Powering the Network

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A battery of analysis

With battery performance variable to conditions, choosing them takes some comparison shopping

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Network reliability and cost to provide service have never been more important for carriers than now--competitive pressures are mounting. While many network-related factors have an affect on these areas, choosing the right network battery systems and managing them correctly are critical to maintaining reliability and streamlining at least one segment of operational costs.

It is important to have some knowledge of various battery designs, performance characteristics and common reasons for failure.

For more than a century, flooded batteries have been the standard for backup power in the telecommunications industry. However, within the last decade, the development of valve-regulated lead acid (VRLA) technology has provided a viable alternative to flooded designs. As users demand more energy density per square foot and applications become smaller, users must fit more power into smaller spaces beside their flooded systems. They must understand the benefits and limitations of VRLA batteries.

VRLA technology arose from users' demand for a "no maintenance" battery that required minimal attention and could be safely used in enclosed cabinets and office environments. However, a truly no maintenance battery does not exist--the term "low maintenance" may be more suitable.

Currently, two types of low-maintenance batteries are available: the absorbed glass mat (AGM) battery and the gel technology battery. Each is similar to the common flooded battery, yet both contain many differences that users, buyers and application personnel should consider. There are some key differences between VRLA battery technologies and the standard flooded design that has long been part of the telecom world.

Technology comparison

Flooded or "wet" design refers to those batteries that require periodic replenishment of water, which is added to the battery through a vent cap. Flooded lead acid batteries have been in use for more than a century, and most users are familiar with them.

Central offices and large uninterruptible power supply applications still use the flooded batteries today. The design has proved reliable and durable for many years. Flooded batteries have the required capacities and service lives--some can live up to 20 years (40 years in the case of Lucent Technologies' Round Cell).

The disadvantages are that flooded designs require large floor space, ventilation systems, rack or stands, acid containment and regular maintenance (Table 1 and Table 2).

TABLE 1
DIMENSIONAL COMPARISON OF BATTERY TECHNOLOGIES

24-Cell system	Flooded	Modular AGM	Gel
Length	192	39.3	172
Width	28.5	25.5	24.06
Footprint (square inch)	5472, w/containment 7300	1002	4138
Weight	5300	4980	9260
Acid containment	Yes	No	No
Maintenance	Yes, quarterly	Yes, semiannual	Yes, semiannual
Gallons of electrolyte	6.3	3.72	3.3
Specific gravity	1.215	1.250	1.300
Ampere-hour	1008	1010	1008

TABLE 2
COST COMPARISON OF BATTERY TECHNOLOGIES (24-CELL SYSTEM)

Item	Flooded	AGM	Gel	Modular AGM
Battery price	$19,416	24,192	20,424	19,296
Rack price	2200	2200	2200	—
Spill containment	1700	—	—	—
Installation	5000	5000	5000	3600
Ventilation	2000	—	—	—
Initial installation cost	30,316	31,392	27,624	22,896
20 yr. maintenance	14,400 44,716	7200 38,592	7200 34,824	7200 30,096
Yearly cost	2443.4	1929.6	1741	1504

Maintenance and installation service based on $60 per hour and IEEE recommendations. Battery life is estimated at 20 years.

The design of flooded batteries is quite simple. Negative plates made of lead or a lead alloy are sandwiched between positive plates of lead or lead alloy with an additive of calcium or antimony. Sheets of non-conductive, microporous material (called a separator) separate the plates.

The plates are pasted with an active material--lead oxide and sometimes lead sulfate--to provide the large surface area for storing electrochemical energy. Each positive is welded together and attached to a terminal post (+). The same method of welding connects all the negative plates to a terminal post (-). The plate assemblies are placed in a container. A cover with a vent cap/flame arrestor and hydrometer hole is fitted to the container.

Typically, the container and cover are glued together to provide a large leak-proof seal. The container is then filled with 1.215 specific gravity electrolyte (combination of sulfuric acid and water). This is a relatively simple explanation of a flooded wet battery.

When charged, the electrochemical reaction within the cell creates the cell's potential or voltage. In elementary form, the two dissimilar materials (negative and positive plates) have a potential difference (cell voltage). A float charge is placed on the battery so that the negative and positive plates remain charged, or polarized.

During this charge phase, water in the electrolyte is broken down by electrolysis, and oxygen is evolved at the positive plates and hydrogen at the negative plates. The production of hydrogen requires the battery to be fitted with a flame or spark arrestor.

There is some degree of recombination in flooded cells but typically less than 30%. Therefore, increasing the recombination efficiency to reduce water loss was a major factor in the development of VRLA batteries.

In VRLA batteries, the efficiency is 95% to 99%. The higher efficiency meant that no watering was required during the life of the battery, sharply reducing the maintenance cost compared with the flooded design. Hence, VRLA batteries became low maintenance batteries.

More importantly, the need for special ventilation, acid containment and racks was eliminated, allowing batteries to be collocated with the electronics or installed in the most space saving manner. Consequently, greater space was available for revenue-generating equipment.

Among the two types of VRLA batteries, the AGM is much like the flooded battery design because it uses standard plates, but it also has a higher specific gravity of electrolyte. However, as its full name suggests, the AGM has a special glass mat used to absorb and immobilize the electrolyte.

Essentially, the mat acts like a sponge. The AGM permits the exchange of oxygen between the plates, thereby making the system recombinant, yet it still provides the electrical separation needed to prevent shorting of the plates.

The thicker the glass mat, the greater the ability to store immobilized electrolyte, reduce the effect of dry out over the life of the battery, and prevent shorting of plates. The AGM's safety vent is the second major difference in design. The safety vent/flame arrestor has several purposes. It prevents the release of oxygen during normal operation. It maintains sufficient pressure within the cell for recombination to occur. It acts as a safety device in preventing sparks and arcs from entering the cell (much like flooded designs). And finally, it acts as a safety release vent during abnormal operation.

The second VRLA design is the gel technology battery, which uses the same plates and separators as flooded batteries. However, with this battery, a pure form of silica is added to the electrolyte, forming acidic gel. As the gel dries out, cracks are formed. If it were placed in a clear container it would appear similar to a vigorously shaken bowl of gelatin. (Because these cracks would be alarming to a user, all gel designs are in opaque containers.)

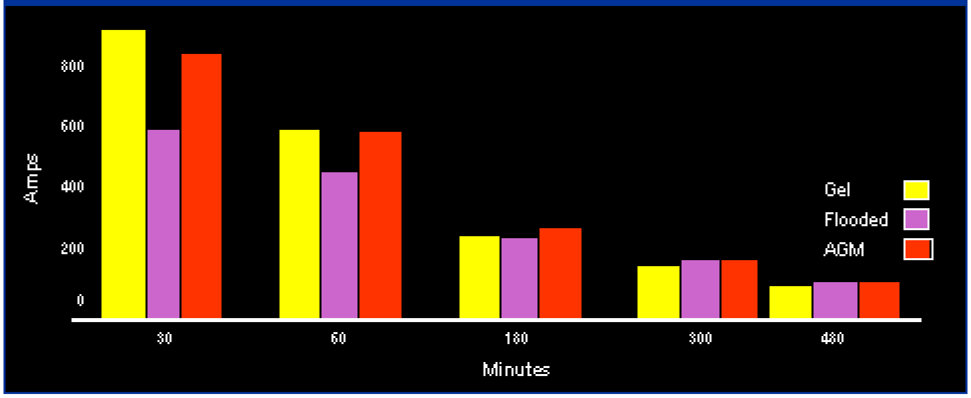
These cracks are essential to diffuse oxygen between the positive and negative plates, making the gel technology recombinant. A more fluid gel technology known as Prelyte may enhance the oxygen diffusion over standard gel technologies and provide longer life.

Like AGM designs, gel batteries have a flame arrestor/safety valve to maintain pressure in the battery, prevent the release of hydrogen and oxygen during normal operation, prevent arcs and sparks from entering the cell, and allow venting during abnormal operation.

Performance comparisons

For performance comparison, we have used batteries of similar ampere-hour sizes and parameters typical of telecom applications (1.75 VPC at 8 hours). The specific gravity of the electrolytes is 1.215 for the flooded battery and 1.300 for the VRLA batteries, all typical of telecom applications.

FIGURE 1
CAPACITY CURVES FOR BATTERY DESIGNS



As the data in Table 3 and Figure 1 indicate, the volume of available electrolyte is the critical factor in performance. This means that flooded batteries with lower ampere hour ratings may exhibit better long-rate performance than larger VRLA batteries of either design simply because they have larger acid reservoirs.

TABLE 3
RATE COMPARISON BETWEEN BATTERY DESIGNS

Battery Model	LTC-1008	LST-1010	HDL-960
Lbs. Elec.	63		
AH rating	1008	1010	1010
Rate	Flooded	Gel	AGM
30	576	804	
60	456	585	573.1
180	247	279	278
300	179	188	188
480	126	126.25	128

Amps to 1.75 VPC, AGM derated 8.7% to equal 1010 AH

Also, AGM designs typically will have the best high-rate performance because they have the lowest internal resistance and the higher-gravity electrolyte (1.300). This comparison assumes all other variables are similar.

Nevertheless, ampere-hour and end-voltage ratings are insufficient factors on which to base a conclusion about flooded batteries vs. VRLA designs. Ventilation, space requirements, acid containment, economic practicality and other factors must also affect the decision.

For example, flooded batteries vent hydrogen gas throughout their entire lives. Hydrogen is highly explosive in a concentration of as little as 4% of room volume. This means that the room containing the batteries must have a complete ventilation system with fans, ducts and other components, all of which must be factored into the total system purchase price.

However, VRLA batteries emit very little hydrogen gas during normal operations and do not require special ventilation systems. While they often are operated in enclosed cabinets, without fans or a heating, ventilating and air conditioning system, the cabinets must be vented or the small amount of hydrogen that is emitted will build up in the enclosure to explosive levels.

Space requirements should also be considered. Table 1 shows that the flooded design requires 32% more space than the equivalent VRLA battery. The space savings are due in part to the rack requirement and the need to provide space to access the battery for maintenance.

With floor space at a premium, most of today's carriers would rather devote as much space as possible to revenue-generating equipment than to batteries. The more space-efficient VRLA batteries offer a greater benefit to the user.

Propensity for acid spills is another important factor. The typical flooded battery has 15 to 19 gallons of electrolyte in each container. A set of 24 cells contains 360 gallons or 3600 lbs. Because the electrolyte is so corrosive, UBC 307.2.3, The Uniform Fire Code, Article 64, and local codes that reference the fire code require surrounding the entire battery with an acid containment system when it exceeds the acid volume limit, typically more than 100 gallons.

This system adds $1700 to $3000 for each rack of flooded batteries. In comparison, the VRLA battery has no free electrolyte and therefore requires no such systems. This translates to a savings of $1700 to $3000.

Regarding cost comparison, Table 2 displays the total life cost, including installation and maintenance for the flooded and VRLA designs. From this data, the VRLA design clearly has a higher initial cost, but when you factor in the additional costs (installation, maintenance, etc.), the VRLA is 21% to 36% cheaper during its life than a flooded design. The worst-case scenario of 21% is based on replacing the VRLA after 15 years vs. 20 years with the flooded design. With the latest catalyst improvements in VRLA technology, a good battery can last 15 to 20 years.

Failure modes

Battery failure is a subject most manufacturers would prefer not to talk about. They would much rather point out the long and dependable life of their batteries. Nonetheless, it is unrealistic to ignore the fact that all batteries ultimately fail.

Grid corrosion should be the main cause of failure for all flooded lead acid batteries. It is the corrosion of the positive grid that typically limits the expected life of the battery. As the battery cycles or ages, the grid begins to deteriorate losing its conductivity and contact with the active paste materials and therefore its ability to maintain the cell capacity. The old analogy is closing the valve in a water pipe. The valve creates resistance to the water flow; the corrosion increases the resistance to current flow.

To prevent premature failure from grid corrosion, users should request information from the supplier on the grid thickness and cycle life. The thicker the grid, the longer it will take for the grid to corrode. Also, the thicker the grid, the longer the usable life of the product. In addition to the thickness, the grid's manufacturing can eliminate porosity. Manufacturing methods such as bottom-pour casting provide high-integrity grid with low porosity that dramatically reduce the rate of grid corrosion.

Like flooded cells, VRLA batteries should fail because of the positive grid's corrosion and growth. However, users have witnessed premature failure of the VRLA products because of problems in product design, application environment, charger controls and manufacturing technique.

After years of perfecting design attributes, manufacturers have found one area that they have not been able to control--the tendency for the negative plates to self-discharge over time and capacity performance to "fall off" prematurely. This fall-off in capacity happens in ideal float operating conditions because of discharged negatives and not grid corrosion.

Another failure condition involves discharged negatives. It is far less recognized, but it may be the most important.

The negatives of a VRLA battery can discharge over time because of the high recombination efficiency. As the battery ages and the recombination becomes very efficient (greater than 98%), the oxygen given off by charging the positive plates is absorbed by the negative plates, electrochemically reducing the spongy lead active material and preventing the negative plates from ever reaching a fully charged state.

At one time, it was thought that as long as enough negative active material existed, the negative plates could remain in a slightly discharged state without substantial loss of performance. Water loss is mainly due to the loss of hydrogen that is given off by corrosion in the positive grid. This occurs when some of the oxygen created at the positive plates does not diffuse to the negative plates but is used to corrode the positive grid.

The resulting depolarization of negative plates allows self-discharge--a chemical reaction--to occur, thus discharging the negatives. The reaction removes sulfate, hence lowering electrolyte gravity and open circuit voltage.

One way to overcome the discharged negative is to equalize-charge, or boost-charge, the battery periodically. Unfortunately, many applications cannot raise the battery to the required voltage level, nor are they equipped to monitor the charge. The voltage necessary to boost-charge the battery would be 2.45 to 2.50 volts per cell. This process will cause more heat and gassing of the VRLA battery but only for a short period, typically about 24 hours.

In VRLA batteries, all the oxygen given off is at the top of charge. The oxygen off the positive plates is either recombined at the negative plates or used to corrode the positive grid. The hydrogen that is given off as a by-product of the positive grid corrosion along with any hydrogen given off due to the self-discharge of the negative plates will be vented out of the cell periodically. This is the main reason for water loss.

The latest technology solution for this condition is to provide a catalyst in the VRLA cell. The use of catalysts is quite common in Europe. The catalyst recombines the oxygen and hydrogen to recover water lost from electrolysis. In VRLA cells, the catalyst attracts and recombines some of the oxygen that would normally be diffusing to the negative plates. This oxygen recombines with the hydrogen present in the headspace.

As a result, the negative is slightly polarized and obtains a full charge. A slight amount of hydrogen is evolved in the process, which then recombines at the catalyst surface. Here are some of the benefits:

- Consistent performance throughout product life. The negative plates stay polarized and maintain a full state of charge, and as a result, battery capacity performance does not fall off prematurely.

- Longer life. The polarization on the positive plates is lowered, reducing the corrosion rate of the positive grid.
- Reduction in float current. Because the plates are polarized, less float current is required to maintain full charge on the cells.
- Reduction in thermal runaway potential. Because there is less current through the cell, there is less internal heating and less of a potential for thermal runaway.
- Reduction in impedance. Because the cell functions at an improved state of charge, the cell's impedance is lowered.
- Reduction in water loss. Less venting causes less water loss.

During high temperature conditions, the float current increases. This causes more heat and gassing, and therefore more release of hydrogen and more water loss. In addition, the positive grid corrosion rate is accelerated and is the basis of temperature derating (for example, 50% reduction in life for each 15 F increase in temperature over 77 F). Loss of water due to high-temperature operation accelerates the dryout and further shortens the life of both AGM and gel VRLA products.

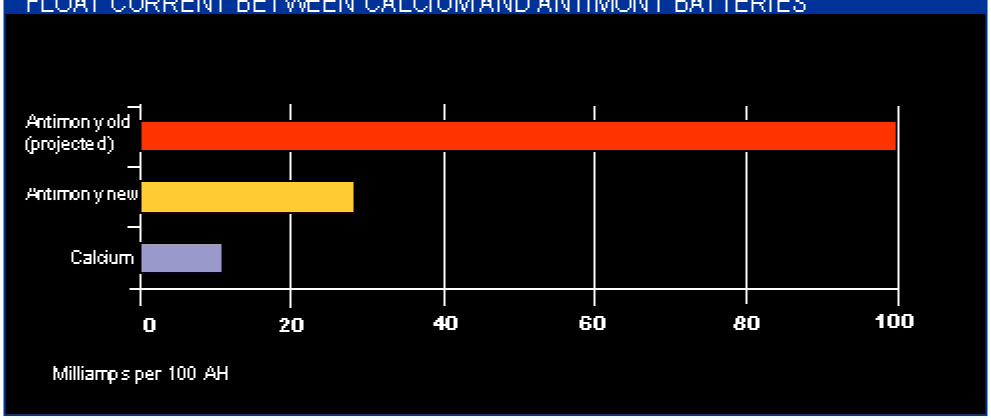
Much of today's newer charging equipment includes temperature compensation and even fold-back capability to reduce the effects of higher temperatures, excess gassing and thermal runaway. Provisions for airflow between cells allows for more uniform thermal distribution from cell to cell.

Repeated cycling is a strong indication of robust battery design. When not properly selected for the application, a battery designed for float service may be prematurely cycled to its end of life. Users often mistake the expected float warranty to be the actual life of the product under cycling conditions. In either case, VRLA batteries can provide excellent cycle life along with a cycle warranty. Users should always request that a 20-year VRLA battery make 1200 cycles to 80% depth of discharge at the eight-hour rate to 1.75.

Antimony is used heavily in motive power (forklift) batteries, but with the introduction of calcium, float application batteries were found to last longer because of slower positive grid corrosion and require much less maintenance. The addition of tin to the calcium alloys in VRLA batteries resulted in cells that provide excellent cycling capability.

FIGURE 2

FLOAT CURRENT BETWEEN CALCIUM AND ANTIMONY BATTERIES



As stated earlier, the VRLA battery is very similar to flooded cells. The antimony additives in VRLA batteries cause the float current and gassing to increase as the battery ages. At the end of life, an antimony battery's float current is six times greater than that of a calcium battery (Figure 2). Therefore, calcium batteries are recommended for most telecom applications to avoid dryout and rapid positive grid corrosion.

Making judgments

Summarizing comparisons of technology, performance and failure, large flooded lead acid batteries have a long history of reliability and extended service life. However, they are the most expensive for initial installation **(Table 2)**. But depending on the application, the total life cost may equal or be lower than that of the VRLA design. They also require far greater floor space and maintenance then the VRLA counterpart. Yet, they have their place in COss and manned facilities, where they typically last more than 20 years.

VRLA designs will operate successfully in partially enclosed environments. They do not require as much space as flooded designs, and they certainly do not require as much maintenance. They can be installed in almost any environment, with the electronics or equipment they serve.

VRLA batteries may be the batteries of choice in the future because of space, location and environment. They may never completely replace the large CO applications--nor should they--but they will continue to become a much larger portion of the telecom backup power market over the next decade as manufacturers continue to improve VRLA technology.

VRLA batteries will continue to decrease in size--i.e., less than 200 ampere-hour designs as applications require smaller enclosures, cabinets, huts and buildings. Lastly, there will be an increase in multiple parallel strings of VRLA products to obtain the energy density needed for Internet service providers, interexchange carriers and competitive local exchange carriers.

Multiple parallel strings aid redundancy. Single strings eliminate redundancy and jeopardize the critical customer loads supported by the battery.

Comparative knowledge of technologies, performance characteristics, general economics and causes for failure of flooded vs. VRLA batteries better prepares carriers to offer the reliability necessary to keep customers satisfied--and it helps them keep their own operating costs under control.

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