of the day would be the closest existing match to meet the emerging market need, but also there were opportunities to refine design attributes to optimize the battery's performance characteristics for the 15 minute constant power application. Some of these could be done quickly, at relatively low capital cost to implement and resulted in the early flooded UPS cells.

Plate Design

One way to get a high amount of power out of a lead acid cell for a short period of time is to increase the surface area of the plates. Unlike a long duration application that requires more active material for the electrochemical reaction, the high rate UPS application is basically a surface discharge of the plates. By using thinner plates, spaced closer together, manufacturers were able to significantly increase the kilowatt (kW) output of the cell at the 15 minute rate in the same physical container. Effectively, the result is a cell with about the same or greater amount of lead, but the proportion of surface area is increased dramatically at the expense of grid wire thickness. This decreases the grid wire corrosion radius and could potentially impact the operational life of the cell. Through alloy refinements (lead-calcium-tin) and manufacturing processes to control lead grain size, as well as optimal float voltage settings in use, manufacturers minimize the normal corrosion process that occurs during float charging to maximize operational life of the UPS cell design.

Separator Design

Telecommunications and Switchgear designs utilize microporous rubber separators that are relatively thick to provide sufficient plate spacing for the excess electrolyte needed to perform the longer duration, deeper discharge duty that these applications require. Recognizing that lower resistance will yield higher power output from the battery, manufacturers developed polyethylene separators that have lower resistance and could be made thinner to permit the closer plate spacing that would increase the kW output of the cell further.

Specific Gravity

Unlike telecommunications and switchgear systems that operated in a relatively narrow voltage window, the new UPS equipment was able to operate in a wider voltage window. This larger window meant that there was the ability to charge at a higher voltage per cell which provided the opportunity to increase the nominal specific gravity of the cells to 1.250, thereby providing another important increase in the power output capability of the cell at the high rates of the UPS application.

Copper Posts

The conductivity of copper is about 10x greater than lead, so using it in the post provides for much lower resistive losses, a better contact between the cell post and the intercell connectors, and less loss of connection torque over time. It is important to completely encapsulate the copper within lead as part of the design and manufacturing process since the sulfuric acid will attack the copper and can cause serious corrosion problems.

These early design modifications help to launch an entirely new family of flooded lead acid products specifically designed to serve the emerging UPS industry.

VRLA – A NEW TECHNOLOGY FOR UPS?

Overview

In the late 1970's and early 1980's, a new lead acid technology is introduced into the market that professes to eliminate maintenance (maintenance free), spills, need for watering, etc. This gives the ability to install the batteries in the proximity of the electrical equipment and is quickly adopted as a suitable product for the UPS application. At the same time, the UPS industry is beginning to introduce more mid-range sizes to serve the burgeoning market that does not require extremely large kVA ratings to run their computer equipment. The valve regulated lead acid (VRLA) cell with absorbent glass mat (AGM) separator design, in 12 Volt formats that look like automotive batteries, quickly become the primary solution for these mid-range systems.

Battery Design

The first versions of VRLA monobloc batteries were very close to automotive batteries with some minor modifications. Container wall thickness was sometimes increased to reduce bulging from the internal pressure generated by the VRLA cell design. Some designs used antimony grids and were manufactured on the same assembly lines as automotive batteries. In some cases, plate thickness was increased slightly to improve the 15 minute discharge performance compared to the cranking requirements of automotive. Most designs used lead flag posts, basically an adaptation of the original automotive post that permitted the use of bolt on cables or connectors. Even some users and resellers were just installing automotive batteries into the application because they were very low cost. Needless to say, some of these early missteps attributed to some serious problems.

VRLA Issues Emerge

As VRLA bloc batteries become embedded in many applications, new failure modes become apparent with VRLA AGM battery designs. Open failures that result from positive or negative strap corrosion occur. The result is an open circuit when the battery is placed on load, and can be relatively difficult to find using conventional maintenance techniques. Batteries become installed in tight fitting places, with little airflow to dissipate the heat generated during the charging process. This, combined with some of the early designs that used either antimony grids or thick wall containers created a recipe for a new failure mode known as thermal runaway. Dryout of the separators also becomes a potential failure mode leading to reduced capacity and higher internal resistance (again contributing to heat generation during charge). Lead posts, that can cold flow over time, can lead to high resistance connections, creating another point of excessive heat generation during the high rate discharge associated with the UPS applications. In some cases, these various issues lead to battery meltdowns, and even battery fires in the worst circumstances.

The Industry Responds

When you reflect back over what happened in the 1980's and 1990's, you see the pattern of denial, anger, bargaining, and acceptance. When problems first started happening, there was denial or disbelief to the cause of the problems. Then, everyone got angry at the battery industry. Conferences like Battcon were born during this period. With perseverance, the community came together and worked on solutions. Manufacturers invested significantly in addressing product design and manufacturing processes, as well as education of the industry with respect to the installation, operation, and maintenance of VRLA batteries. During this time period, we find significant improvements in battery design through the use of lead-calcium-tin alloys, flame retardant jar materials, copper insert posts, improved plastic materials and reinforcement of jar walls to reduce bulge without containing the heat generated on charge. Manufacturing processes and materials are addressed to reduce or eliminate strap corrosion, optimize electrolyte volume through controlled filling and formation processes, improve leak detection and verify product integrity and performance through high rate discharge (HRD) testing. UPS manufacturers modify cabinet designs to improve airflow. Temperature compensated charging is integrated to reduce heat generation when temperature excursions occur. A whole new industry of ohmic test equipment and battery monitoring systems is born to help users identify problems before they occur. These actions lead to the acceptance period, or maybe better stated as the understanding of the technology, its application, and the advantages and disadvantages that comes with it.

THE EVOLUTION OF THE FLOODED LEAD ACID BATTERY IN UPS APPLICATIONS

Flooded Batteries

In the large UPS systems arena in the 1980's, where flooded batteries were the norm, there continued to be the underlying desires from the UPS community to lower cost and reduce footprint. There was also an emerging understanding of two significant differences the application presented to the battery that were different from the traditional applications of telecom and switchgear – ripple and cycling. The UPS system can present a fair amount of ripple current to the battery on charge that can be referred to as high frequency shallow cycling. The industry also began to learn that there were actually many more transfers to battery than expected, given our generally accepted quality of the electric utility grid. Even though there may not be loss of commercial AC input power, very small line disturbances will be picked up by the UPS, causing transfer to the battery to assure there is no loss of critical power to the computer equipment. From this, several advancements are made in flooded UPS design.

Multi-Cell Jars

A significant advancement is the advent of the 4 cell and 2 cell jars to house the UPS cells. These jars dramatically reduce the footprint required for the battery strings, freeing up valuable real estate for other equipment. By using less racking and less real estate, the installed cost for the user is reduced.

Radial Grid and Top Lead

Manufacturers begin to use radial grid designs to expedite the power transfer from within the depths of the cell. Strategically placed diagonal wires, emanating from the top lug area of the plate help to reduce the resistance of the cell, and further increase the power output. Additionally, some manufacturers add a double lug to the top of the plate to increase the cross sectional area of the strap, thereby, increasing the current carrying ability and increasing power output of the same cell stack.

Wrapped Plate

The implementation of the wrapped plate design, while reducing power output slightly, greatly increases the cycle resistance of the cell. This advancement helps to increase the operational life of the UPS cell design in the application as the understanding of the cyclic nature of UPS becomes apparent.

PRESENT AND FUTURE ADVANCEMENTS IN LEAD ACID UPS BATTERY DESIGN

Flooded Batteries

From the early 1990's through the mid 2000's, the flooded UPS battery design was relatively stable. But, the UPS market was shifting. Larger and Larger data centers were and are being built to process the ever growing amount of data that our daily lives depend on. The UPS machines were getting bigger, moving from 500kVA as the standard "big box", up to 750kVA and higher. Major users are also installing mirror or redundant sites to increase the uptime and mitigate the risk of downtime from a terrorist strike. Interruption of data is not tolerated, and the cost of downtime, both in real dollars and company image can be substantial.

To address the shifting market, new, larger 4 cell jars were created to match the high power requirements of the larger UPS systems. This advancement can reduce the battery footprint required for a 750kVA system by up to 26%, providing yet another cost savings opportunity for the users of these large systems. Since many of the new data centers are using multiple 750kVA UPS modules, the cost savings is a significant factor.

VRLA Bloc and Front Terminal Batteries

Despite some of the early challenges with VRLA bloc batteries, the top terminated AGM design has become the product of choice for the mid-range UPS application. Many of the battery designs (but not all) available today are designed and manufactured to provide a highly reliable, cost effective solution that is the underlying driver in the UPS industry. However, there are still drawbacks with top terminated bloc battery designs. These include:

- Limited access in cabinets impedes battery maintenance
- Additional headspace is required to permit terminal access, or
- High cost sliding trays are needed to obtain access to terminals, complicating the wiring
- Individual bloc replacement can require moving several blocs
- Space (footprint) utilization is not optimized
- Several strings required to address higher kVA ratings

One way to attempt to address several of these factors is to utilize front terminal battery designs. Front terminal batteries have been successfully deployed for many years in the telecom segment of the market, but have not found their way into UPS in any significant manner. Reverting to the drivers in the market - cost and footprint – the designs that are available are not optimized to compete with the existing top terminal UPS bloc batteries.

A quick way to develop a front terminal UPS VRLA battery is to take a note from the early pages of the flooded UPS battery design. That is, take the existing batteries that are being used in telecom, make (or not) some minor modifications, and voila, you have a UPS front terminal battery. But, it is not necessarily the optimal solution.

A better approach would be to assess the overall application, and develop the best solution to meet the needs of the industry. These include:

- A cost effective solution
- Space Efficient
- Easy to maintain
- Conducive to incorporating monitoring solutions
- Adaptable to existing cabinet designs where practical
- Scalable to larger capacities to minimize string count

If we look at the predominant cabinet configurations, we find that the top terminated blocs are generally installed 4 deep on a shelf of a cabinet that is about 32" deep. Most 12V front terminal batteries are only 21-22" deep, leaving a significant amount of unused space, thereby costing valuable real estate. One way to optimize the utilization of the space is to use a 16 Volt configuration as shown in Fig 1. This approach provides several key advantages:

- No wasted space
- Fits within many existing cabinet designs
- Easy to maintain due to front terminal design
- Less Connections (30 units instead of 40 in a typical 240 cell configuration)
- Easy to replace (no need to remove other units)
- Easily retrofitted into existing cabinets

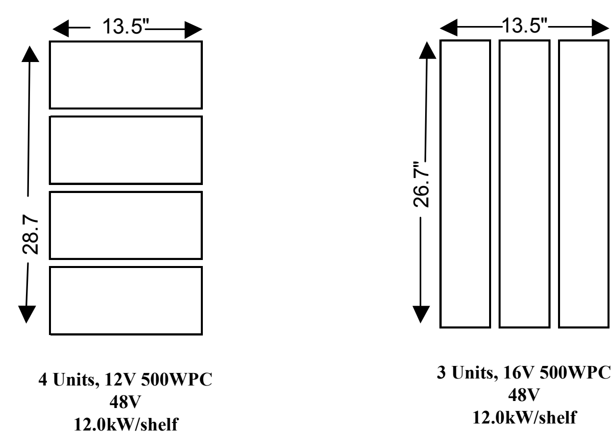

Fig 1. Typical Shelf Layout

Another product development opportunity is to increase the nominal cell power output to reduce the number of strings required in larger UPS systems. Today, the largest 12V top terminated bloc is rated around 500 watts per cell for 15 minutes to 1.67VPC at 77°F. By designing a higher rated cell (like 750WPC), the number of strings required to power larger systems can be reduced. Conversely, the battery run time for a given number of strings can be increased. An analysis of this is shown in Fig 2.

750kVA, 100% Load Comparison 240 cells, 0.9PF, 95% efficiency 1.67VPC at 77°F			
Traditional 12V, 500WPC Bloc		**Front Terminal 16V, 750WPC Bloc**	
Run Time	# Strings	Run Time	# Strings
N/A	1	N/A	1
N/A	2	N/A	2
N/A	3	9	3
8	4	15	4
12	5	22	5
15	6	28	6

500kVA, 100% Load Comparison 240 cells, 0.9PF, 95% efficiency 1.67VPC at 77°F			
Traditional 12V, 500WPC Bloc		**Front Terminal 16V, 750WPC Bloc**	
Run Time	# Strings	Run Time	# Strings
N/A	1	N/A	1
N/A	2	9	2
9	3	18	3
15	4	28	4

Fig 2. - Comparison of 750 WPC rated cell to a 500WPC rated cell

SUMMARY

UPS batteries have evolved significantly over the past 30+ years. Flooded multi-cell designs, with lead calcium grids, multi-cell jars, radial grids, dual lugs, and double bolted copper posts present en extremely reliable, economical, and footprint effective solution for the UPS market. Recent advancements in larger multi-cell formats provide incremental improvement in footprint and cost and are well matched to the larger UPS systems that are being installed today and in the near future.

VRLA monobloc batteries are on the cusp of a transition from top terminated blocs to front terminated blocs. Through detailed analysis of the market needs, a new 16V format product can be developed that addresses many of the desires of the UPS OEM and users from the inception.