PowerShield™
SMART BATTERY MANAGEMENT

UNDERSTANDING UPS SYSTEMS AND BATTERIES

Putting the ‘U’ in UPS

When it comes to an uninterruptible power supply (UPS), the battery is one of the most important subsystems but can be one of the hardest to understand. In this eBook, we have provided a breakdown of the role batteries play in a UPS.

Along with a refresher on the fundamentals of a UPS, we’ll be looking at battery management, battery configuration and charging, as well as installation, environmental and safety considerations.

This eBook is for you, the hands-on, technically-oriented people in a business. To ensure we have a shared understanding of the terminology being used, we’ve included a glossary at the end.

PowerShield is certified to ISO 9001 Quality standard, ISO 14001 Environmental management standard and OHSAS 18001 Occupational Health and Safety management system certification. An active involvement with the IEEE Stationary Battery Committee ensures PowerShield is at the forefront of the industry, continuously working toward providing smarter battery management solutions.

PowerShield specialises in battery management solutions for mission critical operations. We are committed to continuous improvement, quality management and the environment.

CONTENTS

UPS 101 – An overview

It may be UPS 101, but a good understanding of what a UPS is and how it works is essential for getting to grips with the role the batteries play.

The three main subsystems of a Uninterruptible Power Supply (UPS) are:

1. **Rectifier/charger** – Converts alternating current (ac) into direct current (dc) used to maintain the battery at a constant state of charge.
2. **Battery subsystem** – Stores energy; includes multiple cells, mounting equipment, protective devices, and monitoring.
3. **Inverter** – Converts dc back into ac for consumption by the critical load(s).

Other elements include such things as static bypass, maintenance bypass, protective devices, controls, and distribution equipment.

Of the three main subsystems, the battery is what makes the system "uninterruptible". Depending upon the system design, the battery can constitute as much as 50% of the cost of the UPS. Without a reliable battery, the operation of the entire data center can be put at risk. Power interruptions are rare and unpredictable, but when they occur they bring the risk of downtime. Costs of downtime can range from an estimated $9000 per minute for Healthcare downtime, to $740,000 for a Data Center outage.

It is the nature of a battery subsystem to be composed of many connected parts such as cells and interconnecting cables. Each cell is likewise made of components such as plates, containers, separators, and electrolyte. Failure of one or more of any component(s) can impact the performance of this critical subsystem. Usually there is no visible indication that a failure is imminent. That is why particular attention is paid to monitoring and maintenance.

Battery types

Batteries are available in a range of technologies, including lead-acid, nickel- cadmium, lithium ion, lithium-sulfur, aluminum-ion, nickel-metal, and more. Of all these, lead-acid has historically been the battery of choice in UPS applications due to the lower cost, availability, minimal environmental impact and ease of recycling, and proven performance when compared with other leading battery technologies. For these reasons this report focuses predominantly on lead-acid battery technologies.

- **Valve-Regulated Lead-Acid (VRLA)** is the most popular because of its convenience of use.
- **Vented Lead-Acid (VLA)**, also known as "flooded lead-acid" or "wet cell," is still used in some UPS applications, especially those in the megawatt range.

Details on the trade-offs of these batteries will be discussed in the next chapter.

Monitoring versus managing

The old adage goes, 'You can't manage what you can't measure.' The two functions, while intertwined, are separate.

Managing a battery allows you to know the "state of health" of a battery at any given moment. We can measure things such as temperature, voltage, current, and resistance. As batteries grow older they lose the ability to perform. This ability to perform is usually expressed as "back-up time." A battery that originally was able to support load "X' for fifteen minutes might deteriorate to only supporting the same load for twelve minutes. Generally speaking, when a lead-acid battery is able to deliver only 80% of its original capacity, it is time to replace the battery. Battery replacement can be very expensive in both labor and material, so it is desirable to postpone such an event for as long as possible.

By properly measuring and understanding a battery, we can make predictions about when a failure is likely to occur and take proactive measures.

The chapters that follow will each address topics in greater detail. While the goal of this series is not to make the reader into a certified technician, the reader will be able to talk intelligently about UPS batteries and understand how to maximise the investment in a battery system and maximise uptime.

> *"Managing a battery well helps prolong the life of the battery. "*

Within lead-acid, there are still more variations. It is important to focus on two main form factors:

- Valve-Regulated Lead-Acid (VRLA)
- Vented Lead-Acid (VLA)questions or comments

Battery configurations

Battery types

Lead-acid batteries have been until recently the preferred method of energy storage for UPS systems in about 95% of all data center applications. Lithium battery technology has been an increasingly popular alternative in data center UPS applications in recent times. However, the lower up front capital cost, lower fire risk and minimal environmental impact offered by Lead Acid battery technology means that it is here to stay, for the foreseeable future at least. When coupled with an advanced battery management system the risk mitigation advantages of lead-acid batteries in a data center UPS become even more compelling.

Lead-acid batteries can be split into two main categories or technology types: valve-regulated or vented.

Before getting into the technical details of each technology, it is important that we are clear on two terms:

- **Cell:** A cell is the basic electrochemical building block of a battery. It is in a container (sometimes referred to by the slang term “jar”) holding positive electrodes, negative electrodes, and electrolyte. A container can be single-cell or multi-cell. For example, a common 12-volt battery unit contains six 2-volt cells in series inside a single container. The “battery” manufacturer’s specifications apply only to cell units.

- **Battery:** A battery is one or more cells connected in series, parallel, or both, to provide the required operating voltage and current levels required by the load equipment. In other words, the user or integrator assembles the cells (frequently at the owner’s site) to create a battery. A UPS battery can consist of dozens or even hundreds of cells.

Valve-regulated lead-acid (VRLA) cell — VRLA has been the technology of choice in the majority of UPS applications for a number of reasons:

- **“Sealed” construction** – The VRLA cell is usually sealed, so it does not release flammable hydrogen gas and oxygen under conditions of normal use. As the name implies, it has a “valve” that can open and release gas when internal pressure exceeds a specified level such as under fault conditions. This means that the ventilation requirements are not as rigid as they are for vented lead-acid cells (discussed below)

- **Reduced maintenance** – Because the cell container is opaque, visual inspection of liquid levels is not required. Likewise, it is not necessary to periodically add liquid to the electrolyte. Gases created during electrolysis are recombined inside the cell rather than being released into the air.

- **Immobilised electrolyte** – VRLA has no free-flowing liquid electrolyte

- **Smaller footprint** – VRLA only holds about ten percent of the amount of electrolyte required in a comparably-rated vented cell. That makes the cells or multi-cell units quite a bit smaller.

- **Easier assembly** – Because the unit has no liquid electrolyte, it is possible to install VRLA units upright or sideways. VRLA batteries can be enclosed in a cabinet or on racks.

VRLA trade-offs:

- **Low temperature tolerance** – High internal and ambient temperatures can accelerate the evaporation of electrolyte thereby leading to premature failure and/or overheating known as “thermal runaway.”

- **Shorter life** – VRLA cells typically must be replaced more frequently than vented cells. Material, labor and recycling costs must be factored into the purchase decision.

Vented lead-acid (VLA) cell – Historically VLA's were the preferred battery technology before the appearance of VRLA. As the name implies, the VLA vents continuously into the surrounding air. Some of the reasons for continued use of VLA's, particularly in large (megawatt) applications, include:

- **Longer life** – The service life of VLA cells will typically last two to three times longer than VRLA.
- **Greater visibility** – Cell containers are transparent, so it is possible to visually inspect what is happening inside a cell and take corrective action such as adding more water to the electrolyte.
- **Low risk of thermal runaway** - Because of the high liquid electrolyte content, dry-out is unlikely with scheduled maintenance.

VLA trade-offs:

- **Battery rooms** – VLA batteries can only be installed in dedicated rooms with ventilation systems that exhaust battery fumes to the outside of the building rather than circulate inside
- **Large footprint** – VLA cells are only installed upright on open battery racks. The installed footprint can be as much a twice that of VRLA
- **Floor loading** – VLA cells are mostly lead and liquid electrolyte, which makes them very heavy and difficult to install on the upper stories of buildings
- **Spill hazard** – Because of the large amount of liquid electrolyte in a VLA, spills and leaks are always a concern. The active ingredient in electrolyte is sulfuric acid, which is corrosive.

Installed form factor

As mentioned above, batteries can be installed in two configurations.

- **Battery racks** - Both VRLA and VLA can be installed on open racks that allow easy access for inspection and servicing. Racks are usually multi-tier or multi-step to reduce footprint. The trade-off is greater floor loading. Because of the potential of human contact with a dangerous electrical hazard, open racks must be in rooms only accessible by trained and authorised personnel.
- **Battery cabinets** - Only VRLA can be installed in cabinets. Because cabinets can have locked doors, the cabinets do not have to be in battery rooms; they can be installed directly adjacent to the UPS system and/or the information technology equipment. This eliminates the need for long dc cabling. Battery cabinets can be made to be indistinguishable from IT equipment cabinets. They must be properly ventilated to ensure no accumulation of hazardous gas.

Battery charging regimes

In a previous chapter we discussed various stationary lead-acid battery chemistries for UPS applications. In this chapter we look at the role of battery charger subsystem. Charging regimes can generally be categorised into two types: intermittent and float.

Intermittent charging

IEEE 1881 defines intermittent charging as "A non-continuous charging regime, based on:

1. availability of the charging source; or
2. application of the charge by a permanently powered source."

Condition #1 above can best be observed in portable devices, such as cell phones and tools, where the battery spends most of its time disconnected from a charger until its state of charge shrinks to the point where the devices must be connected to a charger. A built-in battery monitor, such as in a cell phone, may warn the user that the voltage is getting critically low, at which point the user can physically connect to the battery to a charger and leave it until the battery gets back to 100% of capacity.

Condition #2 represents most stationary applications in which a charger is always available but is basically turned off much of the time. When the stored voltage reaches a lower threshold, the charger automatically kicks in. The battery might never be charged back to 100% of its rated value. The most common applications for intermittent charging are in renewable energy such as wind and solar. When the renewable energy source is available (such as the sun during the day or on a windy day), the battery is charged. At night, or when the wind dies down, energy is pulled back out of the battery. This type of application is known as "cycling service." Both the battery and the charger must be designed specifically for this type of service.

As early as the 1990's engineers were looking for a way to utilise intermittent charging for UPS. They observed that lead-acid batteries in cycling applications (i.e., long periods of slow discharge followed by a period of high recharge) seemed to last longer than batteries kept on The argument in favour was that continuously charging a battery can have a long-term negative effect on the battery leading to reduced lifetime. The idea was that allowing the battery to "rest" and then giving it a charge can help prevent grid corrosion and prolong battery life. However, this is a controversial topic as there is very little scientific test data to support this concept for UPS applications.

The arguments against intermittent charging fall into three camps. First, allowing the battery to discharge to a low threshold before it is recharged means that the battery is rarely fully charged. What happens if the battery is called upon when it is at its lowest level? The battery would have to be oversized to compensate for the lost minutes.

Second, connecting and disconnecting the charger makes continuous monitoring very difficult, both for the battery and for the charger. Many variations of intermittent charging are in use today. Some let the battery "rest" (or "idle") for a few hours, whereas others may "rest" for as long as a few days or weeks. Another variation on UPS design deliberately schedules periodic partial discharge-and-recharge on a monthly basis. The actual rate of discharge under a given load is compared to the predicted rate of discharge to calculate the probable life remaining in the battery. Monitoring the state of charge can be very complicated under such a variety of conditions. The ohmic measurement data that is collected will vary depending upon where the battery is in the charge/recharge cycle. For example, is the charger on or off? The ohmic data will vary depending upon how recently the battery has been charged.

One variation of intermittent charging is known as "pulsed charging," in which the charger switches on and off several times per minute (or per second). The theory is that the amount of time "on charge" can be cut significantly without lowering the actual state of charge. While theoretically feasible, science has yet to validate this claim and, in fact, suggests that pulse charging actually stresses the battery, similar to the damaging effects of ac ripple. We are not aware of any UPS manufacturers using pulse charging today.

Third, the impact on the connected dc load (such as a UPS inverter) must also be considered to ensure that it can tolerate constant swings in available dc voltage.

Another consideration is that some battery manufacturers will not warrant their batteries when they are charged via intermittent charging.

Float service

Float charging (sometimes called trickle charging) is far and away the most common charging regime for stationary UPS applications. The battery spends the majority of the time on float charge with infrequent discharge. A constant-voltage charge is applied to the battery to maintain it in a fully charged condition, while minimising degradation or water consumption. Unless the UPS is hit with a series of ac power outages in rapid succession, the battery is almost always at 100% of its capacity.

Float charging makes it relatively easy to monitor the state of charge in real time. The monitor can ensure that the voltage being applied to the battery from the charger is appropriate for the charge status. 99% of the time the battery receives minimum voltage; i.e., just enough to keep it fully charged. In the event of a discharge caused by an ac power failure or intentional discharge testing, a higher voltage is applied to bring the battery back to full charge as quickly as possible. The period from the initiation of charging to the onset of gassing is known as "bulk charge," during which charge is returned to a battery at high efficiency.

Charging a lead-acid battery normally does not generate hydrogen and oxygen gas until the battery nears full charge, typically at about 90% of its capacity. This level is achieved relatively quickly. For example, a battery discharged for ten minutes might be recharged to 90% of capacity in ten times the discharge time, or one hundred minutes (1.6 hours). Because gassing is undesirable, charging voltage is automatically reduced until the battery reaches 100% of capacity. That last ten percent, known as the "finishing rate," can take as long as twenty-four hours. The rest of the time the battery sits at "float" rate, the lowest voltage.

There are too many variations of these two charging regimes to describe here. For example, some might use constant current charging instead of constant voltage charging (although the latter is the dominant method). Chargers must be able react to irregular conditions, such as thermal runaway or equalising conditions. These topics can be discussed in future chapters.

- **What charging method is being used** - UPS manufacturers might not always volunteer this information unless asked. If an external monitor expects to see constant float voltage and instead sees lower voltage because the charger is in "rest" mode, it could cause false alarms.
- **What is the battery warranty** - If the battery warranty is not provided by the UPS manufacturer, find out if the battery manufacturer's warranty is affected. Some battery manufacturers treat intermittent charging as excessive cycling and will void the warranty.

Recommended user actions - Ask the UPS manufacturer:

- What charging method is being used?
- What is the battery warranty?

Failure modes in lead-acid batteries

Despite a century of experience, collective knowledge, and wide-spread preference for lead-acid batteries, they are not without some short-comings. In this chapter we go into more depth about how, when and why a lead-acid battery might be made to fail prematurely. Most conditions are preventable with proper monitoring and maintenance. This list is not all inclusive, but some of the main considerations are:

- Temperature tolerance
- Dehydration
- Thermal runaway
- Cycling ability
- Overcharging
- Under-charging
- Contamination
- Typical service life expectations
- The roll of catalysts

Temperature

When we speak of temperature, we must understand that there are two primary temperature conditions: ambient temperature (i.e., room or air temperature) and internal temperature (i.e., electrolyte temperature). Of the two, internal temperature is more important. Of course, ambient temperature can cause a change in internal temperature, but the rate of change in internal temperature lags well behind the external temperature. For example, daily outdoor temperatures might vary by six degrees (°C) between night and day, whereas the internal temperature of a battery exposed to the ambient swings might only deviate by one or two degrees. Conversely, internal temperature can be driven up by factors unrelated to ambient temperature (to be discussed later).

High temperature can have a short-term benefit of pulling more energy out of the battery, but at the cost of reducing the life of the battery. Conversely, cold temperature can improve the lifetime of the battery, but at the cost of reducing the energy that be pulled from it. The biggest problem with high temperature is dehydration (evaporation of electrolyte) discussed below.

Battery manufacturers specify the optimum operating temperature for the battery, usually 25 °C, and all promises about life are predicated on that. The effect of temperature is generally expressed in terms of half-life.

You will hear, "For every 10 °C of average temperature above 25 °C the life of the battery is reduced by 50%."

Such claims sometimes don't say it, but they refer to internal temperature. Short excursions, such as an occasional increase from 25 °C to 30 °C for a few hours can be tolerated, but average temperatures above optimum for weeks or months at a time will definitely shorten the life.

Dehydration

Vented batteries (sometimes called "flooded" batteries) evaporate all the time, but they are designed to make it easy to know when the electrolyte level is dropping and to replenish with water. VRLA batteries, sometimes called "starved electrolyte" or "immobilised electrolyte (or erroneously termed "sealed lead-acid" [SLA] or "maintenance free"), have far less electrolyte than a vented battery, and the cell container is opaque so it is impossible to see what is happening internally. Under ideal conditions the products of evaporation (oxygen and hydrogen) are recombined into water inside the battery. However, the VRLA valve can release gas under high temperature or high internal pressure conditions. An occasional "burp" is normal and is usually of no consequence.

The concern is with extended release of gas. Once released the gasses are lost forever and the battery will dry out. That is why the nominal life expectancy of a VRLA battery is about half the life of a VLA battery. It is also why VRLA is frequently referred to as "low maintenance" (i.e., frequent electrolyte replenishment is not required). Dehydration is the natural consequence of old age. Premature dehydration is a failure condition which can lead to other failure modes.

Thermal runway

Thermal runaway is a catastrophic failure. IEEE 1881 defines thermal runaway as: "A condition that is caused by a battery charging current or other process, which produces more internal heat than the battery can dissipate." For example, excess charging current (caused by internal short or improper charging) creates heat. Heat creates resistance. Resistance creates more heat. This cycle can continue until heat is so high that the cell dries out and catches fire or melts. Several means are available to detect and preclude thermal runaway early in the cycle. Temperature-compensated charging is the most common. It requires temperature sensors to be strategically placed on cells throughout the battery. As temperature increases, charging voltage decreases proportionately, until charging ceases altogether. Some UPS and external battery chargers are capable of temperature-compensated charging, but battery temperature sensors are frequently provided only as an option. Thermal runaway will be discussed in greater depth in a future chapter.

Cycling ability

Cycling service refers to operation in which it is anticipated that the battery cycles frequently with minimum time on float charge, which is common in stored energy systems such as wind, solar, or installations supplied by an unreliable grid. UPS operation, by contrast, assumes that the battery will be on float charge for almost all of its life. A "cycle" means that the battery is discharged and then charged back to its full capacity. Every discharge takes life out of the battery. Some battery types can only tolerate a few cycles in the life of the battery. Others can tolerate thousands of short discharges, but fewer deep discharges. The battery selection process (prior to purchase) should consider the reliability of utility power and therefore the probability of frequent cycling.

Overcharging

Overcharging is any excessive charge that results in damage to a cell or battery. It can be the result of human error (i.e., setting the wrong parameters on the charger), or charger failure. In UPS applications, charging voltage varies depending upon the stage of charging. For example, initial charging following a discharge is at a higher voltage (referred to as "bulk charge") than at standby (referred to as "float charge").

"Overcharging can dramatically shorten the life of a battery and, in worst case, can lead to thermal runaway. Monitoring systems should be able to detect and alarm overcharging conditions. "

Undercharging

As the name implies, undercharging means applying less voltage over time than is necessary to maintain a cell at a desired state of charge. Over a long time (e.g., weeks or months), undercharging will result in the loss of battery capacity and/or shorter battery life due to self-discharge.

Contamination

Contamination of electrolyte is extremely rare in VRLA batteries and is usually a factory defect. Sedimentation and spalling can occur in an aging battery. Contamination is more of a concern for VLA batteries when periodic replenishment of water to the electrolyte occurs (for example, using tap water instead of distilled water).

Typical service life expectations

"Battery life" is a nebulous term that is often exaggerated by marketing people who use terms such as "design life or "useful life." Service life is the only one that matters to a user and is defined by IEEE 1881 as, "the period of useful operation under specified conditions, usually expressed as the time period or number of cycles that elapse before the ampere-hour capacity falls to a specified percentage of the rated capacity."

So if you anticipate that your battery will experience a lot of discharges and/or will be exposed to a lot of heat and/or will be poorly maintained, the service life of your battery will be significantly shorter than the same battery under optimum conditions. For small ampere-hour, high-rate VRLA batteries (i.e., UPS batteries), service life might be only around three years. Larger VRLA batteries might get around eight-to-ten years.

"Properly maintained VLA batteries might get in excess of fifteen years of service conditions. "

Catalysts

A catalyst is a device added to the vent of a VRLA cell to improve the hydrogen-oxygen recombination process inside the cell, thereby reducing dry out and extending the life of the battery. Some battery manufacturers include catalysts in the design of their cells, thereby increasing the initial cost of the battery. Catalysts can sometimes be field-installed as an after-sale accessory and can sometimes rejuvenate an aging battery. Caution is suggested, however, as field modifications introduce the possibility of human error and/or contamination, and should only be performed by factory-trained technicians.

Battery environmental and safety considerations

Environmental considerations fall into two categories:

- The effects upon the battery by the environment in which it sits (small "e"); and
- he effects of the battery upon the Environment in which it was produced, used, and disposed (big "E")

Impact of the environment on batteries

Earlier chapters have discussed the impact of such things as temperature and grid reliability upon the life of a battery system. We will simply state here that it is wise to follow the manufacturer's recommendations. A lead-acid battery, and in particular a VRLA battery, needs:

- well ventilated and temperature-controlled air flow. Cells that are packed tightly against each other will not be able to dissipate heat. The result is that cells in the middle of a row will run hotter – and therefore die sooner – than cells at the end of a row. Likewise, cells on the bottom shelf or tier will be cooler – and therefore live longer – than cells at the top of a cabinet or rack. Hot cells are more likely to vent gas, which then must be ventilated to prevent accumulation to hazardous levels.
- clean air. Dirt and humidity can have a corrosive effect on the battery, and can even be conductive, creating short circuits. Batteries should be inspected and cleaned periodically.
- chemical free maintenance. No chemical should ever be used to clean a battery unless it has been approved and/or recommended by the manufacturer. Some chemicals can deteriorate the cell container, causing leaks.
- sunshine-free location. UPS batteries should never be installed outdoors where they can be exposed to the damaging effects of sunlight.

IEEE 1635/ASHRAE 21[4] is a good engineering reference for designing properly ventilated battery rooms and cabinets.

Impact of batteries on the environment

Lead-acid batteries contain substances that are not good for the environment in which we live. These include: electrolyte (sulfuric acid); lead and lead-compounds; and plastic. Fortunately, these hazardous substances are well-known and are easily recycled. Almost 99% of the materials in a lead-acid battery can be recycled.

Electrolyte

In the developed nations of the world, large format lead-acid batteries (such as those used in UPS systems) have extremely good recycling records, approaching 100%. Regulations in many parts of the world require the battery manufacturer to have "take-back" policies for depleted batteries. From a user perspective, the greatest environmental concerns (other than recycling at end of life) involve accidents such as damaged cells, electrolyte spills, and release of hazardous gasses.

Electrolyte is a major concern because it contains dilute sulfuric acid, which can be corrosive in high concentrations. The specific gravity of electrolyte in VRLA and VLA batteries is quite low (slightly stronger than vinegar), so that most people would be unaffected by contact with the skin as long as it is quickly washed off with soap and water. Contact with eyes or mucus membranes, however, can be serious, so people handling batteries should be using personal protective equipment (PPE) such as goggles and acid-resistant gloves.

The risk of contact with electrolyte is highest for a VLA battery (also known as a "flooded" battery or wet cells), which has free-flowing liquid electrolyte that requires frequent replenishment by technicians. By contrast, a VRLA battery, also known as a starved electrolyte battery or SLA, has only a tiny fraction of the amount of electrolyte of a comparable VLA battery, and the electrolyte is immobilised so it cannot flow. The VRLA cell is sealed, so electrolyte replenishment is not required or even possible; electrolyte can only escape under fault conditions.

Because VLA batteries have free-flowing liquid electrolyte, spill containment is recommended and usually required in order to prevent the spread of electrolyte in the event of a spill or a leak. Because VRLA batteries, by contrast, have immobilised electrolyte, spill containment is not appropriate. Both types, however, require a neutralising agent (such as baking soda) to be readily available when handling the batteries.

Lead

Lead is hazardous if it gets into the water supply or somehow is otherwise taken internally. The lead sealed inside a cell is solid, so it would not normally pose a hazard to a water supply unless it is released in tiny particles such as cleaning terminals with a wire brush. In such a case, lead particles could be inhaled or could find their way into drains and from there into the greater water supply. Lead compounds can form if a seal is broken and corrosion forms around the posts. Such corrosion is powdery and could be inhaled or ingested if it gets onto hands that later contact the mouth.

Electrolyte can contain lead in suspension, so even when it is neutralised it is still considered to be hazardous material and must be disposed of as such. Electrolyte should never be washed down a drain.

Hazardous gas

Hazardous gas usually refers to hydrogen, which is flammable in concentrations above 4%. Most building codes have regulations requiring ventilation to prevent accumulation of hydrogen gas close to the lower flammability level (LFL). IEEE 1635/ASHRAE-21[4] recommends that pockets of hydrogen gas not be allowed to accumulate in concentrations greater than 2% of the air in the space (i.e., a 50% safety margin). Local fire codes and building codes should be consulted to find out if they set different requirements.

In rare failure conditions hydrogen sulfide can be formed (smells like rotten eggs), but its effects are short term unless breathed for long periods in confined spaces.

Carbon footprint

The carbon footprint of a battery must consider several “cradle-to-grave” factors including:

- Mining or other methods to extract raw materials
- Energy used to produce and transport both the raw materials and the final product
- Energy consumption used to keep the UPS battery fully charged during its service life
- Ability to recycle and dispose of the battery at the end of its service life

Available evidence suggest that the carbon footprint of a lead-acid battery’s nearest competitor – Lithium-Ion – is nearly the same as lead-acid when all of the above are factored.

Other considerations

Nickel-cadmium (Ni-Cd) batteries are sometimes used in UPS systems. By definition, Ni-Cd batteries contain cadmium in a dilute solution of potassium hydroxide, which is toxic if swallowed, fatal if inhaled as freshly generated cadmium oxide fume, and may cause cancer through inhalation of dust or fumes. Cadmium is also suspected of damaging fertility or the unborn child and to cause damage to organs through single exposure or prolonged / repeated inhalation of dust or fumes. Cadmium can cause long lasting harmful effects to aquatic life. For these reasons, Ni-Cd batteries are prohibited in some regions of the world. Where used, they must be recycled by specially designated recycling centers. In most cases the manufacturer is responsible for taking back the spent battery and recycling it.

A Safety Data Sheet (SDS), also known as a Material Safety Data Sheet (MSDS) should be provided by the manufacturer and should be readily available for reference in the area where the chemicals are being stored or in use. The Globally Harmonized System of Classification and Labelling of Chemicals (GHS)[5] contains a standard specification for safety data sheets. Labels and/or signage should be posted to identify substances on the basis of physio-chemical, health or environmental risk. Labels can include hazard symbols such as the European Union standard symbols. Consult local building codes for applicable marking requirements.

Because batteries contain hazardous substances, some regions require battery owners to declare the amount of designated substances in their facilities. Large UPS batteries sometimes fall into such reporting requirements. The purpose is for fire fighters and/or other emergency responders to know how to respond to a catastrophic event such as fire or earthquake. Failure to comply may result in fines or other penalties. Consult local codes for reporting requirements.

Battery cabinets vs. battery racks

Early on in a UPS design a decision must be made on whether batteries should be installed on racks or in cabinets. Both have pros and cons. The following are typical design considerations.

Battery technology

Vented lead-acid (VLA) (frequently referred to as "flooded" or "wet cell") batteries, which are sometimes used on very large UPS systems, are ALWAYS rack-mounted.

Valve-regulated lead-acid (VRLA) batteries can be mounted on racks or in cabinets. The remainder of this paper will address considerations for VRLA placement.

Size

Generally speaking, the larger the battery (both physically and ampere-hour rated), the more likely a rack configuration will be considered. There are no hard and fast rules, but typically once a battery unit (single-cell or multi-cell) gets above 100 AH, it favors rack-mount. Below that, cabinet mounting should be considered.

Number

"Number" refers both to the number of cells in a string, and the number of strings. UPS systems frequently operate at high dc voltages (e.g., 250 to 800 Volts). An analysis must be made on whether to have a minimum number of battery strings using physically large units, or to have multiple strings of physically smaller units. Such decision is outside the scope of this paper, but it would include analysis of:

1. **reliability** (e.g., how many single-point failures could there be and where are they?). Every cell-to-cell connection is a potential single point of failure. String redundancy can increase or decrease reliability, depending upon the number of failure points.

2. **maintainability** (e.g., when is a unit too large for a person to handle, thereby requiring special handling equipment?). Anything over about 23 kilograms (50 pounds) is probably too heavy to lift safely. Local and regional workplace safety codes should be consulted for exact threshold.

Location

UPS batteries must be as close as practical to the UPS. They can be located in:

- an electrical equipment room; or
- a battery room; or
- a computer room

Batteries installed on open racks almost always require installation in a battery room. Sometimes they are installed in the same room as the UPS (i.e., electrical equipment room). Local or regional codes may dictate whether batteries are permitted in an electrical room.

Smaller UPS systems (e.g, up to 250 kVA) are commonly installed directly in the computer room along with their respective battery cabinets. The UPS and/or battery cabinets might be configured to look like standard computer equipment racks.

Hazards

There are two primary hazards of concern: electrical and fire.

Open rack batteries expose potentially lethal voltage to any person coming in contact with them. Therefore they must be installed in battery rooms in which room access is restricted to authorised personnel only. Authorised personnel must be trained in battery safety. All exposed terminals and conductors should be insulated or shielded.

Battery cabinets must enclose the batteries behind locked doors accessible only to authorised personnel. As long as the cabinets are kept locked, they can be located in a computer room or other rooms accessible by non-battery technicians.

Because even VRLA batteries can vent hydrogen gas (which is flammable and possibly explosive), ventilation (i.e., air exchanges per hour) must be sufficient to ensure that no pockets of gas can collect at the lower flammability limit
(LFL). Local codes will dictate the safety margin, which is usually at least 50% below the LFL. Battery rooms must be equipped with exhaust means, which is usually a fan exhausting air to the outside of the building. Local and regional fire codes will set the requirements.

Because air exchanges in most computer rooms far exceed the ventilation of a normal work environment, placement of battery cabinets in a computer room is rarely a problem.

Electrical considerations

As mentioned earlier, batteries should be as close as possible to the UPS. The reasons are twofold:

1. Longer cable runs mean greater voltage drop
2. Longer cable runs mean greater potential for damage and/or short circuit. Open-rack battery rooms must be adjacent to the UPS room. Battery cabinets must be adjacent to the UPS equipment. Cable lengths from multiple cabinets should be kept as nearly identical as possible to prevent voltage drop variations.

One cabinet should be able to hold at least one complete string of cells. Best practice is that strings should not be split between two cabinets in order to ensure reliability of the entire string.

A battery disconnect switch should be located as closely as possible to the end of a string. On open battery racks, the disconnect switch can be mounted directly to the rack. On battery cabinets, the disconnect switch should be mounted in the door to allow the battery to be disconnected from the UPS before the door is opened. This best practice is intended to protect a worker from exposure to lethal voltage or arc blast in the event of a fault inside the cabinet.

Figure 1 - Battery cabinet with top terminal cells

Convenience

Ease of use is one of the principle selling points for battery cabinets. It is convenient to service the equipment when the UPS and the battery(ies) are right next to each other. Conversely, it is inconvenient to have to go to a separate room when open-rack batteries are installed.

Accessibility

Accessibility must address two potential hazards: electrical and mechanical. The best electrical design will minimise the risk to a worker of accidentally contacting opposite polarity cells with his or her body or with a tool. The best mechanical design will minimise the risk of dropping a unit during installation, maintenance, or removal. It will also minimise the risk of injury due to lifting heavy units above one's shoulders. Lifting equipment specifically designed for battery installation and removal is recommended. Consult local safety codes for specific restrictions.

From a service perspective, open-rack batteries are usually easier and safer to work on. Racks can be designed with "tiers" (i.e., one row of cells directly above another), or they can be in "steps" (i.e., each row is set back from the row below it so that terminals are accessible with minimum risk of accidentally shorting to the row above.) Tiered racks must allow enough clearance between the top of the cells on one tier and the tier above to allow a technician to safely work on a unit without creating a conductive path between the cell and the rack. Tiered racks can minimise footprint, but they increase floor loading. Stepped racks spread the weight, but take up more space.

Figure 2 - 2-step open rack with top terminal cells

Battery cabinets are frequently criticised for their lack of top clearance. For example, in a cabinet containing multiple strings of low ampere-hour batteries, there might be several shelves, each with one string of cells. The cell units on each shelf might be arranged two, three, or more cells deep. That makes it difficult for a technician to access the terminals all the way in the back. Sufficient top clearance for hands and tools becomes critical.

One alternative (usually seen in telecommunication applications, but sometimes seen on UPS), is front-terminal access. Instead of the terminals being on top of the cell units, the terminals face outward. This makes for the easiest access for service, but it requires a cover (usually transparent) or doors to prevent accidental contact with live dc bus. Front terminal systems are usually preconfigured by the battery manufacturer.

Seismic considerations

In areas geographically designated as seismic zones, additional design features will be required. During an earthquake a battery can experience extreme mechanical damage, including:

- inter-cell and inter-tier connectors warping or breaking
- damage to unit containers resulting in electrolyte leakage or spillage
- short circuits resulting in arcing and/or fire
- battery units sliding off their shelves
- racks or cabinets tipping over

Battery racks should have approved seismic ratings from the manufacturer. These typically include heavy-duty frames and rails to prevent batteries from sliding off shelves. The rails add another procedure for installation and removal of battery units (See Figure 3). Because of its length, a battery rack can experience different torques at the same time in different sections of the battery. Good design anticipates these horizontal and vertical torques and provides some flexibility, including flexible inter-cell connectors. Rigidity can result in damage. Racks are typically seismically secured to a concrete floor. Consult local codes for what is acceptable flooring and bracing.

Figure 3 - 3-tier open rack with top terminal cells and seismic bracing.

An enclosed cabinet reduces the likelihood of batteries sliding off shelves, but the entire cabinet can be prone to movement, especially if it is mounted on a raised floor (which is typical in a data center).

Cabinet doors should be locked at all times when the cabinet is not being serviced. Various approaches to securing a battery cabinet include frames or straps under the raised floor. Under-floor frames are subject to the same building code requirements for fastening to the concrete floor as for racks. They actually raise the center of gravity, thereby increasing the possibility of rocking. Strapping must also be seismically secured to the concrete floor, but it has the flexibility to endure some degree of simultaneous vertical and horizontal movement.

Engage a seismic engineer in the design of any battery system in a seismic zone.

Temperature

As mentioned in earlier chapters for failure modes and environment, temperature must also be considered. Room cooling and ventilation is usually sufficient for rack-mounted batteries. Cabinet design, by contrast, must address the problem of removing heat as well as any off-gassing from the battery. Cabinet-mounted VRLA batteries can be expected to operate in a warmer environment than on a rack, thereby potentially reducing the operational life of the battery. Additional cooling is rarely required for a battery cabinet, but the cabinet must have (1) unobstructed paths within the cabinet for hot air to rise, and (2) adequate openings for hot air and hydrogen gas to escape into the room. The volume of air exchange and the air temperature blown into a properly conditioned computer room usually exceeds the requirements for battery cabinets.

VRLA installation and commissioning

Impact of the environment on batteries

IEEE Standard 1187 establishes the recommended practices for the design and installation of valve-regulated lead-acid (VRLA) batteries. The purpose of this paper is to highlight the most significant considerations identified in that standard, including:

- Safety considerations
- Design consideration
- Receiving and installation procedures

IEEE 1188, which was discussed earlier, describes the procedures for acceptance (commissioning) tests, including

- Pre-test requirements
- Test procedures
- Corrective actions I

n general, work on batteries should only be performed by knowledgeable personnel who have proper training/certification, proper tools, and personal protective equipment (PPE). IEEE Standard 1657 establishes minimum curriculum for battery technician certification. Prior to any task involving contact with a battery, a job hazard analysis should be conducted to identify any potential hazards that might be encountered.

Safety considerations

- **HAZARD NOTIFICATION** - Proactive notification of an impending failure is far better than reactive alarms after a failure has occurred. Continuous (real-time) monitoring is an indispensable tool that, when properly used, can detect and predict failures before they turn into fires, melt-down, arc flash, or other catastrophic failures. Battery monitoring should always be installed by certified technicians, preferably prior to commissioning.
- **SHOCK HAZARD** - Because most UPS system batteries are rated for greater than 50 Vdc, electrically rated and/or insulated gloves should be worn. Energized parts, such as terminal posts and intercell connections, should be insulated or shielded; shields should be removable when a section of the battery is being serviced.
- **GROUND FAULT DETECTION** - GFD is recommended (or may be required by code) for most battery systems, depending upon the grounding method used. Refer to local codes or IEEE 1187 for guidelines. The UPS design will usually dictate the type of grounding.
- **ARC FLASH** - Arc flash is an explosion of heat, light, and pressure. For voltage above 100 Vdc, the hazard is reduced if there is at least 305 mm (12 in) of space between potentials. Below that, exposed parts should be protected. Arc flash PPE below 100 Vdc is not required unless dictated by local code. Above 100 Vdc, arc-rated clothing should be worn.
- **CHEMICAL HAZARDS** – The electrolyte in lead-acid batteries consists of approximately one part sulfuric acid to two parts water. Electrolyte is immobilized in VRLA batteries, thereby minimizing (but not eliminating) risk of contact. A neutralizing agent (such as baking soda) and portable eye wash should be on hand. Contact with eyes or mucus membranes is very dangerous. PPE should include acid resistant gloves and clothing as well as safety glasses.
- **THERMAL HAZARDS** - The greatest thermal hazard is flash burns associated with short circuit or arc flash. Thermally rated or arc-rated gloves should be worn.
- **LIFTING AND HANDLING HAZARDS** - PPE lifting tools and techniques appropriate to the task should be used. Consult the battery manufacturer for recommended material handling slings or lifts.
- **PPE** - Consult local codes or IEEE 1187 for a list of recommended PPE, which will include specifications for arc and chemically rated clothing, gloves, safety glasses, shoes, aprons, and insulated tools.

"Work on batteries should only be performed by knowledgeable personnel who have proper training/certification, proper tools, and personal protective equipment (PPE). "

Design considerations

Decisions about the location and space for battery systems should be made well in advance of delivery. Considerations include space for personnel and handling equipment, floor loading, ventilation, heating and cooling, PPE availability, spill containment (if required), and illumination. Consult local codes or IEEE 1187 for guidelines.

- **MAINTAINABILITY** - Terminals of all cells or units should be easily accessible during normal float operation for routine maintenance and inspection, as described in Unit 8. Avoid installations containing series-parallel connections within a string. Ensure proper alignment and spacing of cells/modules for ventilation, use of lifting devices, and structured cabling.

- **SEISMIC** - Battery racks and cabinets should be designed for identified seismic categories. Racks are typically identified with a seismic rating, and are usually bolted to the floor. Cabinets are often installed on raised floor, so they must be anchored to the sub-floor where necessary. Cabinet doors should be secure to prevent popping open during an earthquake. Racks should be assembled in such a way that they are not rigidly connected at multiple horizontal and vertical points. Batteries need to sway without breaking intercell connections and without sliding off the rack or shelf. Rack or cabinet manufacturers should provide the applicable installation instructions.

- **HEATING, VENTILATION AND AIR CONDITIONING (HVAC)** - As discussed in previous units, temperature management is a particular concern for lead-acid batteries. The ideal temperature is between 20 °C to 25 °C, measured at the negative terminal post of designate pilot cells. VRLA cells – especially those enclosed in a cabinet - typically operate at temperatures above ambient. Conversely, operating in cold temperatures can have a negative effect on performance. There should be no temperature differential greater than 3 °C (5.4 °F) between cells within a battery system. Batteries should be placed so there is no spot heating or cooling, and no stratification between bottom and top racks or shelves. Cells/units must be placed to allow sufficient air flow on all sides.

- **HAZARDOUS GAS** - Because VRLA cells are more sensitive to thermal runaway than VLA cells, which can happen fairly quickly, continuous temperature monitoring is recommended. When a VRLA cell overheats it opens a pressure release valve that vents hydrogen and oxygen into the space. This can be a momentary “burp” or a continuously open condition, depending upon the temperature and charge current. The rate of hydrogen evolution can be predicted. IEEE 1635/ASHRAE 21 standards provide engineering guidance for the design of HVAC to prevent accumulation of hydrogen above the maximum allowed by code. The lower flammability level (LFL) is 4% of the air. The safety margin is typically half of that volume. Consult local codes for the maximum allowable concentration of hydrogen at anticipated temperatures and altitude.

- **BATTERY PROTECTION** – Detailed guidelines for battery protection are provided in IEEE Standard 1375. Briefly summarized, dc-rated fuses or circuit breakers should be located as close as practical to the end of a battery string. Not all circuit breakers are rated for ac and dc applications; for those that are, the dc ampere rating is always lower than the ac rating. When strings are connected in parallel, ideally every string should be individually protected. Parallel strings can cause increased short-circuit current when a fault is downstream of the common dc bus. Size string conductors to compensate for additional current if one or more of the strings are taken offline for maintenance or due to failure.

Receiving and inspection

- **INSPECTION** - Visually inspect every package for apparent damage and electrolyte leakage and note any discrepancies on the bill of lading. Keep records for future reference and warranty claims.
- **UNPACKING AND HANDLING** - Never lift or handle cells by the terminal posts, bus work or cables; instead use proper lifting equipment per the manufacturer's guidelines. Reject any cells with visible defects such as leaks, loose terminal posts, or cracked containers.
- **ASSEMBLY** - Assemble all racks, enclosures and modules following the manufacturer's recommended procedures.
- **CELL/MODULE INSTALLATION** – Prior to installation, measure the open circuit voltage of every cell to verify that there is no more than 0.1 Volt difference from the manufacturer's published value. Report any discrepancies to the manufacturer before proceeding. Also measure internal ohmic values. When significant variation is noted, follow recommendations of IEEE 1187. Install cell units as appropriate for the installation, clean when necessary. Connect and torque connections per manufacturer's requirements. Verify proper positive-to-negative connectivity throughout the battery. Read the voltage of the complete battery; recheck connections if it is less than expected. Mark each cell/module with identification. Read and record interconnection resistance.
- **FRESHENING CHARGE** - Charge the battery to recover capacity that may have been lost during shipping and storage, following manufacturer's instructions regarding voltage, charge current limit and duration.

Testing and Commissioning

Acceptance testing of a battery should be performed at the place where it is assembled. For example, pre-configured battery cabinets should be acceptance tested at the factory or upon initial installation. The purpose of an acceptance test is to confirm that the battery meets the specified discharge rate and duration.

Some batteries are not fully formed until they have been in service for several months. That means that, unless 100% capacity upon delivery was specified, the battery might perform at as much as ten percent below its nominal capacity during acceptance test. IEEE 1188 describes a time-adjusted calculation, running the full published rate. It also describes the procedure to be followed for pre-test and acceptance test. Throughout the life of the battery, all measurements will be compared to the base line established during the acceptance test.

Monitoring VRLA state of health

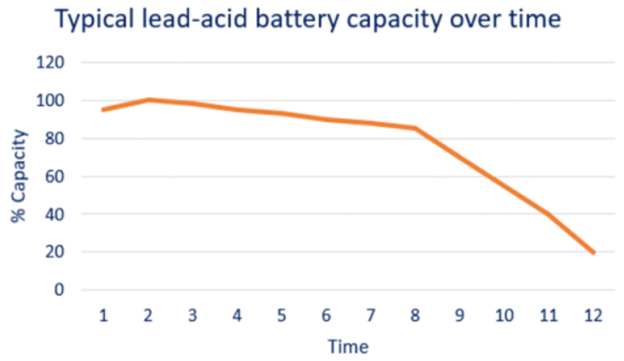

Figure 4 - The typical state of health (SOH) over time

Measuring the health of a valve-regulated lead-acid (VRLA) battery means more than just taking a voltage reading. A cell or battery can have the desired voltage when it has been sitting on float charge, but it might not have enough stored energy to support the critical load for more than a few minutes or even seconds.

IEEE 1881[6] defines two terms that are of great interest to battery owners and operators:

- **state of charge (SOC)** is "the stored or remaining capacity in a battery expressed as a percentage of its fully charge capacity." SOC is akin to "energy," that is, "What is the voltage output of this battery at this moment?" A battery can be fully charged, but because of age or other factors it might not be able to hold up the load for the desired time.
- **state of health (SOH)** is "a measurement representing the present state of a battery's available capacity or remaining service relative to rated capacity or specifications." SOH is akin to "power," that is, "How long can my battery support my load?" It adds the element of time and is useful in predicting the "life expectancy" of the battery.

While these two terms sound a lot alike, there is a difference. The term "state of charge" is often misunderstood and misused when the speaker is really referring to "state of health". SOC tells you the capacity of a battery at the time it is measured (e.g., 95% of its rated capacity). SOH is more predictive, telling us the expected service life (usually expressed in units of time or number of cycles) remaining in the battery before it needs to be replaced. SOH cannot be extrapolated without first knowing SOC.

A lead-acid battery is usually still forming when it is first installed, then in begins to lose capacity over its lifetime. When it reaches 80% of its capacity it begins to rapidly decline. That is why 80% is considered the "end of life" of a lead-acid battery. When the capacity reaches 85% it is wise to start planning for eventual replacement (which may be many months or only weeks depending upon cycling activity).

The most accurate tool in use today to calculate SOH is known as "internal ohmic measurement," defined by IEEE 1881 as follows:

Internal ohmic measurement: "A measurement of the electronic and ionic conduction paths within a cell or unit, expressed in terms of conductance, impedance, resistance, or admittance."

In the late 1990's and into the early 2000's, there was a lot of debate about which was the best indicator of SOH, but in the end the monitoring manufacturers reluctantly agreed that conductance, impedance, resistance, and admittance are all variations of the same condition (i.e., opposition to an electrical current) and all will produce similar results expressed in different units of measurement.

For example:

- Resistance is expressed in Ohms (W) and is measured by applying a load across a cell or multi-cell unit and measuring the change in voltage and current
- Impedance is also expressed in Ohms but is usually applied to alternating current (ac). In direct current (dc) applications such as a battery, it can be measured in one of two ways: by applying a varying load; or by injecting a small ac signal with known frequency and amplitude into the circuit and measuring the ac voltage drop between points. The former is often preferred due to fears of introducing some sort of ripple effect.
- Conductance can be expressed in one of several units: K (kappa), s (sigma), or U (gamma). Without getting too technical, conductance measurement also injects a signal of known frequency and amplitude; it is the ratio of the current density to the electric field strength, measured differently
- Admittance is the reciprocal of impedance and is expressed in siemens (S), or sometimes as mho (℧).

Ohmic measurement is not 100% precise. A single ohmic value can vary because of recent charge or discharge activity in the battery, inconsistent manual measurements, environmental conditions, differing ages of cells within a battery, loose connections, or for other reasons. Therefore, ohmic measurement is only reliable for trend analysis. Ideally, data is recorded throughout the life of a battery (starting approximately six months after installation).

The most accurate tool in use today to calculate SOH is known as "internal ohmic measurement," defined by IEEE 1881 as follows:

"A measurement of the electronic and ionic conduction paths within a cell or unit, expressed in terms of conductance, impedance, resistance, or admittance."

INTERNAL OHMIC MEASUREMENT

Readings early in the life of a battery can be erratic. A base line should be established during the acceptance test but expect that readings will be inconclusive until the battery has matured for a few months or it has experienced some discharge cycles. When stabilized, all cell ohmic readings in a string should be pretty close to one another.

When one cell deviates significantly from the average within the string (i.e., it becomes an "outlier"), it needs to be monitored more closely to determine if the deviation is a one-time anomaly or if the cell continues to worsen. If a cell continues to deteriorate relative to its neighbours, the cell probably needs to be replaced. If several cells exhibit similar behaviour, that would suggest that it is time to perform a discharge test. If the battery fails the test, it is time to replace it. Sometimes the discharge test will actually serve as an equalizer, bringing outlying cells back into the predicted range.

Ultimately, a discharge test is the only way to know with great accuracy what the capacity of the battery is . . . or was before the test. Because every discharge takes life from the battery, the remaining life must be estimated. On a healthy battery, this is not a problem. When a battery is near end of life, a deep discharge might speed up its demise.

Measurements can be collected manually or continuously. Obviously, continuous measurement is the preferred method. Manual collection can be corrupted by such things as inconsistent placement of the probes from one cell to another, incorrect record keeping, use of different measuring devices from one time to the next, loss of records, a long time period between measurements, or other human error.

Continuous measurement has the advantage of timeliness. If a cell starts to fail rapidly, it might not be detected by manual readings for several months, whereas continuous monitoring can detect and send an alarm as soon as significant deviation is noted.

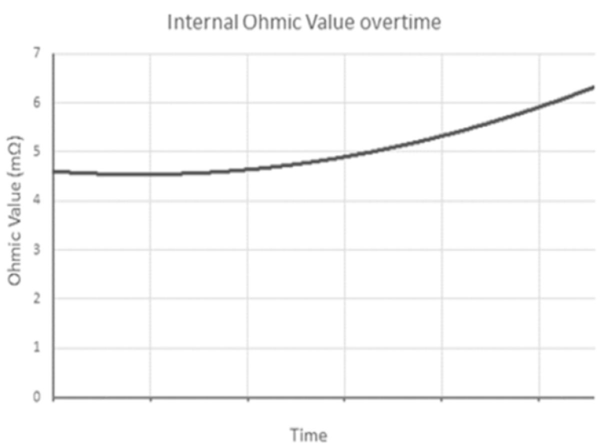

Figure 5 - Ohmic value increase over the age of the battery. Increased ohmic value correlates to loss of capacity over time.

Continuous monitoring is not a substitute for regular inspection and preventive maintenance; both should be practiced. Nor should ohmic measurement be a substitute for capacity testing. Ohmic measurement can alert the technician that capacity testing may be necessary. Trending the aging characteristics of a VRLA battery can be a useful instrument. Consult with the battery manufacturer about what percentage of deviation is acceptable and when a cell or battery is considered to have failed.

Battery replacement intervals

So you bought a battery with a nominal design life of "X" years. The realistic service life is actually significantly less than that, but you don't know what it is. At around the "half-life" (i.e., half way through the design life) an individual cell-unit fails, then another. You replace the cell-units with new ones (maybe under depreciated warranty, or maybe at full price). Service technicians come in to replace the cells. Each visit costs money and disrupts the service while the work is being performed. You're told that the new cells create an imbalance with the rest of the cells in the string. At some point you must decide that the entire battery string needs replacement. How do you know when that time has arrived? How do you know if your battery will be able to ride through the next power interruption?

Several factors must be considered, including:

- How many cells (or multi-cell units) are in the string?
- What has been the maintenance history of the battery?
- Has the battery been exposed to abnormal conditions, such as extreme heat?
- Are there other strings in parallel with this one?
- Do you have a monitoring system capable of taking ohmic measurements on individual cell-units?
- Do you have reliable records capable of comparing the current measurements to the original base-line measurements?
- What is the impact of "down time" when a battery or battery string is removed from service for cell replacement?
- What is the labour cost of cell replacement?
- How did the battery perform during the last discharge (or planned discharge test)?

A lead-acid cell or battery is considered to have reached "end of life" when it can deliver only 80% of its original capacity. A decision on "fix or replace" is very subjective. Generally speaking, when the number of cells needing replacement exceeds a certain percentage of the cells in the string, it's time to replace the entire string. There is no formula that calculates all of these variables to come up with a magic number for what that percentage should be. Let's look at some of the variables.

Number of cells in a string

In a telecommunications application with a 48-volt string consisting of four 12-volt units, one unit is 25% of the entire string. When one fails, it probably makes sense to replace the entire string. By contrast, in a UPS system with a nominal 480-volt string consisting of 240 two-volt units, it probably makes sense to replace a single failed cell. If the battery is fairly new, it's possible that a single cell failure is an outlier, possibly due to factory defect. If the string has been in use for several years, one might conclude that if one cell goes bad, others may not be far behind. The user must make an arbitrary decision as to when too many cells or multi-cell units have failed or are expected to be near end-of life. That number should probably not exceed ten percent of the number of units in the string.

Maintenance history

If the battery has been well cared for, meaning that it has received regular preventive maintenance and has not been exposed to harsh environment, loss of a single unit might not justify replacing the entire battery. Good record keeping might have predicted an impending failure of a single cell as well as suggesting whether other cell failures are soon to follow.

Parallel strings

If the UPS battery system has redundant strings, such that the UPS can still function with one string removed (albeit with a shorter back-up time), full string replacement might be postponed. If the UPS has only a single string, taking the battery out of service for cell replacement (i.e., possibly requiring that the UPS be switched to bypass) puts the critical load at risk. The owner might decide that full replacement makes more sense than enduring multiple downtimes for remedial maintenance and cell replacement.

"A lead-acid cell or battery is considered to have reached "end of life" when it can deliver only 80% of its original capacity. "

Monitoring system/record keeping

The importance of ohmic measurements cannot be overstated. Regular or continuous ohmic measurement allows real-time monitoring of every cell or multi-cell unit. By comparing the latest data from previous weeks or months, one can detect when a cell is aging faster than the average for the rest of the group. If a single outlier is detected, that unit can be replaced before it actually fails. If multiple cells appear to be significantly different from their original base line (e.g., 15% or more), the units should be watched more closely. If they continues to decline relative to their neighbors, it is probably time to replace the entire string. Consult the battery manufacturer for guidance based on the ohmic measurement method used.

Downtime

Although it is sometimes possible to bypass a single cell in a string while replacing it, this is a questionable procedure. Usually work on battery systems means removing the battery from the UPS during maintenance. One must consider the increased risk to the critical load. It may be necessary to schedule such work well in advance so that users can shift their work.

Labour cost

Although some large users have trained battery technicians on staff, most users must bring in qualified technicians, usually in a team. Such visits can be expensive, especially if they have not been budgeted. One must weigh the cost of such service against the value of the battery system. One or two visits might be tolerated. Beyond that, a cost/benefit analysis might suggest that it's time for a new battery system.

Testing

In the first year of service one would expect the ohmic values of each cell to be reasonably consistent. As the battery ages, ohmic values may start to drift apart, some higher than others. That is normal and we usually look at the average. If one cell is significantly different, it may be a warning. Cells do not typically fail catastrophically over night, but they can age faster than their neighbours in a string. When too many cells get "out of whack," it may be time to perform an equalize charge (see Unit 3 for a definition). [Note: equalize charge is not usually recommended for VRLA batteries; consult the battery manufacturer for guidance.] If the equalize charge fails to bring all the cells back into balance, the outlier(s) may be heading for premature failure. While ohmic measurements can identify the probability of early failure, the only way to know is to perform a discharge test. The discharge/charge cycle can have the same effect as an equalize charge. The discharge test can tell you the battery capacity at the time of the test. It cannot, however, guarantee the capacity on the next discharge. If the test reveals that the lead-acid battery is at or close to 85% of its original capacity, it is time to start budgeting for a battery replacement. Once it reaches 80% of rated capacity it should be replaced.

As stated earlier, a replacement decision is subjective and can only be made when all of the above considerations have been weighed for cost/benefit and risk assessment. What is the impact on -- and risk tolerance of -- the business for a battery failure? Every business will apply a different weight to each of the above considerations.

Battery standards

Why standards?

Standards in general are essential to ensure proper communication among everybody associated with a system. These can include manufacturers, transporters, distributors, installers, technicians, operators, fire and safety regulators, environmental regulators, and recyclers (to name only a few). Standards ensure interoperability and compatibility between the many elements of a battery system. Other considerations include product safety and testing, quality, reliability and environmental compliance. Many standards apply to the design, manufacturing, and testing of battery equipment. In this unit however, we limit the scope from many dozens of existing standards to only those most relevant to a user.

What is the difference between a code and a standard?

A "standard" (with a lower case "s") is generally voluntary, although strict adherence to certain standards may be necessary for marketing or other reasons. The Institute of Electrical and Electronics Engineers (IEEE™) publishes three different levels of standards. At the low end is the "Guide" which is primarily tutorial in nature, characterized by use of words such as "may," "might," or "could." In the middle is the "Recommended Practice" which is more about how to do something, characterized by use of the word "should." At the top is the Standard (with upper case "S") directing the exact way something must be done, characterized by use of the word "shall." While adoption of a Standard may be voluntary, strict compliance with the Standard is necessary when it is adopted. Some government regulations might require that "safety standards" must be followed even if they are not specifically codified. For example, if a worker is injured because the employer 'could have and should have' followed existing safety standards and best practices but failed to do so, the company might be subject to penalties and fines.

A "code" is the same as a law or regulation. It is implemented and enforced by a government body. Typically a government (city, state or region) will "adopt" an existing standard – but not necessarily the most current edition. When that happens, compliance is mandatory. Some standards-writing organizations (for example the National Fire Protection Association® [NFPA®] in the U.S.A.) publish "model codes." A government agency might modify the text of a model code to fit local requirements. Local fire codes and building codes are examples. Failure to comply can lead to citations and penalties.

What standards are most important to users of large battery systems?

First and foremost, the user should ensure that the battery supplier guarantees compliance to applicable manufacturing and quality standards. More important to battery users are standards relating to installation procedures, maintenance procedures, and recycling.

Who are the primary publishers of battery standards?

The European Committee for Electrotechnical Standardisation (Cenelec) and the International Electrotechnical Commission (IEC) are the main battery standardisation bodies covering Europe, Middle East and Africa (EMEA) regions. In the Americas and much of the rest of the world, IEEE is the predominant publisher of battery standards. Some other nations create their own standards and codes.

What are the standards most relevant to users of large stationary battery systems?

In this paper we will focus on IEEE standards. The following table identifies those of greatest interest to the user:

IEEE Standard Number	***Title***	***Description***
450	Recommended Practice for the Maintenance, Testing, and Replacement of Vented Lead-Acid (VLA) Batteries for Stationary Applications.	Recommended maintenance, test schedules, and testing procedures that can be used to optimize the life and performance of permanently installed, vented lead-acid storage batteries used in standby service. It also provides guidance on when batteries should be replaced
485	Recommended Practice for Sizing Lead-acid Batteries for Stationary Applications.	Methods for defining the dc load and for sizing a lead-acid battery to supply that load for stationary batty applications in full float operations
1184	Guide for Batteries for Uninterruptible Power Supply (UPS) Systems.	Guide for making informed decisions on selection, installation design, installation, maintenance, and testing of VLA, VRLA and Ni-Cd stationary standby batteries used in UPS systems. Describes how the UPS battery charging and converter components can relate to the selection of the battery systems.
1187	Recommended Practice for Installation Design and Installation of Valve-Regulated Lead-Acid Batteries for Stationary Applications.	Design practices and procedures for storage, location, mounting, ventilation, instrumentation, preassembly, assembly, and charging of valve-regulated lead-acid (VRLA) batteries. Required safety practices are also included.
1188	Recommended Practice for Maintenance, Testing, and Replacement of Valve-Regulated Lead-Acid (VRLA) Batteries for Stationary Applications.	Maintenance, test schedules, and testing procedures to optimize the life and performance of VRLA batteries, including how to determine when batteries should be replaced.
1189	Guide for Selection of Valve-Regulated Lead-Acid (VRLA) Batteries for Stationary Applications.	Methods for selecting the appropriate type of valve-regulated, immobilized-electrolyte, recombinant lead-acid battery for any of a variety of stationary float applications. The purpose is to make the reader aware of all significant issues that should be considered when selecting VRLA batteries, so that the user might make an informed decision.

1375	Guide for the Protection of Stationary Battery Systems.	Items to consider in the electrical protection of stationary battery systems.
1491	Guide for Selection and Use of Battery Monitoring Equipment in Stationary Applications.	Operational parameters that may be observed by battery monitoring equipment used in stationary applications and the relative value of such observations, including a means for establishing specifications for the desired parameters to be monitored.
1578	Recommended Practice for Stationary Battery Electrolyte Spill Containment and Management.	Factors relating to electrolyte spill containment and management for vented lead-acid (VLA), valve-regulated lead-acid (VRLA), and vented nickel-cadmium (Ni-Cd) stationary batteries.
IEEE Std. 1635/ ASHRAE	Guide for the Ventilation and Thermal Management of Batteries for Stationary Applications.	Ventilation and thermal management of stationary battery systems as applied to VLA, VRLA, and Ni-Cd batteries. For each category, both the technology and the design of the battery are described in order to facilitate user understanding of the environmental issues associated with each type of technology.
1657	Recommended Practice for Personnel Qualifications for Installation and Maintenance of Stationary Batteries.	Defines the areas of recommended knowledge for installers and maintainers of stationary standby batteries and related systems to the extent that they affect the battery, personnel safety and reliability of any related systems.
1881	Standard Glossary of Stationary Battery Terminology.	Provides a useful reference for those in the stationary battery industry and harmonizes definitions used across IEEE stationary battery standards.

This table is not an all-encompassing list of battery standards. It is intended to direct the user to about eighty percent of the standards likely to be encountered. The full list would include dozens more. The reader should contact the battery or UPS manufacturer with specific questions about compliance with any standard. The reader should contact the local enforcement agency with questions about applicable codes.

Thermal runaway and thermal walkaway

Thermal runaway is described in IEEE 1881 (IEEE Standard Glossary of Stationary Battery Terminology) as:

"A condition that is caused by a battery charging current or other process, which produces more internal heat than the battery can dissipate."

A note adds the following information:

"The emphasis on this definition is on the presence of excessive internal heat, irrespective of the cause, which could be joule heating and/or high ambient temperature. The consequences of thermal runaway vary by cell chemistry."

An increase in temperature can cause an increase in resistance, which causes a further increase in current, which causes a further increase in temperature, until the battery or unit self-destructs.

Thermal runaway occurs mostly – but not exclusively - in lead-acid cells or batteries. Within that family, thermal runaway occurs mostly in Valve-Regulated Lead-Acid (VRLA) cells. Vented Lead-Acid (VLA) cells are not immune to thermal runaway but, because of the large amount of liquid electrolyte they contain, and because water can be added to replace evaporated electrolyte, thermal runaway in VLA cells is rare.

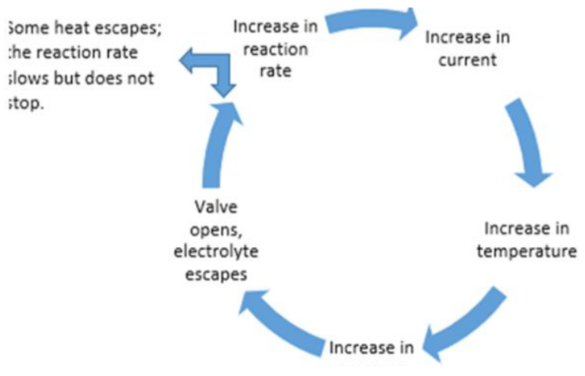

Figure 6 - Thermal runaway cycle

VRLA cells, on the other hand, have "starved electrolyte", i.e., as little as 10% of the amount of liquid present in a VLA cell of comparable ampere-hours. VRLA electrolyte also has a higher specific gravity, making it more sensitive to heat. Plus, VRLA batteries have no mechanism for adding electrolyte to a dehydrating cell.

Thermal runaway is the most catastrophic of all failure modes. If left unchecked, thermal runaway can lead to melting of the case, fire, or even (rarely) explosion. The heat generated by thermal runaway has been known to ignite combustible material in close proximity to the battery.

Thermal walkaway is not formally defined. However, as the name implies, it occurs over a long period of time (usually as a consequence of aging) ranging from months to years, thereby allowing time for discovery and corrective action. Thermal walkaway usually takes the life out of the cells when cell dry out causes premature end-of-life without necessarily resulting in fire. Thermal walkaway is usually a precursor to thermal runaway.

Thermal runaway can happen quickly. Unlike other failures associated with aging of the battery, which slowly degrade over a period of months, thermal runaway is usually the result of catastrophic failure in one or more cells.

Figure 6 describes the cycle of overheating. An increase in current, voltage, or temperature can start the chain of events that culminate in the cell or battery getting hotter and hotter until damage is done.

Conditions that can lead to thermal runaway include the following:

- Malfunctions or improper settings of HVAC systems
- High ambient (room or cabinet) temperatures without temperature-compensated charging to reduce float voltage (see Unit 4: Failure Modes in Lead-Acid Batteries)
- Improper float voltage adjustment
- Inadequate current limiting in the battery charging circuit
- Shorted cell(s) within a battery string
- High ac ripple in the dc circuit
- Charger malfunction

Environmental conditions can initiate the process but are the easiest to detect and/or correct. High room (ambient) temperature is the most obvious cause, but temperature gradients within the room can also contribute. For example, cells in the middle of a row of batteries tend to be warmer than the cells at the end of a row. Likewise, when cells are stacked on tiers or shelves (as in a battery cabinet), because heat rises, the cells at the top tend to be warmer than the cells at the bottom. Cells close to an outside wall that experiences solar heating (or to any other heat source such as electrical equipment) can be warmer than cells deeper inside a room.

Studies have shown that a temperature gradient of only 2 °C to 3 °C of temperature difference can cause problems. Colder cells can be damaged by undercharge and warmer cells can be damaged by overcharge, even though all are series connected within a single string.

Pressure build-up within a cell, along with excess heat, can result in deformation of the cell container, usually described as "bulging". It can also cause seals to crack or break, possibly resulting in electrolyte leaks. An electrolyte leak can create a conductive path that could create a short circuit and result in fire. If cells (or multi-cell units) are packed so tightly together that air cannot flow between the units, cells can expand to the point that, like bricks in a wall, they cannot be removed. Such conditions are most likely to be encountered in battery cabinets.

As a battery ages, positive plate growth can be expected as it is one of the primary causes of cell failure. The aging process can be accelerated by heat. Positive plate growth can be visually observed in VLA cells, but cannot be seen in VRLA cells. Plate growth can -- and probably will -- result in cell bulging.

> *"Studies have shown that a temperature gradient of only 2 °C to 3 °C of temperature difference can cause problems."*

The conditions just described can be detected by regular visual inspection. Realistically, quarterly or semi-annual inspection is a common practice, although more frequent inspection is strongly recommended. By the time these conditions are visible, the damage has already been done and cells or complete battery strings may need to be replaced sooner than planned.

Because temperature building-up inside a cell cannot be visually observed, **visual inspection alone is not sufficient.** A common practice has been to measure the temperature of so-called "pilot cells" placed at one or more points within a string. Such practice can give a false sense of security. Temperature sensors on every block connected to a battery monitoring system allows for early detection of thermal walkaway and thermal runaway.

If a permanently-installed monitor takes daily temperature differential readings and/or float current readings, the battery can never go from thermal walkaway to thermal runaway without the monitor first detecting and alarming the condition.

Once a battery has gone into thermal runaway, whether it is VLA or VRLA, it will gas rapidly, releasing a potentially explosive mixture of hydrogen and oxygen. Such a mixture becomes flammable at around 4% of air volume. At around 7% it becomes explosive. For this reason, IEEE recommends a safety margin of 50% for ventilation systems (i.e., air exchanges to prevent accumulation greater than 2% of air volume in a space). Some building codes are even more stringent, limiting hydrogen gas build-up to no more than 1% of room volume. Hydrogen detectors may be an option to supplement – but not replace – dilution ventilation. If hydrogen detectors are to be considered, the user is advised to consult with experts for selection, placement, maintenance and calibration, because every installation is unique.

The reader is advised that thermal runaway is actually rare, but diligence is recommended. Thermal runaway is preventable with proper installation, maintenance, and monitoring.

Conclusion

Providing clean, quality uninterrupted power means having properly installed, monitored and managed batteries. A UPS is the heart of a data center's backup power, and a single battery cell within a UPS battery string can create a risk of downtime for data center operations.

> *"Battery failures are too often the cause of UPS failures. That's why understanding the role batteries play in a UPS, and the fundamentals of how to manage and monitor them is critical."*

Regular maintenance of your batteries is critical to make sure you have backup power when you need it and avoid the costs and other negative implications of a battery-related outage.

PowerShield has more resources to help with managing batteries available on our website.

www.powershield.com

Battery management is all we do

To be a data center operator is to be a jack-of-all-trades, having to monitor and manage a complex mix of technologies and services to achieve high availability standards.

At PowerShield battery management is all we do. We understand it intimately, so you don't have to. We'd welcome any questions or comments you have about getting more out of your UPS battery investment.

About the author

Steve McCluer has worked in the UPS industry for more than thirty years. He is a Senior Life member of the Institute of Electrical and Electronics Engineers (IEEE), and has served on several other standards and code-writing organizations. He has chaired, co-chaired, or served on the technical committees of many battery standards, most notably as Chair of The IEEE Standard Glossary of Stationary Battery Terminology. After retirement Steve agreed to contribute to the collection of technical papers compiled into this PowerShield e-book.

Glossary

These are definitions of terms that are used throughout this eBook. Where noted by *, the definitions are standardised within the battery industry by IEEE Std. 1881.

General formulae

Ohm's Law is not unique to batteries, but its formula and terms must be understood to use batteries:

E = IR
voltage equals current times resistance

Voltage: Electromotive force (E) or potential difference, expressed in "volts" (V)

Current: The rate at which the flow of an electric charge passes through a conductor or through electrolyte, expressed in "Amperes" (A). [Note: The "I" in Ohm's Law comes from the original French term for current intensity]

Resistance: A quantity that measures how the device or material reduces the electric current flow through it, expressed in Ohms (R).

Power: Units of energy divided by time; the rate at which electrical energy is transferred through an electric circuit, expressed in Watts (W). It is derived from Ohm's law:

P = IE
Power equals current times voltage.

Also expressed as joules per second.

Definitions

The following definitions are listed in alphabetical order for easy reference (not by order of importance):
ampere-hour capacity (or rating): The capacity assigned to a cell by its manufacturer for a given constant-current discharge, at a specified electrolyte temperature, to a given end-of-discharge voltage, for a specified duration.

arc flash hazard: A dangerous condition associated with the possible release of energy caused by an electric arc. An arc flash (sometimes called flashover), is the light and heat produced as part of an arc fault, a type of electrical explosion or discharge that results from a low-impedance connection through air to ground or another voltage phase in an electrical system. An arc flash might also be accompanied by an arc blast, which is the supersonic shockwave produced when the uncontrolled arc vaporizes the metal conductors.

battery: One or more cells connected electrically in series or parallel, or both, to provide the required operating voltage and current levels*. As discussed in chapter 2, large UPS batteries typically consist of hundreds of cells.

battery life: A measure of battery performance and longevity, which can be quantified in several ways: as run time on a full charge (service life), as estimated by a manufacturer in ampere hours (design life), or as the number of cycles until the end of useful service (cycle life).

battery monitoring system: A permanently installed system for measuring, storing and reporting battery operating parameters*.

battery cabinet: A structure used to support and enclose a group of cells*. A battery cabinet can be installed in the same room as the UPS and/or IT equipment; it is usually locked to prevent access by unauthorised personnel.

battery rack: An open structure used to support a group of cells or multi-cell units*.

battery room: A portion of a building or facility with controlled walk-in access, physically set off from the rest of the building by walls, the primary purpose of which is to house a stationary battery or batteries*.

bulk charge: The period from the initiation of charging to the onset of gassing, during which charge is retuned to a battery at high efficiency*.

catalyst: An agent introduced into the headspace of a VRLA cell to mitigate the effect of self-discharge of the negative electrode, thereby reducing dry out and extending the life of the cell.

cell: The basic electrochemical building block of a battery, characterised by a positive electrode, a negative electrode, and electrolyte*, encased in a container. A cell can be a stand-alone unit (typically two volts nominal) or a multi-cell unit (typically six or twelve volts nominal).

charge: The conversion of electrical energy into chemical energy within a secondary cell*.

conductance: The ability of a battery to conduct current. (see internal ohmic measurement)
cycle life: (See battery life)

design life: (See battery life)

electrolyte: The aqueous or non-aqueous medium that provides the ion-transport mechanism between the positive and negative electrodes of a cell*. In a lead-acid cell, the electrolyte is a solution of water and sulfuric acid, the concentration of which is known as specific gravity.

equalizing charge: A charge, at a level higher than the normal float voltage, applied for a limited period of time, to correct inequalities of voltage, specific gravity, or state of charge that may have developed between the cells during service*.

float charge: A constant-voltage charge applied to a battery to maintain it in a fully charged condition, while minimising degradation or water consumption.

flooded: A slang term used to identify a vented cell or battery, in which the electrodes are immersed in free-flowing liquid electrolyte.

half life: As applied to battery operating temperature, the sustained temperature at which the expected service life of a battery is reduced by 50%.

immobilised electrolyte: Liquid electrolyte in a cell that is prevented from free flowing by use of either gelled electrolyte or absorbed glass mat technology*.

impedance: A measure of the opposition to an alternating current; a combination of internal resistance and reactance. [See also: internal ohmic measurement]

intercell connector: An electrically conductive bar or cable used to connect adjacent cells in a battery*.

intermittent charge: A non-continuous charging regime based on the following: (1) availability of the charging source; or (2) application of the charge by a permanently powered source*.

internal ohmic measurement: A measurement of the electronic and ionic conduction paths within a cell or unit, expressed in terms of conductance, impedance, resistance, or admittance*.

internal resistance: The resistance within a cell or battery that causes a drop in the source voltage when there is a current. (See internal ohmic measurement)

lead-acid cell: A secondary cell in which the active material of the positive electrode is lead dioxide, the active material of the negative electrode is lead, and the electrolyte is dilute sulfuric acid*.

multicell unit: Multiple cells in a single container*.

nickel-cadmium (Ni-Cd) cell: A secondary cell in which the active material of the positive electrode is nickel oxyhydroxide, the active material of the negative electrode is cadmium, and the electrolyte is a dilute solution of potassium hydroxide*.

nominal battery voltage: The value assigned to a battery of a given voltage class for the purpose of convenient designation. The operating voltage of the system may vary above or below this value*.

ohmic value: (See internal ohmic measurement)

parallel strings: The interconnection of two or more strings in which the like terminals of each battery string are connected together* to increase the available power without changing voltage.

personal protective equipment (PPE): Protective clothing, helmets, goggles, or other garments or equipment designed to protect the wearer's body from injury or electric shock. Hazards addressed by battery PPE equipment can include physical, electrical, heat, chemicals, and airborne particulate matter, but not all at the same time.

performance test: A constant-current or constant-power discharge capacity test, made on a battery after being in service*.

post corrosion: The formation of compounds on a post that can affect connection quality, and in extreme cases can result in failure of a post or post-to-cover seal and cracking of a cover or container*.

preventive maintenance: Maintenance that is regularly performed on a battery to lessen the likelihood of it failing, usually performed while the battery is connected.

pulsed charging: Variation of intermittent charging in which the charger switches on and off several times per minute (or per second).

rack: An open structure, typically in a battery room, used to support a group of cells/units.

rated capacity: The capacity assigned to a cell by its manufacturer for a given discharge rate, at a specified electrolyte temperature, to a given end-of-discharge voltage*.

recombination: A feature of VRLA cells in which oxygen generated at the positive plates is ultimately recombined with hydrogen ions at the negative plates and converted back into water. In this process, hydrogen gas formation and evolution are suppressed.

ripple: A periodic waveform riding in the dc circuit, normally expressed as peak-to-peak, or root mean square (rms)*. Can refer to voltage or current.

safety data sheet (SDS): A hazard communication form (also known as a Material Safety Data Sheet [MSDS]), by which regulators require a battery manufacturer, importer, distributor, or integrator to identify each hazardous material present in a battery unit; typically readily accessible to anybody expected to perform maintenance on a battery system.

sealed cell: A cell that is designed not to allow release of gas or electrolyte during normal operation*.

sealed lead-acid: (SLA) Another term for a valve-regulated lead-acid cell, derived from the characteristic of VRLA in which electrolyte can be neither added nor removed under conditions of normal operation; also considers that the safety pressure valve is closed to prevent escape of gas under conditions of normal operation.

secondary cell: An electrochemical cell that is capable of being recharged following discharge*.

service life: (See battery life) The period of useful operation under specified conditions.

specific gravity: The ratio of the mass of a given volume of electrolyte to the mass of an equal volume of water at a specified temperature*. Specific gravity options are often available for vented lead-acid batteries; the specific gravity of VRLA batteries is usually fixed.

state of charge (SOC): The stored or remaining capacity in a battery expressed as a percentage of its fully-charged capacity*.

state of health (SOH): A measure representing the present state of battery available capacity or remaining service life relative to rated capacity or specifications. (See battery life*)

stationary battery: A battery designed for service in a permanent location*.

string: A grouping of interconnected cells that has the same nominal voltage as the dc system*. A UPS battery might have a single string or parallel strings.

temperature compensation: The adjustment of charging voltage with respect to temperature, normally accomplished using a slope or step function*, to prevent thermal runaway.

thermal runaway: A condition that is caused by a battery charging current or other process, which produces more internal heat than the battery can dissipate*, potentially leading to fire in a short amount of time.

thermal walkaway: (See thermal runaway) A variation of thermal runaway that occurs over a longer period of time and usually results in battery failure but not necessarily fire.

unit: A single container. This term is usually preceded by “single-cell” or “multi-cell”.

valve-regulated lead-acid (VRLA) cell: A lead-acid cell that is sealed with the exception of a valve that opens to the atmosphere when the internal pressure in the cell exceeds atmospheric pressure by a preselected amount. VRLA cells provide a means for recombination of internally generated oxygen and the suppression of hydrogen gas evolution to limit water consumption*.

vented lead-acid (VLA) cell: A lead-acid cell in which the products of electrolysis and evaporation are allowed to escape to the atmosphere as they are created, also referred to as a “flooded cell”.

* IEEE 1881, IEEE Standard Glossary of Stationary Battery Terminology, IEEE Power and Energy Society, www.ieee.org

Bibliography

[1] ISO 9001, *Quality Management Systems*, International Organization for Standardization. ISO is a registered trademark of the Organisation Internationale de Normalisation, www.iso.org

[2] ISO 14001, *Environmental Management Systems Standard*

[3] OHSAS 18001, *Occupational Health and Safety Management Certification. [NOTE; OHSAS 18001 has been replaced by ISO 45001:2018, Occupational Health and Safety Management Systems – Requirements for Guidance for Use.]*

[4] IEEE 1635/ASHRAE 21, *Guide for the Ventilation and Thermal Management of Batteries for Stationary Applications.* IEEE is a registered trademark of the Institute of Electrical and Electronics Engineers, www.ieee.org; ASHRAE is a registered trademark of the American Society of Heating, Refrigeration, and Air-conditioning Engineers, www.ashrae.org.

[5] *GHS, The Globally Harmonized System of Classification and Labelling of Chemicals, United Nations,* New York & Geneva, www.unece.org/fileadmin/DAM/trans/danger/publi/ghs/ghs_rev04/English/ST-SG-AC10-30-Rev4e.pdf

[6] *IEEE Std 1881, IEEE Standard Glossary of Stationary Battery Terminology, Institute of Electrical and Electronics Engineers/ IEEE Power and Energy Society/Energy Storage and Stationary Battery Committee, 2016.*