IMPORTANT CONSIDERATIONS WHEN REDUCING THE RUN-TIMES OF VRLA UPS BATTERIES

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ABSTRACT

As VRLA batteries improve in reliability, there appears to be a greater propensity of users to consider reducing the run times of their UPS battery bank. Although this clearly can reduce the initial cost and size of the battery installation, this practice introduces several issues that can cause unintended consequences for the user. This paper will discuss several of the important battery related issues that should be considered in these situations. The relationship between shorter run time and end-of-life issues will be reviewed, particularly in relation to time-adjusted vs. rate-adjusted capacity calculations. The effect of this on several groups of commercially available batteries will be shown. Additionally, the coup-de-fouet effect and its possible influence in this area will be introduced as a consideration. With this information, the end-user can make an educated decision on the expectations and the risks involved with the decision to reduce their UPS battery run-time.

BACKGROUND

In the typical, static Uninterruptible Power Supply (UPS) system, batteries and generators are used to provide instant power in case of incoming power failure. If the generators could provide power instantly and seamlessly, there would be no need for a battery bank. The batteries are primarily used to transition to the generator power. Since the generators provide the long-term, temporary power needs, the batteries do not have an inherent run-time requirement, other than to provide enough time to allow the generator to start, sync with the AC and stabilize. This can all be done in less than a minute.

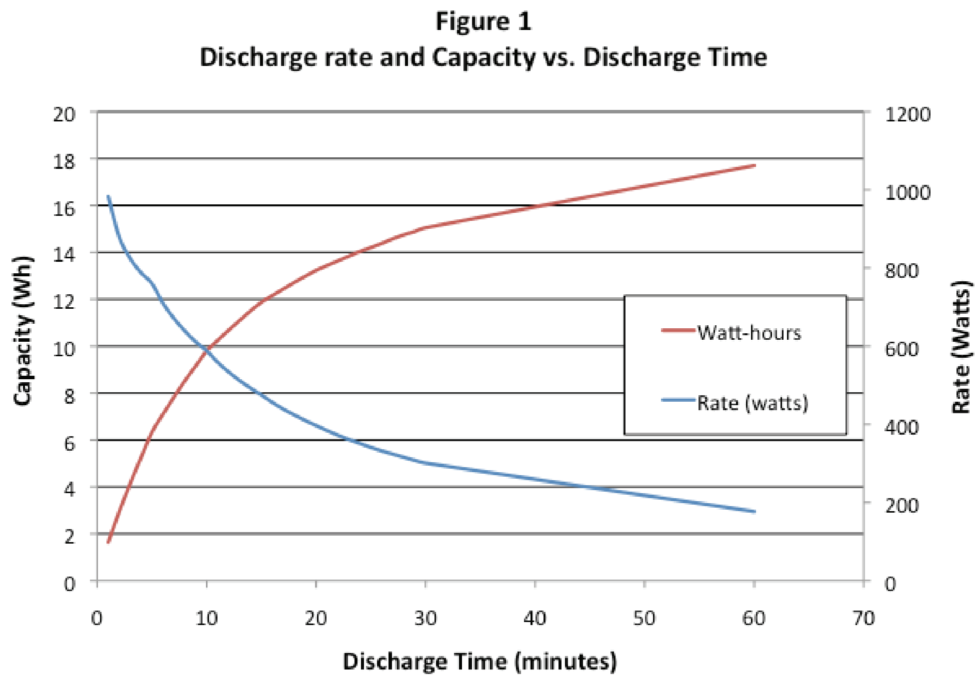
Traditionally, UPS batteries have been sized for 15 minutes of run time. This has become a past industry standard but is now being challenged. As companies look towards reducing capital costs, smaller batteries are being considered for UPS applications. Ten, and even five minute run-times are now being used, with the mindset that this provides ample protection, since the generator is expected to start and sync in less than a minute. This paper will not consider the quick-start function or the reliability of the generator, and will look only at the battery issues. There are several specific issues that should be understood when considering using a shorter duration battery.

END-OF-LIFE ISSUES

Most batteries perform well when installed as new. After installation and commissioning, the battery will then be left to slowly age. This will be observed as a gradual decrease in capacity due to the irreversible side reactions that occur within the battery. Most users know that by definition, when the battery reaches 80% of its nameplate capacity, it is considered at its end-of-life and should be replaced. This issue is how this 80% is calculated. By industry convention, 80% of an 8-hour battery is not calculated the same as for a 15-minute battery. The capacities of batteries sized for 1 hour or less are typically based on their rates, while batteries sized for greater than 1 hour have capacities based on time. As such, a 15 minute, UPS battery is considered at end-of-life when it fails to deliver 80% of its initial rating, and an 8 hour, Telecom battery is considered at end-of-life when it fails to deliver 80% of its initial discharge time. For a more detailed explanation of this topic, the reader is referred to Annex K of the recently released IEEE Std. 450-2010, “IEEE Recommended Practice for Maintenance, Testing, and Replacement of Vented Lead-Acid Batteries for Stationary Applications.” (IEEE, 2010)

Since this discussion is involving battery use of 15 minutes or shorter, the rate-adjusted method should be used, as recommended by IEEE standards. For those who are not used to battery testing, this may not be an obvious selection.

The time-adjusted method is simple and intuitive. If a battery is rated to run for 10 hours at a given rate, when it can only run for 8 hours, it is at 80% and is at its end-of-life. If one was to incorrectly use this convention for a high-rate UPS battery, one would then expect a 15 minute battery to deliver 15 x 80% or 12 minutes of run time at end-of-life. If this was the case, there would be fewer arguments against a user who wanted to reduce his original 15 minute battery to a 10 minute or even a 5 minute battery. With this erroneous thinking, a 5 minute battery would deliver 4 minutes at its end-of-life. This is short, but would probably be considered a reasonable reduction in run-time.



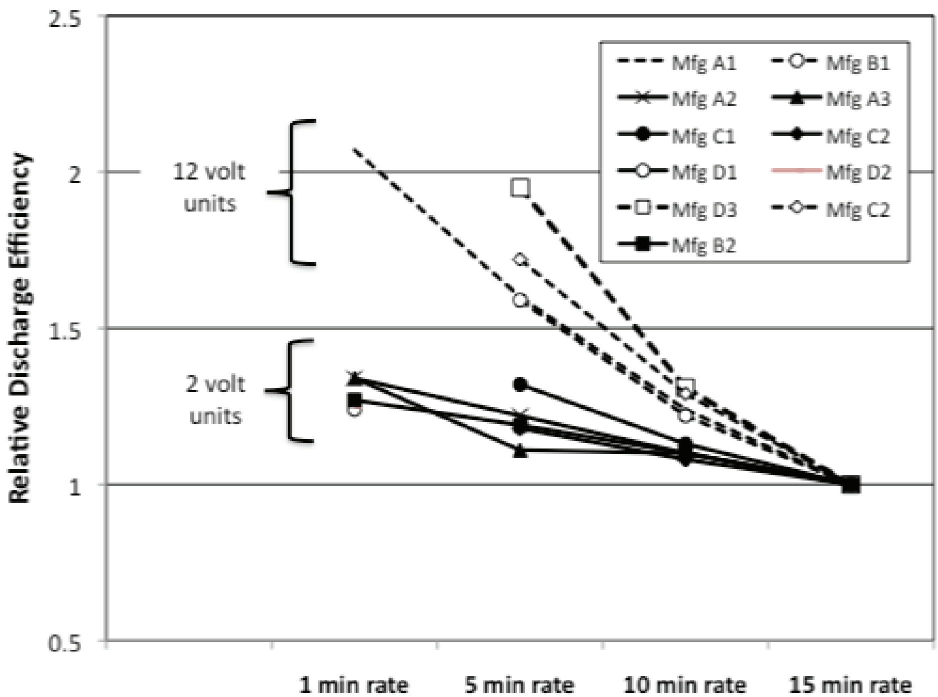
PEUKERT'S LAW

The reason this is erroneous, is because the discharge efficiency of a lead-acid battery varies based on its rate of discharge. In other words, a lead-acid battery will deliver less capacity in amp-hours at a higher rate, than it will at a lower rate. This is known as Peukert's Law. A graph of this law (Peukert's curve) for a widely used, commercial, 12-volt lead-acid battery model is in Figure 1. This shows how dramatically the capacity of the battery changes as the rate is increased. Clearly this is not a linear relationship. It is this effect that must be taken into account when calculating the ending capacity of a high-rate battery.

Although this may (or may not) be interesting to ponder, for the UPS owner, the result of this effect on run-times is especially significant. Real world examples have been compiled below to show how important these issues are.

For this study, eleven different industrial VRLA batteries were selected, from four major battery manufacturers. Figure 2 shows the published data of these batteries, as plotted on an efficiency vs. discharge rate chart. The 15 minute discharge was normalized so that all batteries would have the same starting point. This chart then shows how much greater the discharge rate becomes as the discharge time decreases from 15 min to 1 min. Clearly, there is great variation in the designs, as some designs can deliver more than twice the current when the discharge time is reduced from 15 to 1 minute. This is due to the many variables of the battery design. This can include features such as plate distance, electrolyte strength, separator resistance, and plate porosity, amongst others. (Technical Datasheets, 2011)

Figure 2
Discharge Efficiency vs. Discharge Time



As a group, the 12 volt designs clearly provide a higher efficiency at higher rates than do the 2 volt designs. This is primarily a function of the element design that is tailored to provide the battery service life desired by the market. Two-volt batteries are typically expected to provide lifetimes approaching 20 years, while 12-volt units are typically expected to last 5, and sometimes 10 years. In the real world environment, flooded UPS batteries with a 20 year design have historically provided 12-15 years of life, while 2 volt VRLA batteries with a 20 year design life have historically provided 7-10 years of life. In 12 volt monoblocs sizes, batteries greater than 100 Watts/cell, have typically provided 3-5 years, and for 12 volt monoblocs smaller than 100 Watts/cell, actual life has been typically 2-3 years. All of the preceding average lifetimes were based on a controlled operating temperature of approximately 77 degrees F. As the VRLA battery becomes better understood and optimized, the service lifetimes continue to improve. In general, a 20 year design will have thicker grids, thicker plates, more dense active material, wider plate spacing, etc., all designed to maximize life. Unfortunately for the high-rate UPS owner, these features all reduce the high-rate efficiency of the cell.

However, even within each group, there is a great deal of variation in the efficiency. Some designs have minimized the internal chemical and ohmic resistances, thereby providing a battery optimized for high rates, even as compared to its peers. Other designs are less efficient at rates greater than 15 minutes, presumable to optimize another feature, in most likelihood life.

These variations in efficiencies are all reflected in the ratings tables provided for each battery model. When these ratings are converted into run-times at end-of-life, this difference in efficiency causes dramatic differences, as shown in Table 1.

Table 1. Run-Time Summaries

	As delivered (new)	Run-Time using ***incorrect*** time-adjustment method	12 volt monobloc ***Correct*** rate-adjustment method	2 volt cells ***Correct*** rate-adjustment method
15 minute battery	15 min	12 min	9.5-10.5 min	1.5-3.5 min
10 minute battery	10 min	8 min	5.5-7.5 min	<1 min
5 minute battery	5 min	4 min	<1min – 1.5	--

As alluded to earlier, the issue is not the run-times upon initial installation, the problems occur at end-of-life. A 15 minute, 12-volt battery will run for 9.5-10.5 minutes at end-of-life. This is probably acceptable to most users. However, if a smaller battery is used with a 10 minute run-time, the end-of-life run time is not 8 minutes (80% of the initial run-time), but can be as low as 5.5 minutes. When a 5 minute battery is installed, at its end-of-life it may have less than a minute of run-time. This is far from the 4 minutes of run-time predicted by the incorrect time estimation. The UPS end user may be unpleasantly surprised to discover that his load may not be protected at all.

When a 2 volt cell is selected, the poor high-rate efficiency makes matters substantially worse. A 15 minute battery will not have 12 minutes of run time at end-of-life, but in actuality, may have no more than 3.5 minutes. A 10 minute battery will have essentially no run-time, and a 5 minute battery will have absolutely none. Clearly, this is not an appropriate application for 2 volt cells, unless these effects have been planned for.

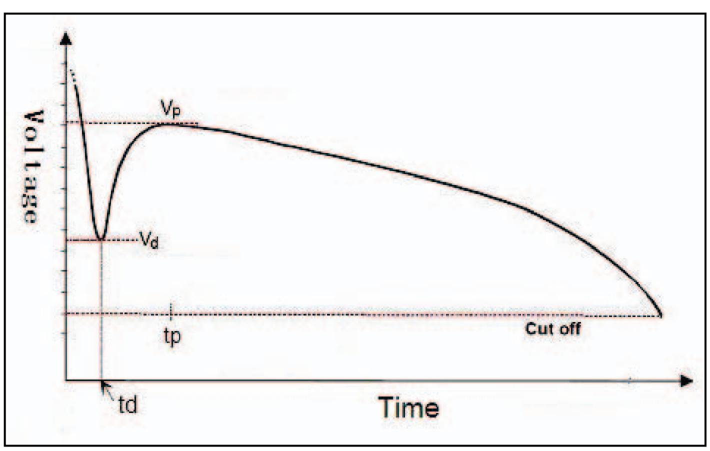
Note that this discussion refers to batteries that age as they are predicted to by the manufacturer. Nothing in this discussion has centered on batteries that fail prematurely due to harsh environments or duty cycles. This will only make these results worse. Because of these uncertainties in run-times, periodic discharge testing would provide valuable information in the evaluation of these UPS battery banks.

Clearly, a UPS user must choose his batteries carefully so that he has the desired run-times at his end-of-life. It is important to point out that although the 2 volt batteries show dramatically short run-times, the actual run-times should stay relatively high until the batteries approach their end-of-life. With the improvements in 2 volt VRLA batteries, an optimist would hope this would be approaching 15-20 years of service.

COUP-DE-FOUET ISSUES

Separate from the end-of-life issues, the coup-de-fouet (CDF) is another issue that should be considered when one is considering reducing the run-time of a UPS battery. This a temporary voltage drop that is seen in fully charged lead-acid batteries at the onset of a discharge. It is usually in the mV range, and can last for seconds to minutes. A typical voltage profile curve of a lead-acid battery is shown in figure 3, where td is the time of the maximum voltage drop, and Vd is the lowest voltage observed.

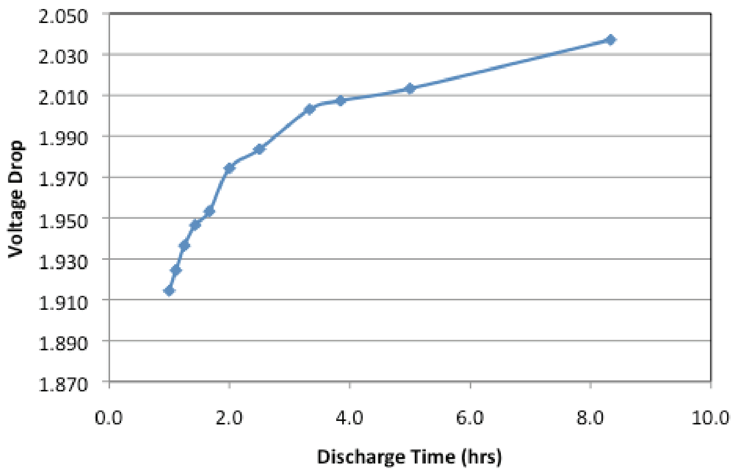
Figure 3. Coup de Fouet



Although the occurrence of the CDF has been recognized for many years, it has been the subject of many studies and it appears there is no simple cause. Crystallization kinetics, oxygen desorption, and electrolyte mass-transport are a few of the proposed explanations for this observation.(Hua, Zhou, Song, & Kong, 2009)(Bode, 1977)

Despite the unknowns surrounding the mechanism of the CDF, there are several studies that have shown the effect of various factors on the CDF. One in particular is the discharge rate. It has been shown that Vd, or the depth of the CDF, is directly affected by the rate of discharge. Specifically, the higher the rate, the deeper the voltage dip. This can be seen clearly in figure 4. Of note is that this relationship is expected to be design specific, and this drop may be able to be minimized in the cell design by careful balance of the influencing factors. Additionally, the slope of this curve has also been reported to increase as the battery ages. This means the voltage dip should get more severe as the battery approaches end-of-life.(Bose & Beaird, 2003) (Anbuky & Pascoe, June 2000)

Figure 4.
Effect of Discharge Rate on Coup de Fouet Voltage Drop



The reason the CDF should be considered is because if the CDF drops below the low voltage cut-off or disconnect, the system will then shut off, thinking the battery has simply been depleted. This will indicate battery system failure, even if the battery voltage subsequently recovers and the battery still has significant capacity remaining.

Although the trends in the CDF effect that have been introduced above should be considered, these effects are not well studied or well known for the high-rate UPS environment. It is recommended that the CDF be measured and documented during the commissioning test. When a battery is reduced in size from a 15 minute to a 10 or 5 minute battery, the resulting situation is a smaller battery that is hit with a greater load. This will increase the CDF voltage drop, possibly approaching the low voltage level.

Since it has been shown that the CDF voltage drop increases as the battery ages, if the CDF voltage is nearing the low voltage level at installation, the risk of hitting the cut-off voltage at the battery's end-of-life will increase. (Moo, Ng, & Hsieh, Nov 2005)

SUMMARY AND RECOMMENDATIONS

The reduction of a lead-acid UPS battery from the traditional 15 minute run-time to shorter times carries with it several risks that should be considered. These issues have been presented in this paper and are summarized below.

- UPS batteries should be sized and the capacities calculated using the rate-adjustment method. This has a significant influence on the expected run-times at end-of-life. If the time-adjusted method is used, there could be a significant error in the actual run-times obtained at end-of-life.
- There are significant performance differences between 12 volt and 2 volt VRLA batteries when used for UPS applications. The 2 volt batteries are much less efficient at higher rates, which significantly affects the end-of-life run-times.
- There are significant performance differences within either the 12 volt family or within the 2 volt battery families. Battery selection within the family is critical when moving to shorter run-times.
- Even if the run-time is sufficient and acceptable, the Coup-de-fouet, or initial voltage dip, may become a consideration in your battery sizing and selection depending on the battery you select and your duty cycle. It should be recognized that the Coup-de-fouet will increase as the battery ages.

As a final comment, it is important to note that most of these issues could be negated if the battery system were sized for 100% capacity at end-of-life. Although this is a common practice in other markets, this is unfortunately a rarity in the UPS market.

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