SAVING MONEY ON SUBSTATION BATTERIES WHILE MAINTAINING RELIABILITY

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ABSTRACT

There is already considerable pressure for electric utilities to cut operating costs, and this drive is likely to intensify as deregulation becomes a reality. One of the areas that will come under the accountants' magnifying glasses (if it hasn't already) is that of substation batteries.

Vented lead-acid batteries have provided reliable service in this application for several decades. Despite that high level of reliability, many users are finding that the demands of specific gravity measurements and other maintenance requirements for these batteries are in conflict with cost cutting edicts. As a result, some have begun installing valve-regulated lead-acid (VRLA) batteries in substations, seeking a lower-maintenance solution.

Batteries may also be subjected to extreme operating temperatures, frequently in small, poorly insulated buildings in distribution substations. For low temperatures, this results in an increase in the size of the installed battery; for high temperatures, battery life and reliability may be compromised. In both cases, increased cost is the result.

This paper provides background information on IEEE maintenance and testing recommendations for vented lead-acid batteries, then goes on to discuss various ways in which substation battery costs may be reduced without compromising reliability. It examines possible alternatives to vented lead-acid, including VRLA and nickel-cadmium. In particular, it points out the possible pitfalls of using VRLA batteries in substations.

INTRODUCTION

Vented lead-acid batteries have been used in substations for decades. For this duty, they are typically of the 'general purpose' type, meaning that the plates are somewhat thinner than in 20-year telecommunications batteries. The normal life of these batteries in float service at 25°C (77°F) is typically around 15 years. Whether the plates are made with antimony, calcium or selenium grid alloys, these batteries are generally quite reliable. To optimize this reliability, many utilities have adopted discharge testing programs to trend battery aging.

With these batteries often costing several thousand dollars apiece, the annualized battery purchase costs for a large utility can be very high. To make matters worse, the cumulative cost of maintenance and testing in accordance with IEEE recommended practices can easily exceed the cost of the batteries themselves. This makes batteries a tempting target for cost cutters.

Once a decision has been made to cut the overall costs of battery ownership, the next choice is where those cuts should be made. Should discharge testing be eliminated? Should the frequency of battery maintenance operations be reduced? Should different battery types be considered? The aim, of course, is to implement budget cuts without affecting battery reliability. However, it is all too easy for the cost cutters to go too far, leaving the distribution system vulnerable to battery failure.

Before examining possible areas for cost reductions, this paper will discuss current IEEE recommendations for the maintenance and testing of vented lead-acid batteries, and their relevance to substation duties. Being familiar with these issues, the reader will then be better equipped to assess the impact of potential cost reduction measures.

ACHIEVING RELIABILITY THROUGH DISCHARGE TESTING

Many users are aware that the only absolute measure of a battery's state of health is a discharge test. Indeed, discharge testing is one of the central pillars of the recommendations in IEEE Std. 450-1995[1]. For vented lead-acid batteries, the IEEE recommendation is that performance capacity tests should be carried out at 5-yearly intervals until the battery shows signs of degradation.

The 5-year recommendation is based on an anticipated battery life of 20 years—the norm for Class 1E nuclear power installations, where such testing first became standard practice. With an acceptance test being carried out in the first year, the third performance test would be at 15 years, or 75% of expected life. Under IEEE 450, a further test would be carried out at 85% of the expected service life, or 17 years. Subsequent tests should be at 1- or 2-year intervals, depending on whether degradation was observed at the 17-year mark.

This pattern of testing allows the variation of battery capacity with age to be trended, so that the point at which the battery degrades to 80% of its original rating can be determined with some accuracy. Beyond this point, the rate of degradation accelerates, and other, more catastrophic, failures become more likely.

However, this trending is only adequate for batteries with a 20-year service life expectancy. What of substation batteries, where a 15 year life is expected? What of battery installations that are subjected to higher temperatures, so that life expectancy is reduced to, say, 12 years? In such cases, a 5-year test interval would not allow meaningful trending, with the possible result that a battery would be used beyond the end of its reliable service life.

The working group responsible for IEEE 450 is addressing this issue, and it is likely that the recommended performance test interval will be changed to be 25% of the expected service life for the battery in question. Thus, the recommendation would be that a 10-year UPS battery should be tested at intervals of 2.5 years; or a 12-year substation battery should be tested every 3 years.

This modified testing regime is good for battery reliability, but it is unlikely to endear itself to the cost cutters. With an average substation battery capacity test costing around $2,000, it is far more likely that testing programs will be eliminated, rather than stepped up in frequency. This is a case where IEEE and the cost cutters are moving in opposite directions. Such a situation is not altogether unusual, since the IEEE mandate to its standards developers is that cost must not be a deciding factor in whether or not to include a certain recommendation.

MAINTENANCE THE IEEE WAY

IEEE Std. 450-1995 recommends a schedule for routine maintenance operations. This includes monthly surveillance visits to make sure there are no serious problems, combined with quarterly and annual checks of various operating parameters.

One of the real time-consumers in these maintenance checks is in the measurement of electrolyte specific gravities. Not only do these measurements take time, but they are also difficult to take accurately and are subject to other vagaries, such as electrolyte level changes and the effects of recent discharges or water additions. The IEEE 450 working group recognized this, and incorporated a relaxed schedule of specific gravity readings into the 1995 version. The recommendation is now to take these measurements on 25% of the cells every quarter and 100% every year. In terms of assessing the state of charge of the overall battery, it is now generally accepted that it is more accurate to measure the float current, rather than specific gravities.

Float voltage readings show whether individual cells are being adequately charged. Such readings are, fortunately, easy to take, requiring no particular expertise or specialized equipment. While these measurements are very useful in assessing the state of health of a battery, they should not be taken too literally. Many hours (and dollars) are wasted by maintenance crews making repeat visits to batteries that are showing a wide variance in float voltage readings. It is often standard practice to equalize such batteries, then to return after 48 or 72 hours to determine if the problem has been cured. Testing with reference electrodes[2] has shown that in many cases where lead-calcium batteries are exhibiting this behavior, the voltage variations are caused by a harmless variability in the negative plates, with no corrective action necessary.

Connection maintenance can be another time-consuming item. Previous practice involved retorquing of connection hardware on an annual basis, but this has been replaced by connection resistance measurements. These measurements require specialized equipment, but are much less time-consuming than retorquing. IEEE 450-1995 recommends checking 10% of connections every quarter and 100% every year, and this is appropriate for most substation batteries. However, this recommendation should be geared to the needs of the application. For example, in a duty with a low rate of discharge, such as SCADA or communications, a longer surveillance interval may safely be chosen. An alternative is to measure voltage drops in connections during a test discharge, but the user must determine whether the frequency of such measurements is adequate for reliable operation.

Much has been written about the benefits of internal ohmic measurements, including ac impedance, ac conductance and dc resistance. These measurements provide a means for checking the integrity of the internal current path of a cell or grouping of cells. While they cannot, as some have suggested, provide a measurement of the capacity of a cell, they are able to go beyond the other maintenance checks listed here, and provide some assurance against catastrophic battery failure. Although they are not part of IEEE 450-1995, these measurements are likely to be included in future versions as optional measurements. The devices for making internal ohmic measurements are generally quite expensive, but readings can be taken quickly and simply.

ENTER THE COST CUTTERS

With vented lead-acid batteries having at least the appearance of being expensive to maintain, many utilities have started to look for ways to reduce battery costs. Their efforts have fallen largely into two categories: cutting maintenance on existing vented lead-acid batteries, or installing other battery types. In at least some cases, utilities have done both. In fact, one of the biggest trends in the switchgear market is the move towards valve-regulated lead-acid (VRLA) batteries.

THE VRLA OPTION

VRLA batteries appeared on the market in the early '80s. Based on the same electrochemical system as vented lead-acid batteries, this technology provides a means of recombining charge gas, thus eliminating water additions. Since the electrolyte in these batteries is immobilized, it is not possible to take specific gravity measurements. Furthermore, the necessity for gas-tight seals reduces the possibility of terminal post corrosion, thus limiting the need for connection maintenance—if a VRLA post seal is leaking, there is more to worry about than the integrity of the connection.

These three operations—water additions, specific gravity checks and connection maintenance—represent a significant portion of the maintenance performed on vented lead-acid batteries. To make these batteries even more attractive, they were (and are) sold with 20-year life claims and the simplest of maintenance recommendations.

The introduction of VRLA batteries coincided with the implementation of distributed switching equipment by telephone companies. These users were looking for batteries to be installed in remote cabinets, huts and vaults. Because of the large number of these systems, the telephone companies knew that they would be unable to perform routine maintenance operations. VRLA batteries promised maintenance-free operation in a very compact package, so they seemed to be ideal for this application. Purchases of these batteries by each of the Regional Bell Operating Companies quickly reached several million dollars per year.

Another notable early application for VRLA was in UPS service. With most UPS users having a low level of battery knowledge and being thus more likely to ignore battery maintenance needs, the minimalist maintenance recommendations for VRLA were highly attractive. VRLA quickly became the battery of choice in UPS duty.

Perhaps fueled by this high level of acceptance, VRLA batteries have found their way into other applications, including substations. A number of utilities saw this technology as a way to reduce their battery spending, and embraced VRLA.

TROUBLE IN PARADISE

For several years, it has been apparent that VRLA technology has been oversold. Many papers have been published detailing premature failures of these batteries[3, 4, 5], and the consensus is that the highest quality VRLA products have a typical life of 7-8 years under favorable conditions. When used under high temperature conditions, battery life suffers even more than with vented lead-acid, due to the fact that the recombination reaction liberates heat, causing the internal cell temperature to rise still further. VRLA batteries also exhibit failure modes, such as thermal runaway and dryout, which are extremely rare in vented batteries. These facts are at odds with the long life claims and minimalist maintenance recommendations of some manufacturers.

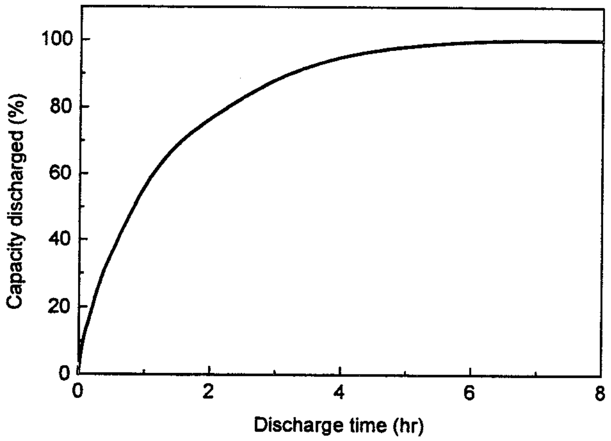

Figure 1 - Battery efficiency

To bring some sense to this situation, the IEEE has produced a recommended practice for the maintenance and testing of VRLA batteries. IEEE Std. 1188-1996[6] is a parallel document to IEEE 450. It is complemented by IEEE Std. 1189-1996[7], which covers the selection of VRLA batteries, including their operating principles and additional failure modes, to help users decide whether to choose them in the first place.

The bottom line is that the reduction in the number of maintenance tasks associated with VRLA batteries comes at a price; their life and reliability are reduced, compared with their vented counterparts. Worse, they are prone to fail in an open condition, either by dryout or through internal failures of the negative straps. To maintain adequate reliability, IEEE 1188 recommends that internal ohmic measurements are made every three months, and that these batteries be discharge tested every year.

To be sure, VRLA batteries have been deployed with some success in the telecom infrastructure, with little or no maintenance. While the telephone companies have had their share of VRLA battery problems, users have been largely insulated from them. With this in mind, it is reasonable to ask, 'If VRLA works for the telephone companies, why can't it work for the utilities?' The difference lies in the method of battery deployment and in the nature of the loads.

Telephone companies typically install multiple parallel strings to support the load, so that if one string fails, there is still some capacity remaining. To understand the operation of parallel strings requires a discussion of battery efficiency. Figure 1 shows how the efficiency of a typical battery varies for different discharge times.

Most batteries in telephone service are sized for 8 hours of operation. In a 2-string system designed for 8 hours of operation, the failure of one string effectively doubles the load on the remaining string. Since there is relatively little change in efficiency over the 3-8 hour range, the remaining string will support the load for just under 4 hours. As the discharge time becomes shorter, however, changes in battery efficiency are much greater. For substations, the critical load that determines the size of the battery is the switching load, which is less than one minute. At this point, the battery efficiency is changing so rapidly that a doubling of the load will reduce the discharge time virtually to zero—the remaining string simply cannot support a load of that magnitude.

Thus, we have a situation in which the normal utility philosophy is to install a single-string battery in a substation. For the VRLA product, this practice leaves the system vulnerable to battery failure in an open condition. Splitting the battery into two half strings, as is done by telephone companies, does not help in supporting the critical switching loads. The only sure way to safeguard these loads is to install fully redundant strings—hardly an effective way of saving money.

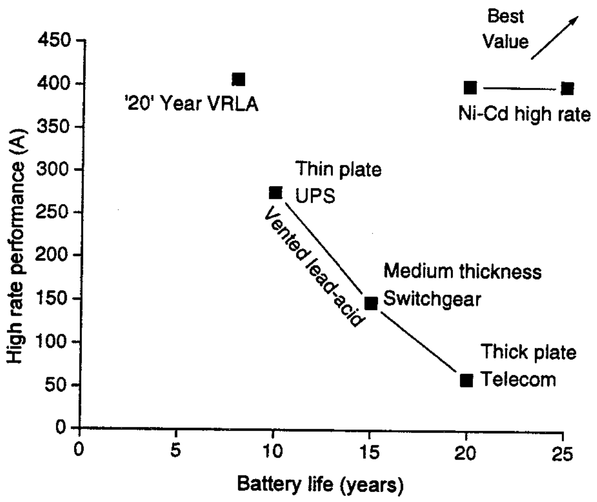

Figure 2 - High rate performance

With this in mind, it is the author's opinion that the use of VRLA batteries in substation duties represents an unacceptable risk to the system that those batteries are intended to protect.

NICKEL-CADMIUM FOR HOT JOBS

Many US users are unfamiliar with nickel-cadmium (Ni-Cd) batteries, although they have been in production since the turn of the century and are quite common elsewhere in the world. They have a higher initial cost than their lead-acid counterparts, but this is offset by their long life and simple maintenance requirements. Recommendations for the maintenance and testing of Ni-Cd are contained in IEEE Std. 1106-1995[8]. While they are often not cost effective in large transmission substations, Ni-Cd batteries come into their own in smaller distribution substations, particularly where high temperatures are encountered, or where high switching currents must be supplied.

On the high performance side, one of the characteristics of Ni-Cd is that the internal steel hardware is unaffected by the alkaline electrolyte, and remains intact throughout life. The positive grids of lead-acid batteries, on the other hand, are gradually corroded away, with the result that batteries with thinner plates give shorter service lives. Furthermore, the initial voltage dip that is characteristic of lead-acid batteries limits their effectiveness for very short discharge durations. IEEE 485[9] for lead-acid batteries recommends that momentary loads be treated as if they were one-minute loads. On the other hand, IEEE 1115[10] allows Ni-Cd batteries to be sized for load durations as short as one second.

Figure 2 plots the 1-minute performance of typical vented lead-acid and VRLA batteries against the 10-second performance of high-rate Ni-Cd designs. The performance ratings are normalized to a rated capacity of 100Ah.

There is a rule of thumb for lead-acid batteries, derived from the Arrhenius equation, that for every 15°F (8°C) increase in operating temperature, the life of a lead battery is reduced by 50%. For Ni-Cd, the corresponding reduction in life for the same temperature increase is only 20%. This effect is cumulative, as shown in figure 3, which compares the life characteristics of Ni-Cd batteries with those of 'general purpose' vented lead-acid batteries used for switchgear applications.

The non-linear nature of the Arrhenius equation means that a relatively short time spent at a high temperature will have a major effect on battery aging[11]. For example, the effects of three summer months spent at 92°F (33°C) will not be offset by three winter months spent at 62°F (17°C), and battery life will suffer as a result.

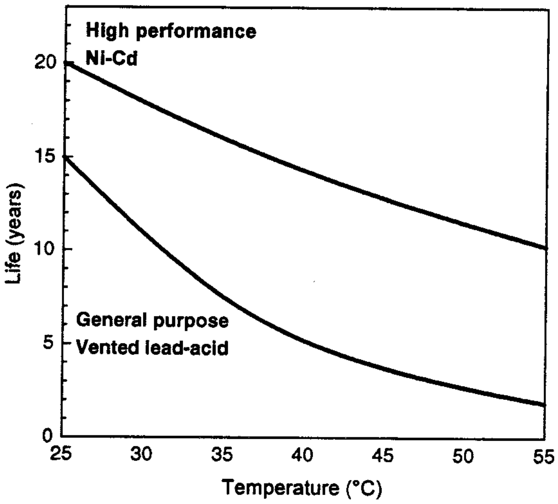

Figure 3 - Life vs. temperature

Thus, Ni-Cd batteries may offer significant cost savings where high operating temperatures are encountered. This will not, however, be apparent in the initial battery price. To realize such savings, it is necessary to consider the overall cost of battery ownership, or life cycle cost. Life cycle costing is the subject of another paper contained in these proceedings[12].

WHERE TO CUT?

In striving to achieve the best results for each battery dollar that is spent, the first thing is to make sure that a cost-effective battery type has been selected. This must be carried out using a life cycle costing approach, since excessive attention to initial cost can lead to *increased* overall costs, due to higher maintenance, poor reliability, or frequent replacement. In general, such an approach will tend to favor vented lead-acid batteries for moderate environments and Ni-Cd for higher temperatures, particularly if high currents must be supplied.

The next area to be examined is battery maintenance and testing. In these considerations, it must be borne in mind that any reduction in the IEEE recommended practices entails a degree of risk to the reliability of battery operation. To minimize that risk, it is important that a reliable battery is chosen, and that it is conservatively sized. Cutting the surveillance of a less reliable battery, or one that is marginally sized, is asking for trouble.

There are two approaches to reducing maintenance costs: increasing the maintenance interval; and reducing or eliminating certain practices. Having a good knowledge of the value of each practice, and the risks involved in its reduction or elimination, will allow a reasoned decision to be made. Other factors to consider are the inherent reliability of the battery, the margins involved its sizing, and the criticality of the load.

The maintenance interval might reasonably be doubled, given favorable past experience with the battery type involved. This decision would be much easier to make if a capable battery monitor were installed. Such monitors are not inexpensive, but their cost can be more than recaptured by the maintenance savings that they allow.

Looking at the procedures themselves, it is probably safe to dispense with quarterly specific gravity readings, assuming again that the user has had good experience with the batteries in question. It is also recommended that the practice of taking annual readings be retained. To minimize operator error and reduce reading time, it might be worth considering the purchase of a digital hydrometer. For a utility with a large installed base of batteries, the time saved would make this an excellent investment.

Devices with datalogging capability for float voltages and other functions are now available. These can streamline the process of recording data and can allow information to be uploaded to programs that analyze the readings and provide warnings for values that are out of tolerance. Care should be taken, however, not to overreact to wide float voltage spreads. As mentioned previously, reference electrode readings may show that such spreads are harmless.

Connection resistance readings are easy to take, given the right equipment for the job. Some of the devices for internal ohmic measurements have specific provisions for making these readings (and all can be adapted for the job, in one way or another). It is therefore possible to 'kill two birds with one stone,' and perform these measurements together.

The very real benefits of battery discharge testing were discussed earlier in this paper. However, if it is decided that it is simply not possible to support the costs of such a test program, it is important to try to fill the gap somehow. While ohmic measurements are not a substitute for capacity testing, they will at least allow severe problems with lead-acid cells to be isolated, particularly those that cannot be seen from voltage or specific gravity readings. Although internal ohmic measurements are not a recommendation of IEEE 450, the elimination of discharge testing, which is a central pillar of the document, makes these measurements all the more important.

Ohmic measurements are of little use with Ni-Cd batteries, since the internal hardware does not degrade over time. However, this also means that these batteries are not subject to catastrophic failure, so there is less need for such measurements.

CONCLUSIONS

The central arguments of this paper can be summarized as, 'You've got to spend a buck to save two.' Concentrating on batteries with a low initial cost makes the system more vulnerable to battery failure, and increases the need for surveillance. Since cumulative maintenance costs can easily exceed the initial battery price, this is obviously not a good idea. The aging characteristics and failure modes of VRLA batteries, in particular, make them poorly suited to switchgear operation.

The first rule in saving battery costs in this application is to install a reliable battery. For moderate operating conditions, this will generally be a vented lead-acid type, while nickel-cadmium should be considered for more extreme environments. A life cycle costing approach will give a good indication of which type will give the lower overall cost of ownership. Only when a reliable battery with an established track record has been installed, is it possible to turn to possible savings in maintenance and testing.

Fine-tuning of the maintenance program will yield some savings, such as the elimination of quarterly specific gravity readings. Based on prior experience with the battery in question, it may also be possible to increase the maintenance interval. However, the realization of major savings without compromising reliability can only come about through additional investment. The biggest savings can be made through the installation of a battery monitor, allowing an extended maintenance interval. Beyond that, purchasing a datalogging voltmeter or other battery-related device, particularly with a digital hydrometer, will increase accuracy, reduce maintenance time and reduce record keeping costs.

Although discharge testing is highly recommended, many users will decide that they cannot afford to do it. In this case, with vented lead-acid, the next best thing is to adopt a program of taking routine internal ohmic measurements. Again, these devices are not cheap, but they do allow catastrophic battery failure to be averted.

It is certainly possible for the wise battery user to save money without jeopardizing safety or other equipment. This requires a holistic approach to batteries, considering not just the choice of battery type, but also the benefits of the various maintenance and testing operations and the potential cost of battery failure through inadequate maintenance. The balancing of these factors can be made easier by the broad array of new battery maintenance tools that are at the user's disposal.

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