Battery Technology for Data Centers and Network Rooms: VRLA Reliability and Safety

White Paper 39

Revision 2

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> Executive summary

The valve regulated lead-acid (VRLA) battery is the predominant choice for small and medium sized uninterruptible power supply (UPS) energy storage. This white paper explores how the technology affects overall battery life and system reliability. It will examine the expected performance, life cycle factors, and failure mechanisms of VRLA batteries.

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Introduction

Valve regulated lead acid (VRLA) batteries have been used in UPS systems for almost 20 years. Compared to traditional flooded cell solutions, VRLA batteries allow higher power density and lower capital costs. VRLA batteries are typically deployed within power systems smaller than 500 kVA. Features of a VRLA battery include:

- Container is sealed; liquid cannot be added or removed
- Contains lead plates in a solution of sulfuric acid diluted in water (electrolyte)
- Electrolyte is immobilized (not allowed to flow)
- Operates at high currents
- Safety vents allow escape of gas only under fault or excess charging conditions
- Oxygen & hydrogen are recombined internally to form water
- Installed in open frames or large cabinets (or embedded inside small power systems)

This paper will explore in greater detail some of the operating considerations of the VRLA battery. Concerns about VRLA batteries generally center on two issues: reliability and safety. Because of their wide usage (deployed at an estimated rate of 10 million units per year), many people have had experience – both good and bad - with VRLA technology. To better understand both the extent as well as the limitations of VRLA technology, we first need to understand the variations in VRLA design and the theory of operation. We can then look at the application and misapplication of this technology. All products eventually come to an end of useful life. We will explore when that should be in a VRLA battery and how that life could be lengthened or shortened according to its application and care. Although catastrophic failures are rare, we will look at what safety hazards are possible when VRLA batteries are misapplied or misused.

VRLA types

VRLA batteries are sometimes identified by their ***technique for immobilizing the electrolyte***, of which there are two types:

- Gel cell - in this type of battery the electrolyte is distributed around the cell plates and separators and prevented from flowing by adding a gel-thickening agent. Gel cells are sometimes preferred for applications such as outdoor cabinets and photovoltaics. They are more widely used in Europe and Asia than in North America.
- Absorbed glass mat (AGM) - in this type of battery a highly porous and absorbent glass fiber mat separates the plates and keeps electrolyte in contact with them in a manner that is sometimes likened to a sponge. AGM is by far the more common and will be the focus of this paper. AGM is preferred for most controlled environment applications such as data centers and network rooms.

VRLA batteries are further sub-classified by their ***plate types***.

- So-called “telecom” or “long duration” VRLA batteries have thick plates designed to allow the battery to reach its end voltage over a period of several hours. They are frequently not discharged below 1.75 volts per cell.
- So-called “UPS” or “high rate discharge” VRLA batteries have thin plates designed to allow the battery to reach its end voltage over a period of only a few minutes. They are typically discharged to around 1.67 to 1.70 volts per cell.

VRLA batteries are also sub-classified by their ***container types***:

- “Monobloc” VRLA is usually a 6-Volt (3 x 2-Volt cells) or 12-Volt (6 x 2-Volt cells) container. Terminals can be either on top or at one end of the container. This is far and away the most popular battery for small and medium battery back-up systems in data centers, network rooms and telecommunications environments.

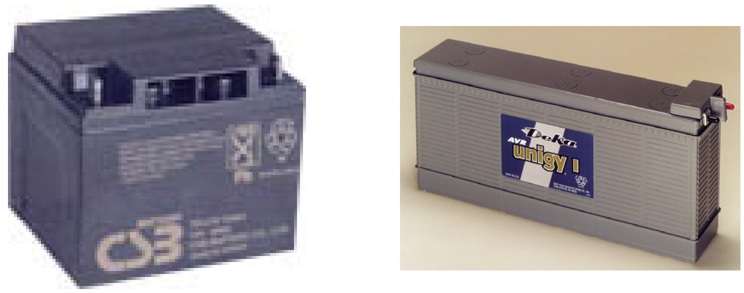


Figure 1

Examples of VRLA “mono bloc” batteries

- “Modular” VRLA are almost always single 2-Volt cells, usually installed horizontally to allow all of their connection and service from the “front” of a system. The cells are usually packaged into steel “modules” that can be stacked one on top of another and connected in series and/or parallel. This version is most common in telecommunication applications for high power, long duration back-up.

Figure 2

Modular VRLA

- “Battery cartridges” are actually multiples of VRLA batteries in a string conveniently packaged to allow their quick installation and removal. Battery cartridges can be plugged into battery cabinets designed with mating receptacles.

Figure 3

Battery cartridge

VRLA theory of operation

The valve regulated lead-acid battery gets its name from a characteristic valve built into the container. Unlike its flooded predecessor, the VRLA battery is designed to prevent the escape of gasses normally given off as a byproduct of electrochemical action and to prevent the ingression of external air. During charging of a lead-acid battery, hydrogen is normally liberated. In a vented battery the hydrogen escapes into the atmosphere. In a VRLA battery, through a process that is beyond the scope of this paper, the hydrogen recombines with oxygen, so water loss is minimized. Under normal float conditions, approximately 95 to 99 percent of hydrogen and oxygen is recombined. Resealable valves vent non-recombined gases only when pressure exceeds a safety threshold.

Although the electrochemical process is similar to a flooded battery, the VRLA is distinguished by the rate at which oxygen is evolved from the positive plate and diffused to the negative plate, ultimately forming water. This rate is several orders of magnitude faster. Because water cannot be added, recombination of water is crucial to the life and health of a VRLA battery. Any factor that increases the rate of evaporation or water loss will reduce the life of the battery. Such factors can include battery container material, ambient operating or storage temperature, and heat from the charging current.

VRLA life expectancy

The term “life expectancy” has been unusually controversial within the battery community. If we disregard “warranted life” which is a business term, there are two commonly used technical terms with different meanings that, regrettably, are often used interchangeably.

- Design life – is used by manufacturers as a measure of comparison. It is a theoretical figure. It is used as a short-hand method of comparison, as in “5-year,” “10-year,” and “20-year” battery, and is the basis for pro-rated warranties
- Service life - is the more realistic time (in years) from the installation of the battery until its capacity falls below 80% of its nominal rating. Service life implies a replacement interval shorter than the design life. In practice, the end of useful life for VRLA batteries can be as much as 50% below its design life. In extremely harsh operating environments life as low as 20% have been reported. When properly applied, monitored and cared for, VRLA batteries frequently achieve 70-80% of design life.

A wag once said that “VRLA batteries don’t die – they’re murdered.” He was trying to say that VRLA’s are often put into applications requiring more than we have a right to expect from the technology. Variables that can affect the life of a VRLA battery include:

1. Design (variations from one manufacturer to another)
2. Quality of materials (impurities / imperfections)
3. Production methods
4. Quality control
5. Cycling profile
6. Environmental operating conditions
7. Charging regimen

Items 1 through 4 are under the control of the manufacturer. Battery buyers must depend upon their knowledge and experience in selecting a trustworthy supplier. The system integrator or user has control over items 5 through 7.

Failure modes

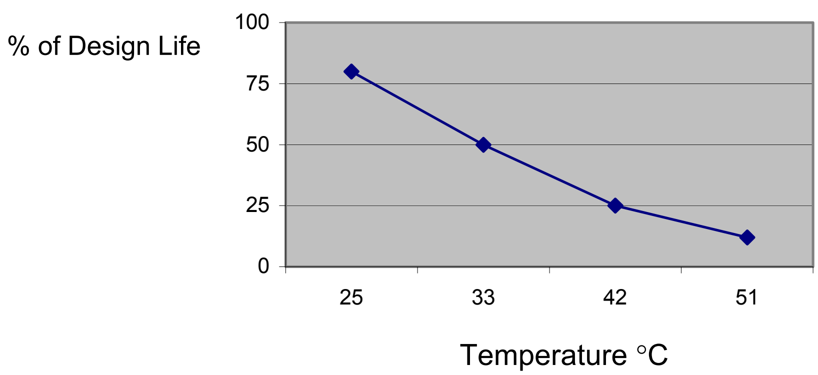
A major cause of VRLA battery death is dry-out. Many failure modes tend to be conditions that contribute to dry-out.

High ambient temperature - battery manufacturers usually describe their warranted or design life in terms of years operating at a particular ambient temperature. In controlled environments reasonable predictions can be made. The rule of thumb for a stationary VRLA battery kept at a constant state of charge (float life) says there is a 50% reduction in life for every 8°C (14.4°F) increase in temperature above optimum 25°C (77 °F). VRLA batteries have gotten a lot of bad press due in part to their widespread use in confined and uncontrolled environments such as outdoor cabinets where wide extremes of temperature are common. The graph in **Figure 4** gives a reasonable service life expectancy for continued operation at stable temperatures such as expected in a data center.

Rules of thumb come with many disclaimers. **Figure 4** addresses only one variable (temperature), but VRLA batteries are affected by many variables. For example, even though room temperature may be optimum, batteries packed tightly together or stuffed into unventilated cabinets may actually experience a higher internal temperature leading to premature capacity loss.

Figure 4

Operating temperature vs. battery life



Cycle life - a battery that is seldom used will obviously last longer than a battery that is discharged and recharged every day. Information about a battery's cycle capacity is seldom published on the manufacturer's data sheets. Every time you pull voltage out of a battery you discharge it. The amount of watts and the length of time you discharge determine the "depth of discharge" (DOD). The rate at which you pull watts out of a battery, the amount of recharge time between discharges, and the rate of recharge are also important. Battery designs generally assume 2-3 deep discharges per year (100% depth of discharge). As a general rule, a VRLA battery can provide hundreds of shallow discharges (e.g., <25% DOD). Actual field experience will include a wide variety of cycle conditions.

Charging regimen - a growing body of evidence suggests that float and charging voltage can have a significant impact on a VRLA battery's life. A practice of periodically "equalizing" a battery at a high voltage, common on flooded batteries, is generally accepted as a bad practice for VLRA batteries. Batteries used in data center and network room UPS systems are typically kept at a constant state of charge, called float voltage. The battery must not exceed the battery manufacturer's level of float voltage. Overcharging can cause dry-out that will drain the life out of a battery and can lead to failure, sometimes catastrophically. Most data center and network room UPS recharge the battery to 90% of nominal capacity in ten times the discharge period. (For example, a 7-minute discharge would be recharged in 10 x 7 = 70 minutes). Faster recharge will stress the battery and reduce its life.

To be suitable for data centers and network rooms, a system must include a control mechanism that will regulate voltage precisely. It should also be able to adjust voltage according to thermal conditions.

A few years ago it was widely argued that ripple current from poorly regulated AC/DC rectifiers was a major contributor to loss of battery life. Today it is recognized that ripple current is not a major problem in most UPS systems, but excessive amounts of AC ripple current can have a major impact on battery internal heat generation and service life. A UPS charger should keep ripple to a minimum (e.g. below 5A per 100 AH).

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:

1. One cell in a series string has a much lower capacity than the other cells in the string
2. The lower capacity cell becomes driven into a reverse condition by the remaining good cells in the string

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.

This is dependent on the system design and tends not to show up on UPS systems with a battery bus voltage below 100 V, or on systems with parallel battery strings. The first condition can be created unexpectedly due to battery degradation or manufacturing defect. Under the combination of the two conditions the reversed cell can be subject to power dissipation up to 5% of the entire battery power capacity, which can cause the battery to seriously overheat or in extreme cases to explode.

Fortunately, the risk of cell reversal in a system design can be nearly eliminated by:

- Using parallel strings of batteries
- Using a reduced UPS DC bus voltage
- Monitoring and control of voltages within the battery string

Paralleling of battery strings takes care of the second conditions because when the voltage attempts to reverse on the subject cell, the current diverts to an adjacent battery string. Battery cartridge systems utilize parallel strings and are not subject to this failure mode because the load current diverts away from any cell that attempts to reverse into an adjacent string.

Internal failures - VRLA failures can include negative lug corrosion, negative strap fracture, excessive plate growth, negative plate capacity loss, and contact between positive plate and negative strap. These failures can show up within 1-5 years of service.

- **Grid corrosion/cell short** – positive grid corrosion/growth is one of the primary causes of failure in VRLA batteries and battery cartridges (especially on shorter design-life batteries). The condition is almost always accompanied by dry out which can precede grid corrosion failure. Grid corrosion on the positive grid is also a common failure mode in flooded cell systems. It causes loss in mechanical strength and eventually leads to loss of contact with the grid. The internal resistance increases and the capacity decreases. In severe cases grid corrosion can cause destruction of the container, cover and terminals. A common mode of failure is shorting between the plates. This failure mode reduces capacity of the cell, but the string can still provide energy to the UPS.
- **Interconnect failure** – most inter-cell connection 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 VRLA battery systems, interconnects can carry

high currents during discharge. 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. Battery cartridge connections are made prior to shipment from the factory and experience a low failure rate. Cartridge systems generally operate at low currents and consequently do not have the same dependence on low resistance connections as flooded batteries.

Thermal runaway - when a VRLA battery is kept at elevated "float" voltage or is overcharged in a fully recombinant mode, almost all of the overcharge energy results in heat. A well-designed application allows the heat to escape and thermal equilibrium is achieved, so there is no problem. However, if the rate of heat generation exceeds heat dissipation, the battery temperature will rise. Higher temperature causes an increased current draw by the battery (float current). More current leads to higher temperatures which requires even more current to maintain the float voltage. More current creates more heat until the electrolyte vaporizes at around 126° C (259 °F). Pressure builds inside the battery until the vents open and allow the release of hydrogen, oxygen, and occasionally minute quantities of hydrogen sulfide and atomized electrolyte. Build-up of internal pressure and softening of the case material at higher temperatures has been known to cause container bulging or even container rupture. If left unchecked, this spiral will continue until the battery dries out and fails. The following conditions can contribute to thermal runaway:

- High ambient temperature
- Poor ventilation / insufficient spacing between cells/units
- Lack of voltage compensation that would reduce the voltage
- Improper float voltage adjustment (charger over-voltage)
- Individual cell failure within a battery string
- Charger failure resulting in high output voltage, current, or ripple
- Oversized or excessive number of chargers (creating excess recharge current)

The twin pillars of thermal runaway are voltage and heat. If either is removed, thermal runaway will stop. Well-designed rectifier plants or uninterruptible power systems incorporate temperature compensated charging. Indeed, fire codes now require an approved temperature compensation device for batteries installed in a data center or network room. Temperature compensated charging monitors battery temperature and reduces the charging voltage in proportion to the increase in battery temperature. Corrective actions for a thermal runaway condition include:

- Reduce the ambient temperature in the room or enclosure
- Reduce the voltage below the threshold that will sustain thermal runaway (for constant voltage operation)
- Reduce the current below the threshold that will sustain thermal runaway (for constant current operation)
- Disconnect the battery from the charger or rectifier
- Turn off the rectifier or charger

Safety

VRLA batteries are inherently safe, and thermal runaway can be prevented. However, there are some risks when VRLAs are misapplied or abused. As already mentioned, the byproducts of thermal runaway are hydrogen and oxygen (the two elements of water). In some cases minute amounts of hydrogen mix with electrolyte and form Hydrogen Sulfide, H_2S. These are discussed below.

Hydrogen gas - the biggest fear people have about thermal runaway in VRLA batteries is off gassing of hydrogen and oxygen. Hydrogen becomes flammable when it reaches the lower explosive level (LEL) at approximately 4% concentration of air. Some sort of ignition (spark) is required. At the minimum 4% level, combustion is too weak to get much attention, but at higher concentrations explosions can be dramatic. Hydrogen is the lightest atom so it always rises, and it is extremely difficult to contain. Hydrogen will escape if it can. Well-designed power systems and facilities will prevent the accumulation of hydrogen pockets. Battery manufacturers can provide the worst-case gassing rates. Standard practice is to control accumulation in cabinets or rooms to below 1% concentration. By comparison, natural atmospheric concentration of hydrogen is 0.01%. The valves on the VRLA battery itself are designed to prevent flame entering the battery and causing an internal explosion.

Hydrogen sulfide gas - people sometime complain of a bad, “rotten egg” smell or tingling of the nose after a thermal event. That is most likely caused by hydrogen sulfide (H_2S) gas. Darkening of copper battery terminals is also an indication of H_2S . Thermal runaway does not always expel H_2S. The exact mechanism is unknown. H_2S is common in nature, frequently as a result of rotting vegetation or animal manure. The human nose can detect H_2S at levels as low as 0.005 to 0.02 parts per million (ppm). The Illinois Dept. of Public Health describes that as “the same as a thimble full of hydrogen sulfide gas in a theater full of air.” The National Institute of Environmental Health Sciences says H_2S can be detected at about 1/400 of the threshold for harmful human effects. The US Government says that 20 ppm is the acceptable ceiling for daily 8-hour exposure. OSHA allows a maximum 50 ppm for 10 minutes acceptable maximum peak above the normal ceiling. While there is some evidence of risk from long-term exposure to H_2S, there is no evidence of risk from short-term, moderate levels of exposure. Symptoms of exposure include eye, nose and throat irritation, and sometimes headaches. At extreme concentrations serious illness or death can result. For exposures below 250 ppm, recovery occurs quickly if exposure to H_2S is brief, and there should be no long-lasting effects.

Because the amount of H_2S given off during a VRLA thermal event is so tiny, the risk is usually insignificant. H_2S can be detected well before it is harmful. However, when H_2S is detected it is prudent to ventilate the room and/or exit the area.

Fire/flammability - most large VRLA battery cases are designed to be self-extinguishing and meet minimum flammability standards of UL94 V0 and 28 L.O.I. (limiting oxygen index). Smaller VRLA’s such as those embedded in UPS typically meet UL94HB. Although some flooded batteries use PVC, which can create hazardous smoke, VRLA batteries almost never use PVC.

Acid spill - the term “acid spill” does not apply to VRLA batteries because the electrolyte is immobilized. VRLA batteries can swell and deform with age, abuse, or manufacturing defect. Sometimes cracks, small leaks or drips, or post corrosion can occur. These are detectable with routine inspection or monitoring and are easily corrected during maintenance. Evidence of electrolyte release in a VRLA battery usually suggests it is time to replace the cell or string. More often there is no sign or electrolyte because, as mentioned, the leading cause of failure is dry-out.

Handling and environmental safety

During normal battery installation, operation and maintenance, a user will have no contact with the internal components of the battery or its internal hazardous chemicals. VRLA batteries contain lead and should be properly returned for recycling by an authorized battery recycler.

Conclusion

When properly applied and maintained, VRLA batteries and cartridges such as those used in small and medium-sized UPS systems can give reliable performance for three to five years or longer (depending upon battery selection). Battery dry-out is a major cause of VRLA battery end of life. Continuous monitoring and control systems can detect and respond to conditions that could cause premature cell failure. Temperature compensated and current limited charging can help prevent thermal runaway. Use of redundant, parallel strings can reduce the consequences of a cell failure and increase the life of a battery system.

VRLA batteries are safe to use in data centers and network rooms when properly applied and maintained. Neglect, abuse, or improper application can create conditions that could push a battery into failure mode. In extreme cases, catastrophic failure can cause fire and/or release of hazardous gases. Proper cooling and ventilation, regular monitoring, use of parallel strings, and temperature compensated charging can all contribute to long battery life and safety.

About the author

Stephen McCluer is a Senior Manager for external codes and standards at Schneider Electric. He has 30 years of experience in the power protection industry, and is a member of NFPA, ICC, IAEI, ASHRAE, The Green Grid, BICSI, and the IEEE Standards Council. He serves on a number of committees within those organizations, is a frequent speaker at industry conferences, and authors technical papers and articles on power quality topics. He served on a task group to rewrite the requirements for information technology equipment in the 2011 National Electrical Code.

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References

1. Culpin & Wainwright, *An investigation Into the Effect of Abuse Charging and Thermal Runaway in VRLA Batteries*, INTELEC 2001, *Conference Publication No. 484*
2. C&D Technologies, *Charger output AC Ripple Voltage and the Effect on VRLA Batteries*, www.dynastybattery.com/cd_dyn/contact/tech_support/2131.htm
3. Rhodes, Vaccaro & Lee, *VRLA Batteries: Predominate Problems and Concerns, a Battery Manufacturer's Evaluation*
4. Onada, Noda, Abe & Kobayashi, "Development of Reliable and Long Life VRLA Batteries," INTELEC 2001, *Conference Publication No. 484*
5. *IEEE Guide for the Ventilation and Thermal Management of Stationary Battery Installations* [Draft], Jan 2001
6. International Code Congress, *International Fire Code,* Section 609.3
7. Illinois Department of Public Health/ Division of Environmental Health, *Fact Sheet: Hydrogen Sulfide Gas*
8. OSHA, 20CFR1910.1000, Subpart Z
9. Public Law 104-102, 13 May 1996, 110 STAT.1329, 42 USC 14301-14336

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