ALTERNATIVE BATTERY SIZING METHOD FOR END-OF-LIFE RUN TIME

Robert Malley
VP Quality

Allan Williamson
Manager Product Test Laboratory

C&D Technologies
Blue Bell, PA

Abstract
End of life run time is the critical sizing factor for battery systems – especially for large data centers and other high-power applications. Current recommended practice is to oversize battery systems based on product watt-hour capacity. Battery design and testing practice, however, determine life based on reduction of run time at fixed energy discharges. Using run time as the basis for determining product sizing matches industry practice and provides for more efficient system sizing which can save users both space and cost.

Introduction
Mission critical power systems typically use a defense-in-depth strategy with alternative AC power sources, local power generation and emergency power batteries integrated to provide the maximum possible reliability for the application. Given the nature of the applications being protected by these systems, conservative design is necessary for all components.

The overall reliability of an integrated emergency power system is a product of the reliability of the basic components. With adequate maintenance, the reliability of most components (switchgear, generators, alternative power feeds) can remain the same for many years. Battery systems, however, have a lifespan that is set by chemical reactions within the cells, which must be accounted for when designing the overall system. Battery system life is typically a fraction of the expected life of the system it is protecting, whether it is a power plant, communication system, data center or other application. Regular replacement cycles must be planned to assure continued critical power availability. In addition, the performance of a typical battery system will change over its lifespan, especially as the system approaches the end of its lifespan. These changes must be accounted for in the initial design of the battery system.

The starting point for most large battery system designs is the criteria for end of life run time at a specified battery load. Both parameters are set by the needs of the system being protected – the power load is defined by the needs of the system and the run time is defined by duration of the tasks that need to be completed prior to the battery system shutting down. The end of life run times can vary widely, from a matter of a few minutes for data centers to many hours for power plants. After determining these two parameters the battery system can be designed to provide the needed backup power.

Sizing for End of Life

IEEE-485[1] provides recommended practices and general guidance for sizing batteries for stationary applications. This standard defines end of life for typical lead-acid batteries (VLA and VRLA) as 80% of the initial capacity. Using run time as the basis for determining product sizing matches industry practice and provides for more efficient system sizing.

While the statements are straightforward, the interpretation of capacity has taken several forms, including:

1. Compensating power while leaving run time fixed. For this process a battery system would need to be rated at 125% of the power at the end of life run time. Thus, for a 1000 kW battery demand (kWB) system rated for 10 minutes at end of life (EOL) run time the system must be able to provide 1250 kWB at 10 minutes at the beginning of life (BOL). This method is problematic, especially for on-site verification or commissioning testing. All current carrying components in the back-up system need to be oversized by 25%, for a discharge rate that the actual system will never see in use. This method is commonly used in nuclear power plants but sees little use elsewhere.
2. Compensating run time while leaving power fixed. In this method the run time is increased by 25% while leaving the power level fixed. For the same 1000 kWB system rated at 10 minutes at end of life, the battery is sized to provide 12.5 minutes at the beginning of life.
3. Compensating total energy and recalculating run time. In this method, which is the most popular in our experience, the total energy (watt-hours) needed at the end of life is calculated, increased by 25%, and the beginning of life run time is re-calculated keeping the power level fixed. The ratio of beginning of life to end of life run times can vary depending on whether the power vs run time relationship is linear or variable.

For long duration run times (most switchgear and telecommunications applications with run times greater than one hour) the power vs run time curves are relatively linear, and method two and three give the same results. For UPS and other short duration discharges the relationship between discharge power and run time is more complex, as the cell's internal resistance dominates the discharge process although acid diffusion still has some influence. At very short run times small changes in power result in large changes in run time. At a five-minute run time, a one percent change in power results in a three percent change in run time for VLRA, and six percent change in run time for flooded batteries. Figure 1 shows this behavior for typical VRLA and flooded batteries.

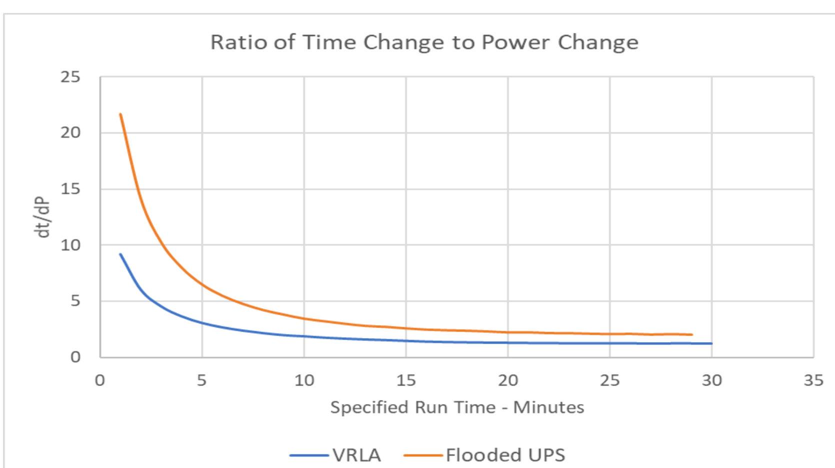

Figure 1

For short duration UPS applications, the straight application of the 125% aging factor (Method 3) can result in significantly longer discharge durations at the beginning of life. For a five-minute end of life run time the initial run time may exceed 11 minutes in a VRLA system (2.2 BOL/EOL run time ratio), while a flooded product may exceed 14 minutes (2.8 BOL/EOL run time ratio). The question of whether these systems are oversized depends on how end of life is defined and the performance of the batteries in the application.

Life Behavior and Relationship to Product Sizing

The reason for adjusting the battery system size is to assure that the system can perform at the end of life. How battery product life is determined, and the capacity behavior of products during their useful life has a profound effect on whether the aging factors are effective (the system can still perform at the end of life) and efficient (the system is not oversized for the end of life conditions).

To fully describe the system requirements the user needs to define the following attributes:

- Full power discharge rate (usually considered fixed over the life of the system)
- End of life run time – how much time is required to complete essential tasks
- Desired service life – how many months or years before the system will be considered unable to perform to end of life conditions and must be replaced.

The discharge rate and the end of life run time are generally defined by the application (UPS size, type and nature of the application and other backup systems etc). The desired service life is not dictated by the equipment or application, and is usually worked out in partnership with potential suppliers. It can profoundly affect the initial and total cost of ownership of a project. Selection of a low initial cost battery with short life can require multiple replacements (increasing total cost of ownership), while selection of a long-life product with life matching the system can greatly increase initial costs.

One of the biggest questions in the industry is what is the actual application life of a battery. Despite years of field experience, actual capacity behavior of batteries in real applications is scarce. Routine capacity testing is expensive and usually only performed in regulated applications. Nearly all of these applications are for flooded systems with long run times. Ohmic readings have been used as proxies for capacity testing in UPS and other short duration systems, but the correlation between ohmic readings, capacity, and life expectancy is inconsistent. In reality, most non-regulated systems are replaced on a standard calendar basis well before end of life, limiting the amount of field data that are available for analysis.

Accelerated life testing of products remains the most useful source of information for estimating behavior of battery products over their lifespans. Accelerated life testing for stationary float service products involves placing the batteries on charge at elevated temperatures and periodically testing to determine capacity. Accelerated aging factors (derived from internal testing at multiple temperatures or from standards such as GR-4228) can then equate life at temperature to estimated life in the field.

The assumption in the IEEE standards and most application specifications is that a lead acid battery product will lose capacity over time, and that when the product is 80% of initial capacity there is no more useful life in the product. This is true, all batteries eventually will fail, but when and how they fail has can have a profound effect on how the system should be sized.

Using the simplest example, an application may call for a 20-year life expectancy. Using the IEEE standards, the system will be oversized by 25% no matter what type of battery is used. However, with the selection of the proper battery, this safety factor may not be needed. Figure 2 shows typical behavior of a flooded battery system in a sub-30-minute application. At 20 years, the product is still delivering nearly the same run time as it did at the beginning of life. Since the discharge power does not change, and the required run time does not change over the application life of this battery, it delivers the required power at the beginning and end of life without any need for oversizing the product. The safety factor recommended by the specifications simply increases the size and cost of the battery system.

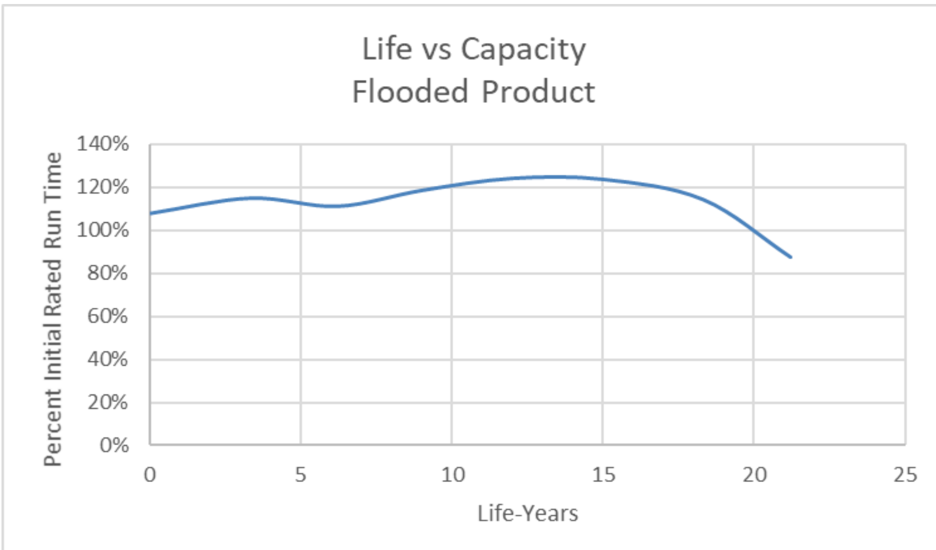

Figure 2

Flooded batteries and twenty-year replacement cycles are increasingly rare in today's applications; however, the same principles can be applied to VRLA products on shorter lived systems. Figure 3 shows life vs capacity behavior for multicell monobloc VRLA cells, today's most popular choice for large data centers. Both types of batteries are used in these applications, however, the life vs capacity behavior is very different. Battery A has a steady decline in capacity from beginning of life to past five years. Battery B has a flat capacity curve initially, but then declines sharply after 4.5 years.

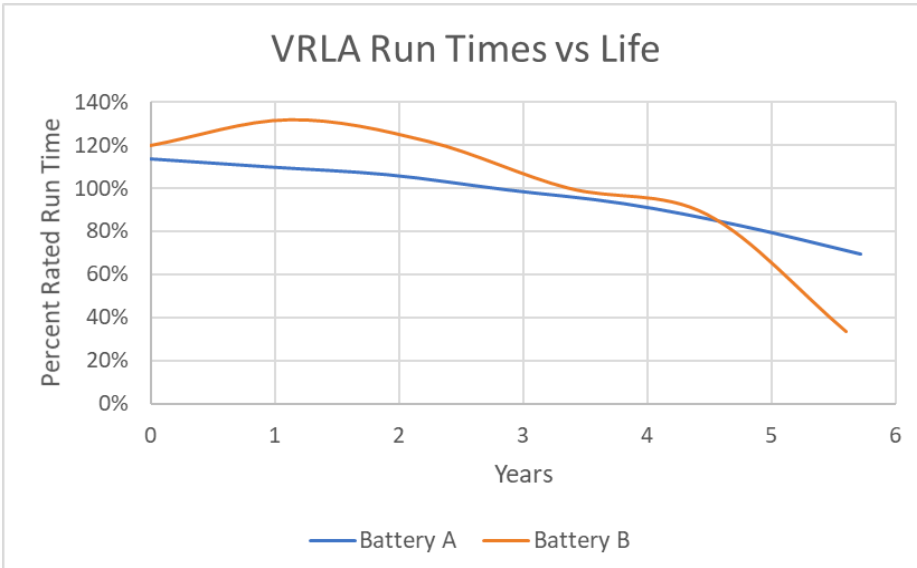

Figure 3

When sizing systems using these products a straight 25% aging factor may not be necessary. At three years life (a popular choice for routine replacement of 12 or 16V monobloc batteries) both types of products are at or above 100% rated run time. Since the run time at three years is the same as new, the batteries have not "aged", and again oversizing simply increases the system size and cost.

At five-year life (another popular replacement point) both products have fallen below 100% rated capacity, and some form of aging factor is required. Here the battery behavior during life plays a critical role in how much larger the battery must be sized to achieve rated capacity. Battery A has fallen to 80% of its initial run time. To achieve the desired end of life run time, the battery must be sized so that it achieves a minimum of 125% of the end of life run time. (i.e., if the end of life run time is 5 minutes, the battery should be sized for at least 6.25 minutes or more). Battery B, which has a steeper curve at the five-year mark requires a larger factor. It is at 60% of its initial run time, thus the battery must be sized to achieve 167% of its end of life run time (for the same 5-minute example the battery should be sized to provide 8.3 minutes or more).

It should be noted that the rating discussions above, the run time is compensated, not the overall power or system capacity. For Battery A, the run time is increased by 25% over its end of life requirement. As noted above, changes in run time at high discharge rates require relatively small changes in power. Battery A's capacity would only need to be increased by approximately 10% to achieve a seven-minute initial run time. Battery B would require an increase of 17% to achieve a nine-minute run time. Both factors are significantly smaller than the 25% recommended by specification.

The difference in sizing methods can profoundly affect the cost and size of the battery system required for a particular application. For batteries with flat life vs capacity curves using the same beginning and end of life run times can reduce system sizes by 25%. This can make longer design life products more competitive than shorter life product. Even for products with significant drops in capacity at the specified life, the change in product size can mean a reduction in unit size, or even elimination of a parallel battery string.

Conclusions and Recommendations

The use of a standard aging or oversizing factor can be useful when little is known about the capacity vs life behavior of a battery product, however, battery sizes (and costs) can be optimized with little risk by incorporating the life behavior and replacement cycle into the sizing calculations.

In order to take advantage of the actual life behavior of battery systems it is essential that the user work closely with the battery manufacturer to obtain the best possible models for capacity during life. In particular, the following precautions must be taken

- The life data used must represent the actual application as closely as possible. Batteries can have different life behavior (and different failure modes) at high discharge rates. A life test using telecommunication discharge rates (3-8 hours) may have a flatter capacity vs life curve than one using short duration (5-15 minute) UPS discharge rates. This will profoundly affect the product sizing.
- The aging factors used to convert test data to years in service must be based on either an internally calculated activation energy, or should use a relevant external standard.
- Product variability should be accounted for in the life curves. Using the best life performance, or even average performance, will lead to under sizing the product. The calculations from the life testing should be adjusted so that there is three sigma or better compliance (99%+ of the life tests performed run better than the minimum specified life).
- The other factors considered in sizing need even more careful consideration. Replacing the standard aging factor represents a reduction in the overall safety factor for system sizing. Internal connector loss (if not included in the battery ratings), battery system to load loss and capacity and life variation due to temperature factors all need to be included and accounted for in the final battery system sizing.

[1] IEEE-485-2010: Recommended Practice for Sizing Lead-Acid Batteries for Stationary Applications IEEE Power Engineering Society, New York 2010