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UPS Battery Design
Using VRLA Batteries in High Availability Applications

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Abstract

Critical site facilities engineers have several choices for UPS energy storage. Flooded batteries, sealed batteries and flywheels all have their pluses and minuses. Flooded batteries are undoubtedly most reliable but also most expensive. VRLA batteries are least expensive and can be more reliable than flywheels for the first few years but that reliability will be compromised without proper site design & care.
This paper presents both equipment and service design guidelines for using VRLA batteries in high criticality applications. Such designs reduce projected failure rates by an order of magnitude over conventional VRLA installations.

UPS DC power choices

Flooded cell batteries, sealed cell batteries and flywheels today are the only practical choices for reserve power in UPS (Uninterruptible Power Supply) systems. Flywheels are useful for certain space-critical applications or extreme cycling application but provide less than 1 minute reserve, cost more than most batteries and are subject to bearing reliability & seismic issues due to high spin speeds. Batteries dominate the field by a wide margin. Unquestionably, flooded or “wet” cell batteries are the most reliable DC choice available, exhibiting documented MTBF levels many times better than either flywheels or VRLA (Valve Regulated Lead Acid) batteries on a string-for-string basis. Additionally, flooded battery jar failures are normally short circuit in nature, making them transparent to the critical load in the vast majority of cases. But they are also most expensive, both on first cost, and on installed cost. This is due to requirements for spill containment, air changeout systems, hydrogen monitoring, eye wash & acid neutralization systems, and large footprint separate battery rooms. Currently over 90% of UPS systems with module power levels ranging up to 500KVA or more rely

Fig. 1 - Typical flooded cell battery room

on sealed VRLA batteries. In sharp contrast, VRLA battery systems avoid the majority of support costs, and are sharply lower in initial cost as well, thus, their enormous popularity. The compensating issue has always been maintaining long term reliability.

Factors affecting VRLA continued reliability

One often-referenced study by the French UPS manufacturer MGE, (ref Cun-Fiorina IEEE), demonstrates that some VRLA batteries can fail in mass in as often as 3 to 5 years. Granted, that particular study encompassed higher cycling 6 pulse rectifier applications and involved older single phase systems with proven overcharge problems. But the fact remains that the failure rates did occur. So how do we avoid them?

VRLA batteries can be either gel cell type or absorbent mat type in construction. In the USA, absorbent glass mat batteries are the dominant UPS battery type, outselling flooded batteries, flywheels, and gel cell batteries combined. They are what most people refer to when they say “VRLA” batteries, and they are more reliable in controlled ambient applications, so we will focus on that design here. But most statements which follow apply to either type VRLA battery.

There are a series of factors that directly affect VRLA reliability and service life. Other papers have addressed these in detail so we will touch upon only the major factors here. Heat is perhaps the single biggest enemy of stationary lead acid batteries. Depending upon manufacturer & product, expected life of all lead acid batteries will be cut in <u>half</u> for every 10 – 15 degree (F) rise in temperature over recommendation (usually 77 degrees F). For VRLA types, impact of excessive heat is most severe because it will lead to dry-out and open circuit failure, and in worst case scenarios in combination with older chargers, can contribute to thermal runaway, with explosive results *(Fig 2).*

Fig 2 - 6.2 yr old VRLA Monobloc with dramatic failure. Surprising many, no evidence of electrolyte spill here.

Next up on the list is cycling or battery discharge events. Most UPS systems cycle batteries not just during outages, but also for changes in load levels as well as large dips in input voltage. In fact, many battery companies now limit warranties based upon the number & duration of these discharge cycles. Charge voltage, current and duration also have impact on VRLA reliability. Older or defective chargers can overcharge or add ripple current leading to heat buildup and premature failure.

Clearly, it is good idea to keep temperature controlled to 77 degrees F or less, and this is easily and regularly done. Just as clearly, it would be prudent to select UPS systems that limit or eliminate both discharges from load fluctuations or "steps", as well as deep undervoltages or "sags". Deep sags are actually more responsible for both battery cycling and unprotected load crashes than actual outages are by a surprisingly wide margin *(Fig 3)*.

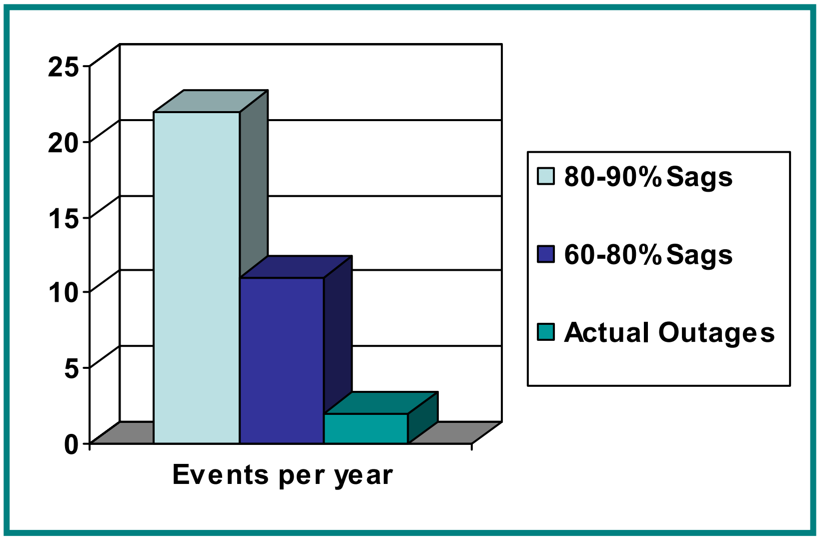

Fig 3 - Average USA Utility Power Quality Disturbance Data

Today, low cycle UPS systems are available commercially. Look for systems that avoid slow response 6 or 12 pulse per cycle rectifiers in favor of either very fast response IGBT conversion, or completely unregulated diode bridge conversion. Lastly, check that charger circuits are equipped with temperature compensation and low AC ripple current to avoid thermal runaway and optimize battery life.

But even if all of the above factors are carefully addressed, what about <u>continued</u> reliability, say in year 4 or 5, with VRLA systems?

A way to design VRLA systems for high availability

Redundancy is not a new concept in mission critical applications. Yet, many would be surprised just how often the essence of the term is missed when designing UPS battery systems. Statistically, one is always best served when investing capital equipment "redundancy" dollars in the weakest links in the critical power chain. The most failure prone link, and easiest to address, is the DC system. Empirically, the vast majority of UPS DC systems fail far more often than the AC (rectifier-inverter) sections of modern UPS systems.

Most sealed VRLA batteries currently being manufactured and bid for UPS applications in the USA have a five year design or target life. This can vary upwards with reduced ambient, cycling, and manufacturer, or downwards with factors already discussed. Unlike their more expensive flooded counterparts, VRLA cells tend to fail about as often open circuit as short circuit. This is due primarily to dry-out of electrolyte due to venting of generated hydrogen & oxygen from electrolytic charge & discharge through the one-way valves. As alluded to earlier, dry-out has an extremely high impact on reliability since a single open circuit cell can make an entire string inoperative.

VRLA batteries are generally supplied one string per cabinet in medium to large systems. There can be as little as one string, or as many as 5 or 6 strings deployed to provide the required reserve time. Since a great many UPS systems are purchased “low bid” and many end users do not know the difference, the battery systems provided with such systems could be the cheapest that meet reserve time specification. This will invariably mean single string, or sometimes worse, two string designs for as little as 5 – 10 minutes of reserve time in UPS systems 150-200 KVA or smaller in size. Single string batteries are the most common supplied today. They are very cost-effective and, as empirical data confirms, quite satisfactory for many if not most UPS applications, but not for true high availability (i.e. – high 9’s) applications. Two strings can actually be worse than one for some low reserve time applications because if either of the two is lost, the entire load is lost - even for a split second outage. This fact is rather ironic, since VRLA battery strings are relatively inexpensive and easy to parallel.

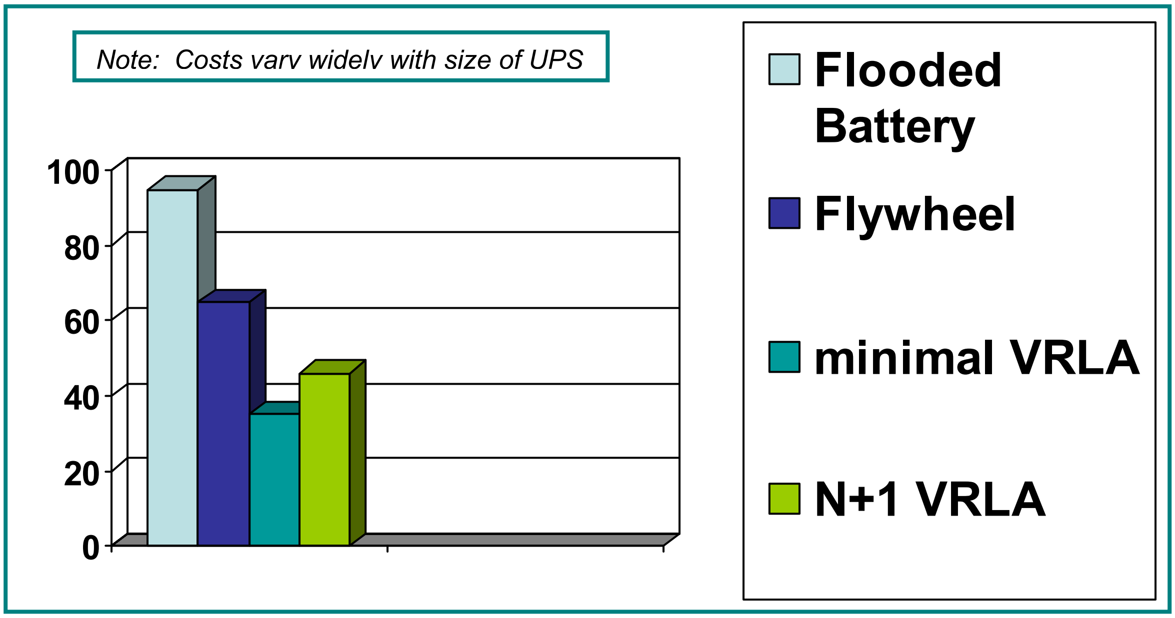

Fig. 4 - Relative Installed Cost

The better way to design with VRLA for high availability applications is to understand the costs, as well as the reliability over time of the various elements of your UPS system and use that in the decision matrix. Looking at the UPS, battery (single string), and genset components of an overall system, batteries are least expensive, most prone to fail, and have highest impact on critical load crash potential. Let's look at an example. Simplifying for clarity, let's assume you have a UPS design load of 200 - 300KVA, a 99.999% availability target, and an installed budget of perhaps $250K for a UPS system & upgrade to your existing diesel generation-backed utility system. Since modern gensets start & accept load in 10-30 seconds after power failure, you only need a minimal battery reserve, conventionally "5 minute" (actually 2-3 minute), to effect safe transition. This would likely mean a two string VRLA battery at this power level. Adding a third string, even with associated & recommended circuit breakers, would typically add perhaps $10K, or just 4%, to the installed cost. But let's look at what you get for that 4%:

- 15 minutes or more reserve time at full load, and over a half hour at probable initial 50% loading. Perhaps enough time to fix a diesel system no-start due to a valve or ATS switch in the wrong position.
- N+1 redundancy at full rated load, likely N+2 redundancy at initial loading. This improves overall battery system MTBF (Mean Time Between Failure) rating almost an order of magnitude.
- Elimination of "cell reversal", a potentially catastrophic condition stemming from wide disparity in capacities in single string systems, even if one string is down.
- Tremendous flexibility in maintaining & changing out battery strings with minimal risk to critical loads.

There are some PQ experts, this author included, who feel that given a choice between 1) redundant VRLA battery strings and single diesel generator (but with absolutely excellent maintenance and redundant batteries), or, 2) redundant (expensive) gensets and non-redundant VRLA UPS battery, choice 1 is always preferred. This is because when most stand-by duty gensets fail, they do so due to poor maintenance (i.e. – bad batteries!). Further, they are only required to start in far less than 5% of events which would crash computers or other critical loads. (ref. EPRI DPQ study data)

A better way to design a VRLA service program

Now that you have an N+1 or even N+2 VRLA UPS battery system, you have access to the final piece of the VRLA reliability puzzle. Today, almost all VRLA battery strings deployed for any single UPS are changed out at once. This is driven in part by cost, but largely by convenience and a pervasive misunderstanding of battery reliability over time. The MTBF rating for any single VRLA battery will <u>not</u> be the same in, say, year five (5) as it will be in year one (1) of service. In fact, the probability of failure will be many times higher. Batteries, unlike other UPS components, are chemical devices and age plays a key role. The reliability and failure incidence follows a bath tub curve. *(Fig 5)*

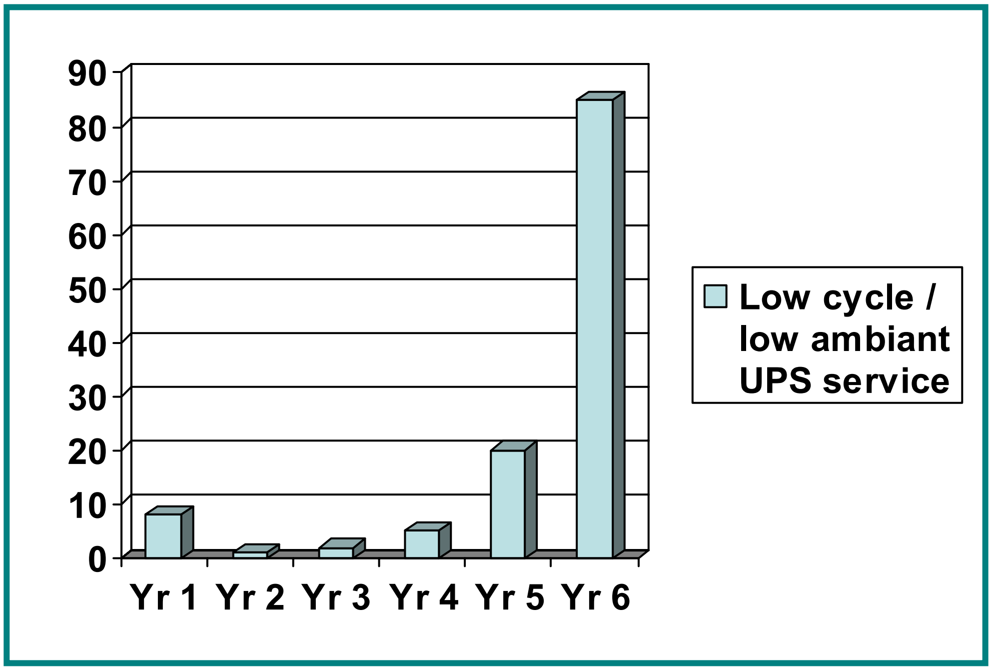

Fig. 5 - Typical Surviving Cell VRLA Battery Failure Rate Approximation

Therefore, a primary goal of a true high availability UPS maintenance program should be to arrange changeouts so that no more than one string (the "redundant" string if you will), is still in service in the high risk last year of design life. This is typically year five, but, again, will vary with factors above. In a three string N+1 VRLA design, this would mean changing out the first string prematurely in year 3, the second string at year 4.5, the last string late, perhaps even year 5.5 or later depending upon maintenance test results, operating conditions and budget. Second level changeouts would occur perhaps five years later in each case. The higher the availability requirements, the more string redundancy and/or faster the changeouts.

Good UPS maintenance will include battery voltage, resistance or impedance testing, some of which is built right in to modern UPS charging & monitoring circuits, as well as visual inspection, cleaning and later on, retorquing or IR scanning connections. This will help determine which jars are more likely to fail in the short term and which are not. With top quality UPS systems & minimal cycling, VRLA cell failures and required VRLA maintenance is almost zero for the first two years. Therefore, UPS facilities & maintenance departments may want to vary PM requirements with the VRLA aging process, particularly if not staggering the changeout schedules. Depending on the battery charging & monitoring system, it may be hard to detect a shorted cell condition in a multiple paralleled string system which could cause some unequal energy flow & further contribute to fail potential. Rather than the industry common 2 PM visits every year of service, a better designed plan for the same budget dollars might allow one or even zero PM visits the first year ramping to four (4) visits a year by the fourth or fifth year of service.

Conclusions

Overall UPS system reliability is more dependent upon the DC component of the system than any other element. VRLA batteries will remain the DC component of choice for most UPS systems for many years to come. By integrating good system & service design, very high levels of VRLA battery reliability & availability can be achieved, both initially and over the long term.

The Author

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