Battery Technology for Data Centers and Network Rooms: Battery Options

White Paper # 30

Legendary Reliability®

Revision 10

Executive Summary

The lead-acid battery is the predominant choice for Uninterruptible Power Supply (UPS) energy storage. Over 10 million UPSs are presently installed utilizing Flooded, Valve Regulated Lead Acid (VRLA), and Modular Battery Cartridge (MBC) systems. This paper discusses the advantages and disadvantages of these three battery technologies.

Introduction

Although energy reserve technologies such as fuel cells, flywheels, and Nickel Cadmium batteries are being explored, today data center and network room UPS systems almost exclusively use Lead acid batteries with one of the following three technologies:

Vented (flooded or wet cell) - The oldest of the technologies is the flooded (or vented) cell. Commonly used in automotive and marine applications, this technology is predominantly used in UPS applications above 500 kVA. An example of a flooded battery is shown in **Figure 1**.

- Non-sealed system for serviceability
- Continuously vents hydrogen and oxygen
- Requires periodic water replenishment
- Electrolyte stored in liquid form
- Usually too heavy to be lifted manually
- Transparent container allows plate inspection
- Operate at high currents
- Connected by large bolted terminals
- Stored in open frames or large cabinets
- Requires spill containment & hydrogen detection
- Typically 15-20 year life
- Usually considered part of the facility

***Figure 1** – Flooded (Vented) Battery*

Valve Regulated (VRLA) - VRLA batteries have been utilized for approximately 20 years. This technology offers a higher power density and lower capital costs than traditional flooded cell solutions. VRLA batteries are typically deployed within power systems rated below 500kVA**.** An example of VRLA batteries is shown in **Figures 2** and **3**.

- Sealed system (“non-spillable”)
- Hydrogen & oxygen recombine internally
- Opaque container
- Electrolyte is immobilized
- “Starved electrolyte” makes it weigh much less than vented cells
- Operate at high currents
- 6- and 12-volt “Monobloc” for small & medium UPS
- 2-volt steel-clad modules for large DC systems

***Figure 2** – Modular VRLA Front-connected*

- Connected by bolted terminals or quick-connects
- Stored in open frames or large cabinets
- Pressure relief valves open under fault conditions
- Typically 3-10 year life
- Usually considered part of the electronic equipment

***Figure 3** – "Monobloc" VRLA with top posts*

Modular Battery Cartridges (MBC) - MBC battery technology was introduced several years ago. This solution utilizes modular, multi-cell VRLA cartridges arranged in a parallel-series architecture that allows for easy installation and replacement. An example of a modular battery cartridge is shown in **Figure 4**.

- Sealed system
- Electrolyte immobilized in absorbent glass mats
- Contains thin lead plates for high-rate discharge
- Typically used in multi-string (redundant) applications
- Enclosed modular cartridge
- Easily attached to a Common DC bus
- Plugged into pre-manufactured battery cabinets
- Contains temperature and monitoring sensors

***Figure 4** – Modular Battery Cartridge (MBC)*

Attributes

Each battery technology presents a unique set of features. This section will compare each battery type by installation requirements, life expectancy, and typical failure modes.

Installation

Installation requirements differ significantly between the technologies.

Vented cell systems (more commonly called "flooded cell" systems) require a substantial investment upon installation due to safety code requirements. Please see APC White Paper #31, "Battery Technology for Data Centers and Network Rooms: Safety Codes". Flooded cells are usually housed in open frame racks and are shipped fully charged, but can be transported dry, partially filled, or fully filled with electrolyte. Flooded batteries require on-site battery rack assembly, battery installation and commissioning by authorized and qualified personnel. Because they continuously vent gases, flooded batteries must be installed in controlled-access, specially ventilated battery rooms with spill containment. Flooded battery systems are usually considered to be part of the building's fixed power infrastructure. Flooded batteries require periodic inspection of electrolyte and plates. Maintenance often includes measure and recording of electrolyte specific gravity and replenishment of water when required.

Conversely, **VRLA** and **MBC** solutions are sealed systems and therefore do not require special maintenance. VRLAs typically ship connected in series within a cabinet, or they may require installation and connection at site. MBCs are usually shipped uninstalled. However, the MBCs are easily installed and do not require installation by authorized technicians. The modular cartridge simply slides into pre-manufactured cabinets and connects via a floating connector to a common DC bus. These differences are summarized in **Table 1**.

Table 1 *– Installation requirements as a function of battery technology*

	Flooded	VRLA	MBC
Site specific battery rack/frame design	Yes	Varies	No
Mechanical assembly required at site	Yes	Varies	No
Site specific engineering required	Yes	Varies	No
Field Wiring (electrical connections)	Yes	Varies	No
Hazardous material per DOT regulations	Yes	No	No
Acid filling required	Yes	No	No
Potential Shock hazard when handled	Yes	Yes	No

Life Expectancy

Life expectancy varies with battery type. Flooded cell systems traditionally enjoy long lifetimes provided that they are regularly maintained and serviced. VRLAs and MBCs are sealed systems that do not require or even permit the maintenance needed on flooded batteries. As a result, the lifetime of these battery types is significantly shorter than flooded cell systems. **Table 2** shows the battery lifetime expectations.

Table 2 *– Life expectancy*

	Flooded	VRLA Large	VRLA Medium	VRLA Small	MBC
Design Life	20 Years	20	7-10 Years	5 Years	7-10 Years
Expected lifetime	15 Years	7-13 Years	5 Years	3 Years	3-5 Years

Failure Modes

The different battery types vary with respect to their failure modes and mechanisms. Failure modes vary with respect to their predictability, Mean-Time-to-Recover (MTTR), and consequence on the critical load protected. **Table 3** indicates the distribution of failure modes by battery type. Please see APC White Paper #39, “Battery Technology for Data Centers and Network Rooms: VRLA Reliability and Safety”. Note: The values in **Table 3** are for primary failure mode. Dry out is often a secondary effect of other failure modes

***Table 3** – Failure modes*

	Flooded	VRLA	MBC
Grid corrosion	86%	59%	59%
Cell short	10%	< 1%	< 1%
Leakage	1%	2%	1%
Block Interconnect open	3%	3%	1%
Cell Interconnect open	<1%	1%	2%
Dry Out*	<1%	33%	36%
Interconnect overheat	<1%	<1%	<1%
Thermal runaway	<1%	1%	1%
Cell reversal	<1%	1%	<1%
Failure Mode (Primary)	Shorted	Open	Open

*Dry-out is often a secondary result of other failure modes. The values in Table 3 are for the primary failure mode. The values in this table are approximate.

Grid Corrosion/Cell Short

Although VRLA batteries and MBC can experience grid corrosion, they frequently fail due to dry out prior to the grid corrosion failure. Flooded cell systems also experience corrosion on the positive gird. Grid growth causes loss in mechanical strength and eventually leads to loss of contact with the grid. This is why visual inspection of a flooded cell battery is required. The internal resistance increases and the capacity decreases. A common mode of failure is a shorted cell because the dross material collecting in the bottom of the jar eventually creates a short between the plates. This failure mode reduces capacity of the cell, but the string can still provide energy to the UPS.

Electrolyte Leakage

The leakage failure mode is different between the battery technologies. In flooded batteries, “wicking” of electrolyte at the terminal posts typically leads to corrosion of connections and hardware. The leakage is a result of a crack or hole causing liquid electrolyte to escape. Ironically, a common cause of electrolyte loss on flooded batteries is dripped liquid during specific gravity inspections, as part of routine maintenance. The primary hazard is that areas wet with battery leakage constitute conductive paths to ground that can pose a very serious risk of ground fault. The biggest concern for flooded batteries is that the battery could somehow tip and spill its liquid contents during maintenance or natural disaster. That is why containment systems are required around flooded battery racks.

VRLA batteries, by contrast, contain significantly lower volumes of electrolyte and the electrolyte is immobilized. Ordinarily, electrolyte is captive inside the container. In the event of a crack or rupture, the primary consequence of leakage is non-hazardous premature dry-out of the battery. If wicking occurs through a post seal or a failed VRLA jar seal, the risk of electrical shock is the same as for flooded batteries.

Dry-Out

Over time, VRLA and MBC systems will lose water and dry out (82% - 85% of the failures exhibit signs of dry-out). In normal operation at “room temperature” the typical failure mode for a VRLA or MBC system is negative strap corrosion, and the loss of electrolyte will be gradual. In high temperatures and/or high voltage charging, dry-out is accelerated. This leads to loss of capacity and eventually the cell will fail open. If the cell is arranged in a series configuration, this will prevent energy from being delivered to the UPS. Because of this failure mode, it is recommended VRLAs be deployed in parallel redundant strings. By design, MBC are arranged in a parallel-series arrangement thereby always providing energy to the UPS in the event of a cell failure.

Interconnect

Most interconnect failures result in an abrupt open circuit condition and are not hazardous. However, a small fraction of interconnect failures are stable high resistance conditions. In flooded and VRLA battery systems, interconnects operate at very high currents during discharge and a high resistance interconnection can result in serious overheating or fire. Battery systems with current and temperature monitoring can detect and or prevent this type of failure mode before it becomes critical. MBC systems with parallel strings typically operate at much lower currents and consequently do not have the same dependence on low resistance connections.

Thermal Runaway

Flooded batteries rarely experience thermal runaway. The primary hazard of thermal runaway with VRLA and MBC systems is the emission of hydrogen and hydrogen-sulphide gas, an irritant. It is possible for these batteries to enter a state in which heat is generated faster than it can be dissipated during charging. The increasing battery temperature results in more current being drawn from the charger, which in turn further raises the battery temperature. The cycle continues until the battery internal pressure causes the vents to open. From Concorde Battery Technical Information Library[1], “The battery will reach a moderate internal temperature (approximately 260°F) at which point the water in the electrolyte vaporizes and the battery vents steam. As the separator is glass, it is unaffected by this temperature. The loss of water caused by the venting reduces the conductivity between the battery plates and the battery ceases to accept further charge. The battery slowly cools.” When implementing VRLA or MBC solutions, best practice calls for temperature compensated voltage charging as well as current-limited charging protection. Wet cells rarely experience thermal runaway because convection currents in the fluid electrolyte stop the process.

Cell Reversal

Cell reversal is associated with large series strings of batteries and is primarily restricted to VRLA batteries. This occurs only during battery discharge and when the following two conditions are true:

- One cell in a series string has a much lower capacity than the other cells in the string (possibly due to battery degradation or manufacturing defect)

[1] http://www.concordebattery.com/products/techinical_info/thermal_runaway.htm , 09/2001

- The remaining good cells drive the lower capacity cell into a reverse condition. The overall voltage of the string is sufficiently maintained despite the reversal of the subject cell, such that the load continues to draw current from the string.

Cell reversal rarely occurs on UPS systems with a battery bus voltage below 100V, or on systems with parallel battery strings. Under the combination of the (2) conditions, the reversed cell can be subject to power dissipation up to 5% of the entire battery power capacity, which can cause catastrophic failure.

Fortunately, the risk of Cell Reversal can be eliminated in the system design by use of

- Parallel strings of batteries
- Reduced UPS DC bus voltage
- Monitoring and control of voltage charging within the battery string

Paralleling of battery strings nearly eliminates the second condition because when the voltage attempts to reverse on the subject cell the current diverts to an adjacent battery string. MBC systems utilize parallel strings and rarely experience this failure mode.

Conclusions

Vented (flooded or wet cell) batteries have a very long life but present significant complexity of installation and maintenance, the most significant being the need to build a separate battery room. These limitations have historically restricted the application of wet-cells to very high power installations.

The VRLA battery was developed in response to the limitations of the wet-cell battery, and provides significant benefits in the area of installation costs, maintenance costs, energy density and safety. However, VRLA reliability can be compromised through improper installation and/or misapplication. Although the battery life of the MBC is shorter than that of Wet Cells, the benefits of this technology, even with a shorter battery life, present a compelling value proposition for today's data centers and network rooms, especially in systems smaller than 500kVA.

All of the hazardous failure modes can be controlled by appropriate system design. Parallel string designs, ventilation, overcharge protection, temperature compensated charging, and battery monitoring are the principal techniques utilized to eliminate battery failure hazards.

About the Author

Stephen McCluer is a Senior Applications Engineer for external codes and standards compliance at APC. He has 25 years of experience in the power protections industry, and is a member of the IEEE Stationary Battery Committee where he chairs two working groups. He also is a member of NFPA, ICC, IAEI, ASHRAE, and the USGBC. He is a frequent speaker at industry conferences, and has authored technical paper and articles on power quality topics.