NINE WAYS TO MURDER YOUR BATTERY
(THESE ARE ONLY SOME OF THE WAYS)

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ABSTRACT

Battery system design and management is critical to the ultimate success of every energy storage application. However, the application itself must be properly evaluated to determine what type of battery should be used and how to manage the operational environment for the system. The application evaluation step is critical to the implementation of a successful system that uses lead-acid batteries. This paper details nine ways that improper design, implementation, and/or applied battery management techniques result in poor battery performance with focus on the selection of a battery for a particular power or energy application.

INTRODUCTION

Although lead-acid batteries have been in use for more than 100 years, recent advances have helped to dramatically improve the performance of both the Vented Lead Acid (VLA) and Valve Regulated Lead-Acid (VRLA) adaptations of the technology. However, to realize optimum performance and life expectations of lead-acid batteries, it is essential that battery systems are appropriately designed and integrated to support the specific application. That approach has not been the case in many implementations of the technology and lead-acid batteries have taken a lot of criticism for their lack of performance in a specific application. Typically, VLA and VRLA batteries are designed for optimal performance in either a power or an energy application, but not both. That is, a battery specifically designed for power applications can indeed deliver reasonable amounts of energy (operating car lights) but is not designed to deliver substantial amounts of energy on a regular basis. In comparison, an energy battery can deliver high impulses of power (engine starting) if needed although it is not specifically designed to do so. In either case, improper implementation of a power or energy battery in the wrong application will ultimately lead to premature failure. Many system integrators have lost touch with this constraint and have used whatever battery is available (usually the least costly, after all, *it's just a battery*) to support their energy storage requirements whether the application is for power or energy. Many times battery systems do not meet performance expectations for multiple reasons among which are implementation of the wrong battery type. Another reason for performance shortfall is improper battery system management in the application even when the proper battery type is integrated. This paper highlights battery failure drivers and some probable outcomes, selection of the appropriate lead-acid battery depending on the specific application, and how improper battery management schemes exacerbate the problems that lead to premature battery failures.

TYPICAL LEAD-ACID BATTERY FAILURE DRIVERS

When battery systems are properly managed, batteries die a natural death after all the active materials have been consumed or the positive grids have deteriorated because of normal corrosion which occurs throughout the battery lifetime during routine use. When battery systems are improperly managed, the batteries will not meet performance expectations and ultimately die (literally are murdered) prematurely. There are specific failure situations that can be avoided if proper battery management techniques are applied. It is also critical that proper system design and battery selection techniques are applied that focus on the application in which the batteries are to be employed. Failure to follow appropriate design and system management guidelines almost always guarantees an early failure of the battery system or, at best, reduced system performance. The following is an abbreviated list (certainly not all-inclusive) of common premature battery failure drivers and their expected outcomes.

1. Overcharge. Chronic overcharge results in many effects that ultimately lead to premature battery failure. In VLA batteries, the grids warp and may become shorted, water in the electrolyte hydrolyzes sometimes leading to grid exposure, excessive grid corrosion occurs, and a potential for thermal runaway exists. In VRLA batteries, excessive gassings occurs leading to dry-out; grids warp and active material shedding accelerates, excessive grid corrosion occurs, and thermal runaway is a real danger that may lead to a fire or even an explosion as hydrogen gas may become concentrated because of extensive out-gassing.

2. Over discharge. Over discharge affects both VLA and VRLA batteries in much the same way. Over discharge results in the probability of developing large lead sulfate crystals deep in the active material paste of the plates which causes cracking of the paste surface ultimately leading to the shedding of active material and premature loss of capacity. In addition, large and very hard sulfate crystals typically develop on the surface of the grid. These sulfate crystals may be very difficult and sometimes impossible to reconvert during routine charging again leading to premature capacity loss or eventual total battery failure.

3. Excessive charge rates. High charge rates, especially at near top-of-charge, are damaging to both VLA and VRLA batteries. As batteries near full charge, the natural increase in internal impedance can result in excessive heating (I^2R) of the battery which may then lead to thermal runaway. Vigorous gassing activity also occurs at near top-of-charge that can lead to out-gassing and ultimate dry-out in VRLA batteries and can cause excessive "boil-off" of water in the electrolyte in VLA batteries which may ultimately expose the tops of the battery plates to the air leading to warping, shorting, and/or capacity loss. In extreme cases, large quantities of hydrogen may be evolved which can lead to an explosion if the hydrogen is allowed to concentrate in an enclosed area. This potential failure driver is especially sensitive to elevated environmental temperatures which may lead to thermal runaway and catastrophic failure.

4. Excessive discharge rates. Both VRLA and VLA batteries can be damaged by excessive discharge rates. Discharge rates above design specifications may cause localized heating of the internal grids that can then lead to permanent damage to the plates. Rapid expansion of the grids in response to the heating caused by excessive currents can cause active material shedding leading to premature capacity loss. This potential failure driver is especially sensitive to the improper selection of energy batteries for power applications.

5. Improper equalization. All battery cells, both VLA and VRLA configurations, are not created equal and, in normal operation, cells will respond differently to operational conditions. In cycling applications, when a battery completes a recharge, it may be at the proper DC bus voltage which is the sum of the individual cell voltages of the series, typically 6 cells in a 12 volt module for automotive batteries or 60 cells in a 120 volt battery for a utility-type application. However, although total string voltage may be in the correct range, individual cell voltages in the string may vary significantly from typically 1.6 to 2.4 volts. During a discharge of this string, this variation in cell voltage typically results in the low voltage cells becoming over discharged leading to a situation in which the battery is not able to meet load demands. Normally, in stand-by applications (i.e. UPS systems not subject to frequent discharges), a long stand at applied trickle charge voltage is adequate to maintain cell equalization. On the other hand, in cycling applications, it is necessary to occasionally apply an equalization charge at elevated voltage for a specified period of time, on a routine basis, in order to maintain equalization of the cells. Too frequent equalization will reduce life because of overcharge reactions; too infrequent equalization will result in serious sulfation of the weaker cells which will lead to early failure. Depending on the application and manufacturer's recommendations, equalization is not recommended for some VRLA systems.

6. Hot operational environment. Both VRLA and VLA batteries are very sensitive to hot operational environments. All battery specifications for both variants are based on operation at a nominal temperature of 25ºC (77ºF) internal to the battery. Excursions above that temperature have a detrimental effect on battery life, even in a thermally cyclic environment, for example, operating at ambient temperatures between 70ºF and 95ºF on a day-to-day basis. As a rule of thumb, for every 10ºC of average temperature operation above the 25ºC standard condition, the expected battery life will be halved. In other words, a battery with an advertised 10 year life (given that all other stress conditions and failure drivers are successfully mitigated) can be expected to provide its intended services for only 5 years if it is operated at an average of 35ºC (95ºF), or for only 2.5 years at an average of 45ºC (113ºF). If other conditions, such as those contained in this list, exist in addition to the hot environment, expected battery life will be even shorter.

7. Cold operational environment. The primary effect on both VRLA and VLA batteries is the reduction of available capacity which does not necessarily affect battery state-of-health. In some cases, batteries which operate fine at normal ambient temperature may be damaged when operated at low temperatures under some conditions. At lower than normal temperatures (i.e. 5ºC (41ºF)), a constant power discharge to the typical cut-off voltage of 1.75 VPC has the potential to over discharge a battery introducing the detrimental effects of that failure condition. Additionally, dwelling at low state-of-charge in temperature conditions below freezing may result in the formation of ice crystals in a VLA battery electrolyte which can permanently damage the surface to the plates leading to shedding of active material resulting in reduced capacity or even total battery failure.

8. Extended storage period. Both VRLA and VLA batteries self discharge under open circuit conditions just sitting on a shelf in storage, although, depending on battery chemistries, VRLA batteries may not be quite as sensitive to storage degradation as VLA batteries. Typically, a lead-acid battery is subject to a 3-5% self-discharge loss per month of storage at standard temperature (25ºC) depending on the construction of the battery and the make-up of the electrolyte. Problems become serious after approximately 6 months of storage as the battery typically loses more than 30% of its fully-charged capacity. Dwelling at this state-of-charge after a 6-month or longer stand may result in permanent damage to a battery as significant sulfation occurs. Additionally, stratification may also be an issue in VLA batteries as self-discharge produces water that tends to collect at the top of the battery which may lead to hydration and permanent battery damage. Higher than standard storage temperature results in the acceleration of self-discharge leading to permanent damages in periods significantly less than 6 months.

9. Improper battery for application. The selection of the proper type of battery, a power or an energy battery, is critical to the successful performance of any battery system. Power batteries are constructed with many thin plates which allows high currents to be generated as more electrolyte is in contact with the higher surface area of the plates; however, the thin plates restrict the amount of active material available for long discharge periods, even at reduced currents. Energy batteries are constructed with fewer, thicker plates which allow lower currents to flow for longer periods of time as there is more active material in the thicker plates; however, high currents are not available as there is limited surface area in contact with the electrolyte. The use of a power battery in an energy application, i.e. an automotive starting/lighting/ignition (SLI) battery installed in a golf cart, will result in a dramatically shortened life for the battery. The use of an energy battery in a power application, i.e. a golf cart battery installed in an automobile for SLI purposes, will have the same results, dramatic shortening of expected battery life. In many applications, power batteries are able to deliver significant energy and energy batteries can deliver significant power but the ultimate cost is extremely poor life performance in both cases.

This list of failure drivers and their expected outcomes is not all inclusive but represents areas of battery management and proper battery selection for a particular application that, when improperly applied or not applied at all, typically results in premature battery failure.

BATTERY SELECTION ISSUES AND AVOIDING FAILURE DRIVERS

Ideal battery selection and system design occurs when a specific application is identified which precisely specifies the functional requirements of the battery, battery support system, and loads (charging power source, charge/discharge rates, energy requirements, space requirements, operating environment, loads [periodic/daily cycle], etc., etc., etc.) leading to the selection of a specific battery that will support all the functions required by the application. The following is a list of some of the functional requirements of the application that must be considered during the initial design study:

- depth of discharge,
- rate(s) of discharge required to support the load,
- ability to immediately recharge the battery following a discharge,
- operating environment (temperature, vibration, etc.),
- physical environment (where is installation),
- location (local or remote),
- criticality of the load,
- difficulty and cost of battery replacement, and
- the value of the load being supported.

This list is but a cross section of the requirements of the application that must be completely understood before proper battery selection is possible. Ignoring any one of these aspects can easily lead to the unsuccessful integration of a battery system for the intended application. In other words, successful implementation of any battery system is a bottom-up design activity which must consider all the operational requirements for the application in order to select the right battery for the application and to provide the proper support for optimal battery performance. Proper battery selection depends entirely on the application. Selection of the wrong battery design will lead to early failure as enumerated above. System design considerations must focus on all aspects of the application in order to result in the selection of the correct battery for the job.

Criteria that must be considered for the selection of the proper battery for a specific application are outlined below.

1. Power application. Power applications typically require short bursts of high current (cranking an engine) or the delivery of reasonably high current for perhaps as long as 15 minutes (UPS). The battery selected for this application typically has many thin plates that provide the surface area necessary for high rate electrochemical reactions necessary to produce high currents. Because of the thinness of the plates and the disbursement of active material over a very wide area, these batteries are incapable of routinely delivering high currents for longer than specified by the manufacturer. Typically, a power battery can sustain less than 30 full discharges, sometimes as few as 10 full discharges, before the active material in the plate paste is used up even if proper charging and battery management procedures are applied. Power batteries do not deep cycle well and will quickly fail if operated in a routine deep cycling environment. For example, if a power battery is discharged slowly, as is typical of an energy application, other failure actions take place such as over discharge and undercharging. Undercharging usually occurs because the typical charging operation for power applications is inadequate to properly charge the battery.

2. Energy application. Typically, energy applications require low currents that allow the battery to slowly discharge over a period of several hours to several days. The plates of the energy battery are much thicker and fewer than a power battery. This allows for the availability of more active material throughout the plate's volume, and not just on the surface area, that can be used to generate current. Energy batteries are specifically designed to discharge slowly and recharge in substantially less time than the discharge period. Although an energy battery can sustain relatively high currents for very short periods of time, continuous high currents will quickly damage the battery initiating an over-rate failure. Additionally, if a slow discharge is not terminated at the proper time, the over discharge failure process will be initiated.

CONCLUSIONS

Proper management of all functions of a battery system is critical to the successful operation and ultimate performance of any battery system. Although only nine failure drivers were listed and discussed, other battery system management shortfalls can initiate many other failure drivers that were not listed. These other failure drivers also contribute to the potential murder of a battery. For example, one can operate a cycling battery at intermediate states of charge (not discussed) for a substantial length of time without damaging the battery or compromising system performance; however, if the battery is not managed properly and periodically equalized, capacity will decrease and performance will be degraded. This is but one example not discussed. And the list goes on and on.

One of the most important design considerations for any application is the selection of the correct type of lead-acid battery for the particular purpose. The selection of the right battery is critical to the successful implementation of any energy storage application. That selection must be based on a complete understanding of all requirements of the application and the designer's willingness not to compromise any detail to reduce cost or complexity. This understanding and willingness not to compromise good design practices will lead to the selection of a battery that will perform ideally and predictably in the application. And this must be followed-up with proper battery system management practices or else even this system is doomed. Any criteria that are ignored, for whatever reason, will ultimately lead to the premature failure of the system and the selected battery