Reducing Battery Maintenance Costs Through Enhanced Charge Control and Improved Testing and Monitoring Techniques

Daniel C. Cox
Midtronics, Inc. USA

Abstract:
This paper will introduce readers to field battery audit results from a managed case study of two very different Outside Plant (OSP) battery installations. The field data is being developed in high temperature climate locations but the relevance is not limited to a high temperature scenario. This paper will include both laboratory and field data that illustrate how economies can be achieved through appropriate charge control and simplified battery analysis techniques used in conjunction with regular scheduled maintenance activity. Additionally, we will present data obtained from an installed automated battery monitoring system capable of providing the necessary insight for understanding what direct field activity may be needed and at what intervals. Maintenance programs are designed to support and ensure some minimum system performance objectives. We will compare the designated site performance targets against the actual measured performance observed at these installations and report our preliminary conclusions based on this data.

The Original Test Plan

Battery manufacturers and others have published studies showing the decline in battery service life based on the destructive affects of high operating temperatures**.** Rapid battery failures have been more prominent in populations of Valve Regulated Lead Acid (VRLA) batteries in part because of the large numbers of VRLA batteries installed into uncontrolled environments. The optimum recommended operating temperature for most lead-acid batteries (depending on the manufacturer) range from 20°C to 25°C. It is understood that a stable operating temperature is not realistic in most OSP applications, but this is an issue related to the battery life expectancy.

In our study, the company operating the equipment relies on outside contractors to do scheduled battery maintenance and battery replacements. According to their current practices, maintenance activity actually refers to simply replacing installed batteries with new ones on a four-year rotational basis. This replacement strategy was believed to guarantee acceptable field performance. However, the field experience to date has been well below the standard they consider acceptable based on repeated outages in certain locations.

The Installations

Valve Regulated Lead Acid design batteries have experienced what has come to be known as Premature Capacity Loss or PCL. The PCL phenomenon is often associated with water loss in VRLA cells. Water loss is accelerated in batteries operating in high temperatures and is a critical factor in forecasting loss of battery service life. **[1]** PCL in VRLA cells has been a dominant topic of multiple battery user conferences in recent years. Our plan was to study nine strings of 12 volt, 25-Ampere Hour batteries being removed from service to identify what extent PCL could have affected their discharge capacities. Our original intent was to look only at the batteries being removed from a Controlled Environmental Vault (CEV). However, while doing some related field site testing with a conductance battery tester, we identified an above ground equipment cabinet with what appeared to be a seriously failed 6-volt battery.

These equipment installations are located in Florida. The OSP site was an above ground equipment cabinet housing three parallel 48-volt battery strings, which were housed in the equipment bay. The 48-volt battery strings were made up of eight, 6-volt mono-blocks in series. All of these battery samples were rated at 125 Ah, and had matching February 1999 manufacturer date codes. Site records indicated that they were installed within two months of their manufacture date. The initial test data was being taken in May 2001, which meant these samples had been in service for just over two years. With one mono-block measuring "*zero*" conductance, the site managers' decided to replace all 24 batteries immediately. It was believed that whatever caused this one cell to fail dramatically, could potentially happen to the remainder of the cells.

All of the installations observed had one rectifier with no temperature compensation capability. Temperature compensation is used to regulate float voltage to an appropriate level based on the battery temperature. When we made our observations at the OSP site, it was early morning with an outdoor ambient temperature of 29°C and the power plant was set at 54.28 volts. Battery temperatures, however, were measured between 38°C on the string mounted in the lowest position in the cabinet and 42°C measured on the top string. An infrared, non-contact thermometer was used to measure in-cabinet temperatures and this temperature stratification points to the obvious need for improved cabinet ventilation. This high battery temperature was believed to be the residual from daily ambient heating conditions and from heat generated by the equipment. This observed float voltage is much higher than the battery manufacturers recommendation for VRLA batteries operating at these temperatures. With no forced air circulation and only minimal convection circulation, elevated temperatures should be expected.

This high air temperature issue is part of the overall problem that will need to be addressed before any substantive battery life cycle performance improvements can be expected. **[2]** Annual temperature data from a similar OSP cabinet is shown in **Figure 1.** Although this data is not the exact location now under review, it is from a similar cabinet installation and climate location and therefore representative of what we expect in this site.

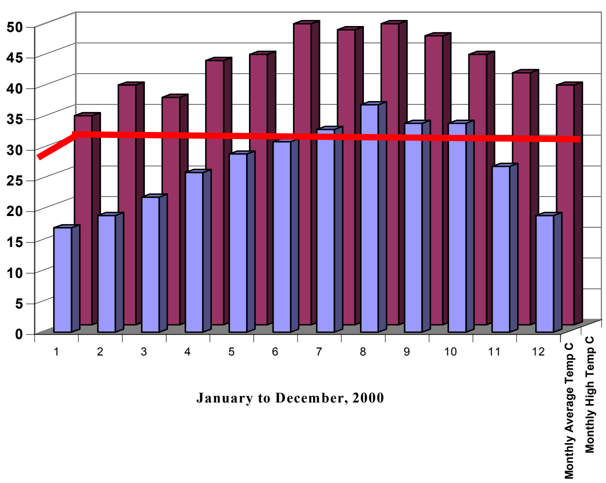

Figure 1: OSP Cabinet Annual Temperature Data

Data Collection Method

Ideally, all installed battery samples would have been capacity tested immediately as they were taken off line. With practical limitations however, the batteries were transported back to Midtronics laboratory and were placed back on float charge. The float charging was done at the manufacturer's recommended value of 2.25 VPC in a 24°C ambient environment. No attempt was made to equalize or boost charge any of the samples so the conditions would match as close as possible to actual field conditions. All batteries were float charged for a minimum of 24 hours before being capacity tested. Each battery was cataloged and kept in string sequence so the capacity testing arrangements would match the field conditions. Two tests were actually run on each battery. First they were discharged individually to document specific capacities. After recharging, the 48-volt strings were re-assembled and then string capacities were observed. It is fair to say that a wide variation was observed in individual battery performances.

The battery manufacturers 3-hour capacity ratings were used to establish the constant current discharge rate. The discharges were run at 7.5 Amps and 37.0 Amps respectively for the 25 Ah and 125 Ah batteries. String performance loss was most dramatic in the 125 Ah string containing the single "zero" Siemens battery. The obvious capacity failure was predicted by the low conductance reading. The string capacity performance indicates a failure that could have been described as catastrophic. If field equipment were operating with a single battery string with this module in it, there would have been the potential for this type of a catastrophic failure. These are the battery failure that can make local news headlines. The relationship between the measured battery conductance and the discharge capacity was obvious.

When we looked at the actual site load conditions, the per-string current load would have been relatively low. The actual equipment load in the site with the 25 Ampere-Hour batteries was very low. We measured a mere 1.5 Amps per string, which would calculate to nearly 20 hours of battery reserve capacity. The OSP cabinet had an equipment load of just over 15 Amps, placing just a 5 Amp load on each string presuming they were delivering equal amounts of power. These run time calculations presume the installed batteries were capable of delivering 100% of their rated capacities. Without de-rating for low temperature operation or aging, these systems would function on one healthy battery string for longer than the specified 8-hour run time.

Field Audit Results

Initially, both individual battery performance and battery string performance capabilities were to be documented in this exercise. Prior to removing any batteries, every individual mono-block was conductance tested to establish a baseline. With the measured conductance, we would then compare that data to the specific discharge capacities. Ultimately, the most significant focus of our testing would be to record the string discharge capacities and then compare that performance to the power demands of their equipment loads. With batteries installed as part of a system, we felt it was more relevant to compare how the system would perform, and not just what the microscopic view or each individual battery load capacities would be.

The main objective of the string capacity testing was to gain some insight into how reliable the batteries being removed from service actually were. With the corresponding conductance data, minimum performance levels could be established by comparing the two data sets. **[3]** We wanted to quantify any available economies that would result from only replacing batteries testing below a minimum conductance level. With this kind of data, future replacement decisions could be done by passive conductance testing in lieu of capacity testing or scheduled replacements, presuming the data was statistically viable.

Replacing batteries with significant remaining capacities and service life is expensive. Companies with large numbers of installed batteries find actual capacity testing each battery string on a scheduled basis almost impossible to manage. Scheduling the properly trained personnel who have the necessary equipment to complete the full capacity testing may not be realistic with work force reductions and corporate philosophies focusing on "costs". The conductance testing was done to save time and to give an indication of how many batteries could be identified with enough reliable capacity to remain in service.

Design Site Performance Levels

Site performance requirements were uniform in all locations. Each site specified a minimum of eight hours battery backup was required. The first logical step was to compare the rated capacities of all installed batteries for the sites to see how well provisioned they were compared to the site load profiles. These systems were operating at 48 nominal volts, using either two or three parallel battery strings per equipment bay. Our test data will suggest how many batteries could have been considered "serviceable" based on the site power demand. Remember that only the 25 Ah batteries were initially scheduled for replacement, and yet the 125 Ah batteries were the ones most likely to have a performance problem based on the conductance test data.

In **Figure 2,** we show the test results for the 36 individual 25 Ah batteries that were removed from service. These examples are ranked in descending discharge or run time order. The corresponding measured conductance is shown with the parallel descending line on the same plot. Although "percent of relative conductance measurements" are not intended to be used interchangeably with "percent of discharge capacity" performance results, the relationship and trend is undeniable. This relationship has been shown in previously published technical reports and is again supported through this field experience. **[4]** High relative conductance batteries had greater reserve capacities, and visa versa. This is where we felt some realistic economies could be developed.

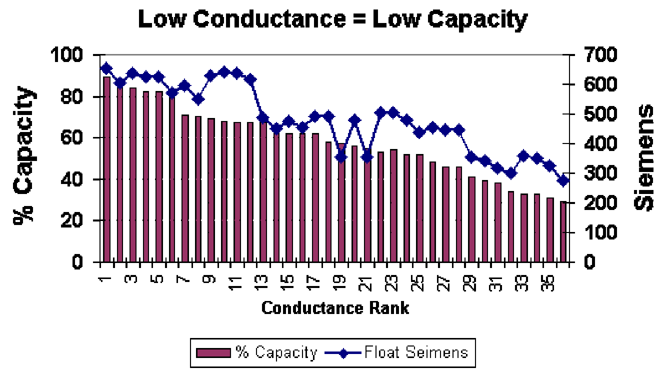

Figure 2: Capacity/Conductance Data for 25 Ah Batteries Removed From CEV

Figure 3 illustrates the discharge performance of one of the 125 Ah battery strings, which as a system delivered less than 3% of the rated capacity. All three of these 125 Ah battery strings were removed from the cabinet as a precautionary measure. This cabinet operates in full sun light every day where it routinely experience high operating temperatures. As the temperature data in Figure 1 indicates, this installation should expect operating temperatures in excess of 35°C virtually all year long with the potential for seasonal highs in excess 50°C. This factor alone will cause accelerated aging of any battery installed under these conditions.

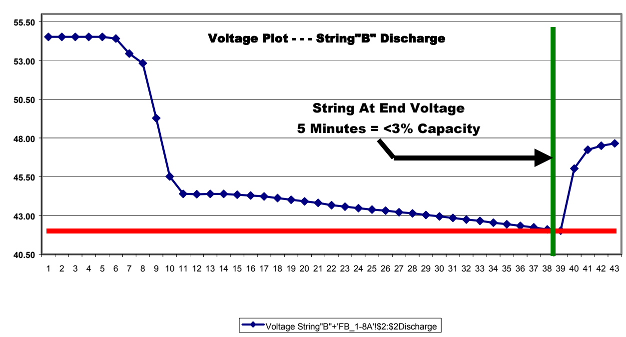

Figure 3: 125 Ah = String Capacity Failure

By contrast, the four-year-old 25-Ah battery samples were operating in the temperature controlled underground vault. With the CEV being temperature controlled, those batteries would never experience the wide variations in conditions seen in the OSP cabinet. There were no surprises when we looked at the performance variations between battery discharge data from these two very different types of installations. The 25 Ah batteries delivered capacities as high as 89% to a low of just 30% of the rated capacity. Although not ideal, there was a predictable slope we could identify regarding the capacities relative to the measured conductance. The two-year old OPS batteries had a much broader performance range from the rated capacities. We found capacities ranging everywhere from 103% down to essentially "zero" capacity. The zero conductance battery went to an end voltage of 5.25 volts in less than 30 seconds. This is not exactly the battery performance you would choose to protect your company's economic future. This single bad battery in the string was the main reason we saw the string voltage collapsed down to 42.00 Volts in less than 5 minutes.

New Battery Capacity Testing

The following information shows some of the first data taken on the new batteries in an extended field study to identify the actual operating conditions at representative sites in Southern climates of North America. The battery operating temperature is only one aspect of what will influence the life expectancy of the battery systems. Ongoing battery performance data from the newly installed batteries will continue to be acquired throughout their service life. These capacities without-regard to the operating environment, at least at the eight-month mark. As a part of these trials, we anticipate collecting additional battery discharge capacity data periodically in the future to assess the rate of capacity loss being experienced and also to continually assess actual system readiness.

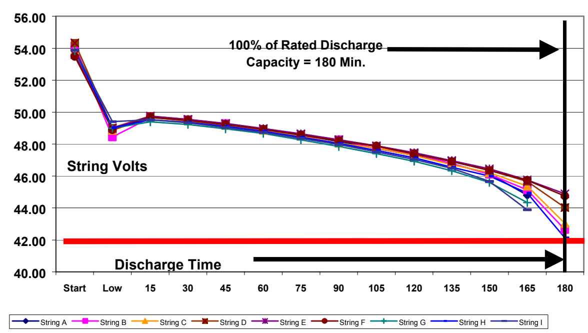

Figure 3. **New String Capacities**

Where Are The Savings?

The 25 Ah CEV batteries were being exchanged with identical battery types. When testing new battery samples from this manufacturer, 700 Siemens is the measured values we typically see on averages, which we suggest is an appropriate reference conductance for these batteries. To maximize the service life from the installed batteries, we theorized that all the batteries with at least half the original measured conductance could be used in a parallel battery system to successfully support these field loads. Statistically, that suggests more than 70% of the batteries removed from the field could have remained in service for at least one more year with no significant performance risk to the systems. As a practical matter, the system operator could have been a bit more conservative and raised the conductance cutoff point to guarantee some additional protection. Based on these measurements, if replacements were only done on batteries that measured less than half the 700 Siemens reference conductance, this would mean everything testing above 350 Siemens could potentially have been left in service. Based on these test results and the established analysis criterion, more than half of the battery replacements done in this sample could have been deferred for at least one additional year of service.

The point of this effort is to show that there is a huge difference between doing a minimal amount of managed battery maintenance and testing, compared to arbitrary product exchanges. By revising the company policy to exchange batteries in every CEV on a four-year basis, this was the ongoing expense the operator hoped to reduce. Additionally, it is apparent that uncontrolled sites need additional attention to prevent serious field capacity failures. The arbitrary replacement approach would have been perfect if the process eliminated all problem outages. That had not been the experience.

The 125 Ah batteries were not scheduled for replacement until after another two years of operation. In spite of that schedule, the magnitude of the single gross battery failure was easily identified with a passive test that took less than ten seconds per mono-block to complete. It is important to mention that while first observed under float conditions, the one battery identified as being seriously failed measured 6.74 volts zero Siemens. This would not have caused any suspicion or concern on the part of a maintenance person if they were only taking cell voltages.

Cost Justification

The cost for maintenance is always hard to justify, in particular if there have not been any recent specific problems to respond to. In North America, we have one of the most reliable systems of electric power generation, transportation and distribution networks anywhere in the world. This highly reliable power delivery system helps minimize the overall risk of any major power disturbance or interruption. Even so, the electric power distribution network relies on its own set of batteries to perform automated switching functions, radio communications and emergency lighting for power control rooms. The nuclear industry in particular has a set of mandatory rules governing what to test and when to test based on the proportionate risk of a failure in a nuclear plant. Senior managers in the communications industry can easily rationalize, "If nothing blows up or falls apart causing a system outage, we must be doing enough maintenance." Nothing could be further from the truth.

Effective maintenance programs are the cornerstone of successful service delivery and ultimately required for controlling the total cost of operation. Nuclear Power sites for example, must adhere to stringent rules to test specific battery requirements along with other site testing. This includes generating mandatory reports on system performance levels and conditions to both company officials and government agencies. Taking risks associated with non-performance in a nuclear application would be unacceptable. By contrast, companies that operate a small building UPS system with no critical loads attached have a bit more flexibility in terms of how they do maintenance on their battery back-up systems compared to what is required in nuclear power installations. Most communications providers needs fall somewhere between these two extremes.

The precise financial impact is hard to predict without either knowing the exact business costs associated with your maintenance program or by making some general assumptions. What will be more relevant is to identify the actual site performance profile minimums your organization and your customers consider acceptable. If these expectations are not fairly close to one another, you may already be in trouble. This analysis should start with a site audit identifying the power requirements, and then comparing that data to the rated discharge capacity of the installed batteries. From there you still need to identify the relative performance capability of the installed batteries. Using this information, a reasonable risk assessment can be made and a plan of action can be based on that.

Conclusions

- Not all batteries being replaced lacked sufficient capacity to function successfully in their applications.
- Each application has unique performance requirements and the challenge is identifying exactly what those performance minimums are.
- Battery operating temperatures must be managed at some minimal levels to gain meaningful service life.
- There is an ongoing need to support the cost of doing maintenance in order to guarantee service quality and protect the operating company's revenue path.

1. Water Loss in Valve Regulated Lead Acid Batteries by C. Bose, proceeding of INTELEC, 1999, paper 4-2.

2. Improving Life Expectancy of VRLA Batteries Installed in Outdoor Cabinets, proceedings from BATTCON 2001 by J. Zulaski, pages 6-1 to 6-10

3. Battery Performance Monitoring by Internal Ohmic Measurements, by E. Davis, D. Funk, EPRI Final Report TR-108826, page 2-19 dated December, 1997

4. Design, Operation & Safety Overview of VRLA Batteries in Telecommunications Applications, by S. Rosellini & G. Lodi, proceedings from BATTCON 99, pages 9-1 to 9-6

5. Impedance/Conductance Measurements as an Aid To Determining Replacement Strategies, by M. Kniveton & A.I. Harrison, proceedings of INTELEC 1998, pages 297 - 301