REAL WORLD RESULTS WITH VRLA BATTERIES IN THE UPS ENVIRONMENT

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INTRODUCTION

For many years batteries have been poked, prodded, measured and monitored. This paper presents a comprehensive high level performance review of many thousands of VRLA batteries over the period 2004 to 2011. The relative performance, parameters and modeling of the battery data is presented. A modeling and telemetry system example is detailed to demonstrate how continuous resistance measurement provides excellent indications to state of health and manufacturer variances, including indications of premature failure and field events that cause erroneous data. We detail best practices in place that have resulted in over 1 Billion hours of availability since 2006 with 100% availability.

SYSTEM DESCRIPTION

As reported previously and since 2005 our team (1) has been preserving telemetry and on site performance details on many thousands of stationary batteries installed for UPS (Uninterruptible Power System) duty across North America, now consisting of more than 40,000 strings. This paper presents a field-derived analysis of the performance of a subset of these batteries. Data presented is limited to VRLA batteries, typically 12 Volt units; however we utilize 2, 4, and 6 volt units of VLA and VRLA construction using the same techniques. By collecting battery telemetry over a long period of time (often 2 or more cycles of string replacement) in real world use they can be characterized with very few modeling terms. The charts and data presented are gleaned from approximately 10 million temperature, voltage and internal resistance measurements for TWO very similar battery types. From a macro level, office and field colleagues (many hundreds of them) have been recording parameters in compliance with IEEE standards (2) and following additional measurements to our own requirements and best practices as part of a comprehensive battery maintenance, lifecycle management and reporting system. By policy, we measured many parameters, with each electrical inspection represented. For the performance series and this study, we have only reported and concerned ourselves with the following key data points:

- Environmental temperature
- Negative post temperature
- Voltage across the battery Jar at full charge (float)
- Frequent internal resistance measurements
- Initial baseline Resistance

As part of our own best practices, customers whose batteries are significantly above 77°F are advised during each inspection that the recommended temperature is above limits, and we implement remedies to bring every string into compliance with this maximum temperature.

Also, as part of our inspection and maintenance process for the UPS systems, we strive to float charge batteries at the manufacturers' recommended values, and again, when outside these values, we work closely with our customers to bring all strings back to within policy.

We enjoy the benefit of a well-trained and educated staff, which has resulted in 99.6% compliance based upon inspections. Having such a well-defined set of data collected for battery jars has resulted in providing us the ability to track how any given unit performs over time. The primary indicator of battery state of health we have chosen to use is internal resistance (3).

STATIONARY AND PORTABLE INSTRUMENTS

Permanently-installed resistance, impedance and conductance measuring systems have continued to gain market acceptance in recent times (4). This paper does not seek to dissuade the reader from any particular instrumentation approach, but that stationary resistance instruments are a key element in our particular process. Battery voltage-type monitors are an alternative popular methodology, as are float current and temperature-only monitoring and may be installed for alarming purposes. However, these systems do not provide an indication of battery health (1) in UPS, high voltage, high unit count implementations. These alarm-based systems were not considered suitable for increasing availability, while resistance and conductance methods do provide an indicator of battery state of health data, particularly when data is compared over the full lifetime of a given unit and compared against an initial baseline. Permanently-installed battery management systems utilizing a resistance, impedance or conductance meter have become more commonplace in 30 kVA and larger UPS systems (8). The derived data and assertions below demand a very accurate unit-specific, in-situ baseline resistance and periodic subsequent resistance readings.

Portable instruments are a key element of system data delivery in the described process. Portable instruments are utilized to confirm telemetric data from the stationary instrument and provide initial data in support of a battery unit's initial baseline if the stationary instrument was not installed during string startup. The portable instruments utilized provide the same values of internal resistance (in μOhms) as a stationary instrument, but are less repeatable due to their portable nature and variances (1). Finally, a key element in maintaining the highest availability from a battery string is an in-person physical inspection. Some failure modes are visible through inspection well before they affect the performance indicators that are measurable remotely from the battery. For example, a leaking post seal is obvious through inspection, but only affects the internal resistance as that leak begins to cause internal dry-out.

Finally, stationary instruments are a key necessity in the analysis modeling due to the frequency of measurement that is possible and the very high degree of repeatability they afford (1).

The full end-to-end telemetry gathering system consists of the elements detailed in figure 1. Each battery unit is connected to a resistance and voltage measurement instrument. Resistance and Voltage tests are conducted periodically, typically 15 days or 30 days between readings. Field data is stored and analyzed through three independent systems (4).

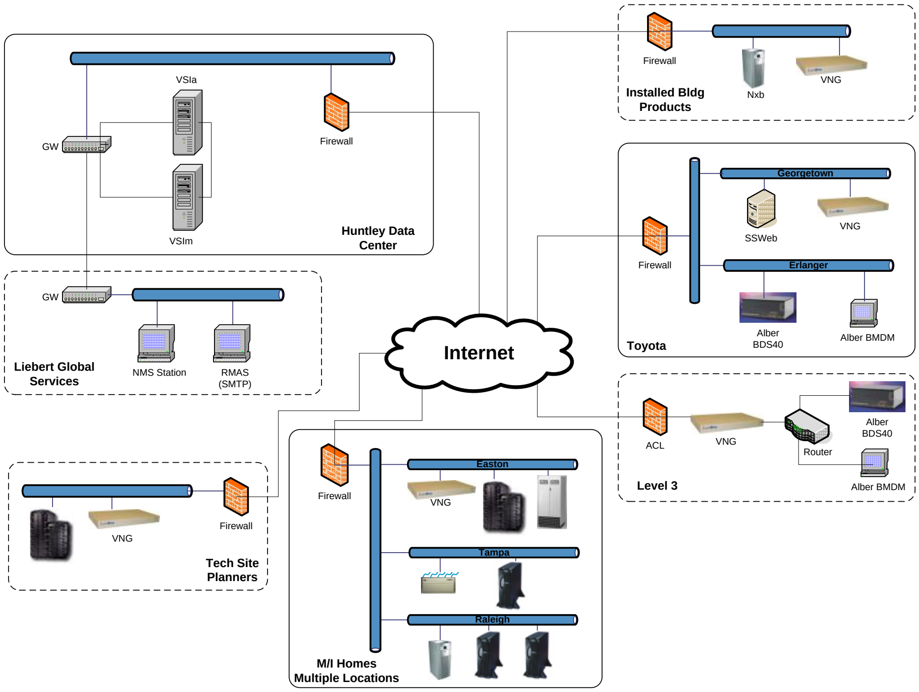

Figure 1. Full End-to-End Telemetry Gathering System

First, all remote real-time data is transported securely to a portfolio database. This database stores resistance tests and associated data sequentially so that through automation, notifications are generated for resistances that have climbed 25% or more over their initial baseline. Alarms are generated at 50% over the initial baseline. This database is also the portfolio database that is utilized for the polynomial creation described later.

A second database is located on the customer network and provides localized storage for a large amount of real-time telemetry, specific set points and recording of live events where the batteries are delivering energy. This database contains entries during a UPS event every minute, recording the loaded voltage profile of the battery units as they are discharged. Customers experiencing an outage may track the actual performance of their battery string during discharge and recharge.

A third database contains each field inspection data entry, field staff observations, the key values collected via portable instruments and any remedies implemented during the lifetime of each battery unit.

Together the analysis that follows is based upon more than 250,000 string analyses. The strings are typically 40 units of 12 volt VRLA, 80 units of 6 volt VRLA, etc. This equates to more than 10 million individual data sets across more than 2,000 battery unit types.

These three data systems are utilized by a team of battery experts who monthly examine data from each string. In turn, the analysis teams are alerted to examine further those strings and units whose state of health indicators have changed from previous readings or initial baselines. The data derived from the back end systems provides both alerts and confirmation of the failure and data integrity once an issue is uncovered. No strings or units are changed without a confirmation by an analyst.

LESSONS LEARNED

Processes executed by humans occasionally contain errors. Instruments ultimately fail and require calibration. We have found that automatic telemetry systems often just keep on recording without regard to the integrity of the data provided. A key element in separating out usable telemetry on battery health was based upon surprises encountered in the inbound data streams from the three paralleled data collection engines described previously. Each source of error-filled data is examined.

A stationary instrument is often directly-affixed to the battery cabinet or located in a rack shelf near the batteries. Harnesses are attached from the stationary instrument to each battery. Instruments provide and publish the acquired data with the appropriate signal level filtering, isolation and frequency response for good performance. However; analysis of our data streams have indicated that a great many outside (often human) based influences can reduce the quality of the acquired data. Each of these influences must be accounted for in post processing and workflow process to return the data to full integrity, and, most importantly, so that the data can be examined across the portfolio of units, manufacturer and models in the field.

First, when an on-site battery inspection is performed, or a service event occurs, it is possible to disrupt, disable and skew results provided by the data collection instrument(s). Voltage sense wires from battery units are smaller in diameter and thus are more easily damaged than current-carrying cables. Unless the field engineer is both aware of the implications of their actions and trained to confirm perfect operation of the stationary instrument before they leave the site, it is possible to cause acquisition errors. From a field technician standpoint, there may be no indications visually. From a data standpoint errors are very obvious. We have found that if the *dr*/*dt* (change in resistance over time) of the inbound resistance changes instantaneously, then it is likely the data acquisition system has been compromised for that channel. Figure 2 below exemplifies this kind of fault from a real world incident. As is readily visible, the slope of the resistance is very high. Ideally, the field engineer self corrects the issue. In this case a follow-up on-site visit was required to reseat the telemetry connection; obviously not an ideal situation.

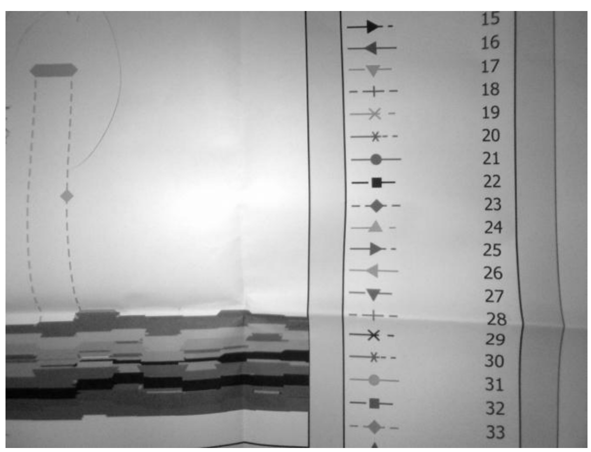

Figure 2. Fault from a Real World Incident

A second cause of loss of data integrity includes issues related to processes, which in turn causes a breakdown of the tight coupling required between field staff operations units, field engineers, instruments and the analysis teams. Telemetry systems are examining data from a collection instrument by channels regularly and periodically. It is absolutely mandatory that the instrument and analysis team be informed immediately if a battery is changed as part of the service event process.

Also, if a battery is replaced, the data from the removed battery must be archived and a new baseline resistance established, including a new age of battery or the manufacturer's date code. If a new battery is put in place for cause, then often the *dr*/*dt* (change in resistance over time) will be largely negative. Figure 3 details an example of a battery change in resistance that is typical for 70 Ah VRLA batteries. Note that this battery's initial baseline resistance will likely settle near 5250 uOhms. Figure 3 also details an excellent example of why it is important to begin initial baseline consideration 90 days after installation. This is typical of our results for many battery units and this has caused us to reject manufacturer-provided baselines. When a specific unit settles to its running baseline the initial variance from manufacturer's baselines is shown to vary by as much as 25%. By our policy if we are engaging analysts at 25% over initial baseline and a given manufacturing line is trending 25% high, this leaves no buffer before alerting the analysis team and our customers.

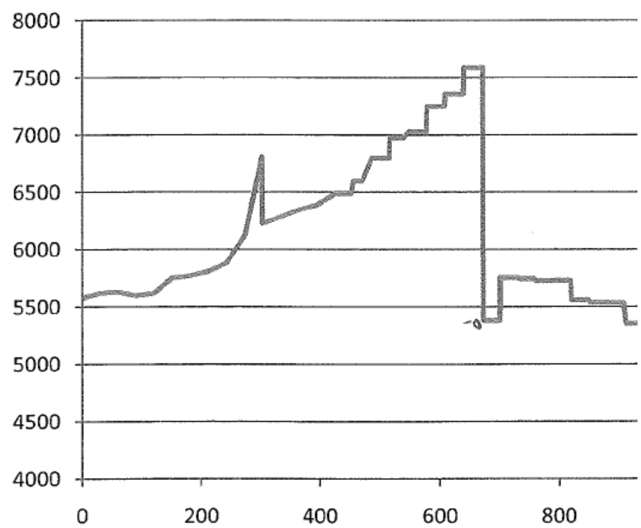

Figure 3. Typical Trending Results for Some Battery Units

Third, when it becomes necessary to service the collection instrument or perform periodic maintenance and calibration, then the incoming data changes together as a set. This requires a correction of inbound data often determined by the construction and architecture of the measurement instrument. For example, if a particular hardware design is based upon 16 channels on a single circuit board assembly, four boards to a system, the errors associated with inbound data will likely change in groups of 16 when repaired or serviced. Calibration changes also directly affect returned values. Initially, observing the inbound data shift with calibration events was unexpected by our analysis teams. Although calibration changes are very small and unnoticed in a single channel's data stream, taken together they are easily observed and accounted for. Figure 4 below details an example of a 40-unit calibration performed on an instrument with 40 channels, with a calibration change of 0.5 to 2.0%. From a policy standpoint, and in order to preserve baseline values, we have chosen to "push back" all calibrations to the T=0 (first baseline reading) by the most recent test calibration factors retrieved. For example, if T_0 resistance was 5542 μOhms on battery unit 3, channel 3, and at day 632 we recalibrated the instrument causing a 200 μOhm shift upwards, we would calibrate our baseline resistance comparison upwards by 200 μOhms also. The new calibrated baseline resistance of Unit 3, channel 3 would become 5742 μOhms. This results in an instrument value of 5742 * 1.25 = 7177 as the new warning alarm threshold requiring analyst team investigation. As a side note, we have taken care to never change the accumulated and preserved data on our databases, only using these calibration factors for analysis as presented here.

Together operators, field engineers and analysis engineers have demonstrated 100% uptime and availability since 2006 with over one billion hours of runtime across more than 40,000 strings. There are several key elements of this comprehensive approach which has yielded such high availability.

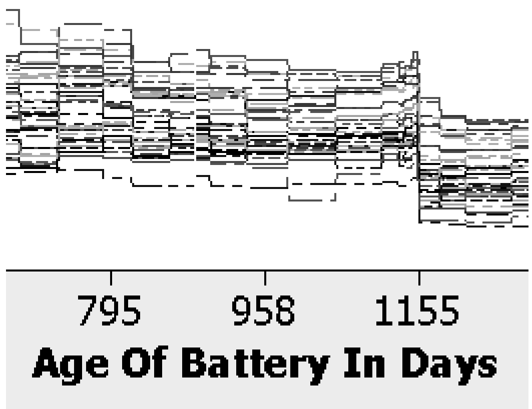

Figure 4. Battery Deterioration in Days

RESULTS

Batteries that are failing are quickly identified and removed from service. It is very important for UPS service batteries that the float voltages are kept at the appropriate levels for each and every unit. A battery that is beginning to fail causes an imbalance that adversely affects the life of the other units in the string.

We have found that battery baselines vary far too much to utilize published resistance values. Our process of installing the battery string, observing the resistance as the battery “forms” and establishing a system baseline for that particular installation, battery type and instrument are necessary to producing repeatable, verifiable telemetry comparisons. We then calculate a percentage resistance rise over initial baseline as our key metric of battery health through automation. The graphical rendering of a string’s performance over the entire lifetime on a single page since “zero day” for engineers and analysts on a string basis allows experts to quickly determine if further actions are required.

This graphical representation provides a backup confirmation to maintain a high confidence in the remote telemetry system. New batteries, forming batteries, damaged wires and updated instruments are portrayed graphically and help provide guidance and insight to our staff for the entire life of the battery string. These representations also quickly identify our own mistakes.

CONCLUSION

Knowing how an entire portfolio of batteries performs in a real world application has enabled a very high demonstrated level of availability. This is only possible with in-person physical inspections, stationary instruments producing very repeatable results and an analysis system supported by skilled engineers working collaboratively. The end resultant benefit has ultimately resulted in longer battery utilization and real dollar savings in operational uptime for critical facilities operators.

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Works Cited

1. Ratcliff, G. *A Comprehensive Management Approach To Maximizing Ups Availability .* Battcon Conference Proceedings 2011 paper 15-1

2. IEEE 1188 *Recommended Practice for Maintenance, Testing and Replacement of Valve-Regulated Lead-Acid Batteries*

3. Albér, G.. *Ohmic Measurements: The History And The Facts.* Battcon Conference Proceedings 2003, paper 1.

4. Furlong, T. *Yes...Internal Cell Resistance Measurements Are Valid.* Battcon Conference Proceedings 2000, paper 3.

5. Donato, J. *Real-Time, Remote Monitoring Key to Optimal Battery Performance*. Battery PowerMagazine, January 1, 2011, pp. 8-9.

6. Emerson Network Power. *The Effect of Regular, Skilled Preventive Maintenance on Critical Power System Reliability.* November 2007 Liebert.com: http://www.liebert.com/common/ViewDocument.aspx?id=852

7. Kiel, M., Sauer, D., & Turpin, P. *Validation of a Nonintrusive Continuous Battery Monitoring Device.* Battcon Conference Proceedings 2008, paper 18

8. 2011, from Microsoft TechNet: http://technet.microsoft.com/en-us/library/bb727041.aspx

9. Stukenberg, T., & Dwyer, T. *Using Conductance Technology To Ensure Battery System Reliability.* Battcon Conference Proceedings 2003, paper 3.