Long term observations of VRLA batteries using conductance.

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Abstract: This paper will show specific data observed on Valve Regulated Lead Acid (VRLA) battery installations in typical telecom locations. This will be primarily a summary of the information obtained through extensive field observations in multiple climate, cabinet design and operating conditions. These data observations and other published data suggest that capacity loss in VRLA batteries can occur at random intervals, which make scheduling maintenance difficult. This is an obvious source of concern if you don't know which sites may need maintenance and when to schedule it.

Because of the apparent random nature of these VRLA capacity failures, there must be a plan to identify problems as they occur (monitoring) and an idea of how to address each problem when found. With that being said, we will show one practical way to actively monitor battery condition, and guarantee the battery strings are in acceptable condition in order to avert any unplanned Network service outage.

I. Objective:

Any study of battery installations should include as much data as possible to form the most complete picture of the factors influencing the battery life cycle. Laboratory studies are capable of producing stressful operating conditions, but the ultimate performance test must be in the field with customer service is held in the balance. Laboratory information is only valuable if it is used to improve component designs, which will strengthen the overall quality of the related network systems. The operational proof is found in the real-life observations of the components in the operating environments where they must fulfill their mission. The "mission" referred to, be to provide service for the paying customers and generate revenue for the company responsible for the site.

One of the most prominent factors shown to reduce Valve Regulated Lead Acid (VRLA) battery life is ***sustained high temperature operation***. The high temperature affect on VRLA batteries causing premature capacity failure phenomenon are referenced in battery manufacturers' published data. [1] Other independent studies also point to the risk of batteries operating at temperatures consistently above 25°C. [2] On site battery temperature must be considered when developing a management strategy to improve overall plant readiness. You can't change where you will be required to provide service, ***but you must add temperature factors into any site development and/or maintenance strategy.***

There is no question, the VRLA design battery has become the most popular battery choice in multiple applications, not just Telecommunications. It is important for anyone involved in power plant provisioning and maintenance to be aware of the performance characteristics of the VRLA battery designs. Analysis of equipment and its suitability for any given application should be quite simple. Virtually every service provider will have a corporate policy or ***service plan*** in place. This plan will define a level of service and the objectives needed to fulfill certain business commitments. By taking time to become familiar with the details of the current company standards, they will be your roadmap for establishing customer service.

II. What site data was observed:

We have had a number of Telecommunication sites under remote observation for an extended period of time to document actual plant operating conditions. Some of our data covers more than 3 years of Outside Plant (OSP) operation. The data collected included battery conductance measurements and battery voltage (in six cell segments), plant float voltage, and battery temperature. These subject sites are from very different geographical areas with various battery and equipment designs represented. The exact details are not particularly significant in relation to content of this report.

The information from these sample sites was obtained using an installed battery conductance monitor. These sites were remotely polled on a regular basis and summary results will be shown here. This battery monitoring was all done without discharging or cycling of the battery in any way. The passive conductance monitoring technique used here constantly update the real-time battery status and the relative state of health of each battery string. That status can then be reported through a host alarm system and action can be initiated when it is needed. The biggest advantage of this type of monitoring is the capability to report battery conductance/condition changes as they occur. This information is critical for managers responsible for site maintenance. With this information, they can logically prioritize needed maintenance activity and technician work schedules. This is powerful information for anyone responsible for managing distributed power systems.

Site Summary: Trending conductance data over time was the first priority of our extended study. We also wanted to show an accurate picture of what VRLA battery life is like in these typical installations. The following data is from four representative sites chosen for this report.

Site A: Description; OSP, Ontario, Canada
Observation period; June, 1996 to Feb, 1999
Battery information;

- Manufacture date - January, 1995
- Installation date - Undocumented
- Design - 3 Cell VRLA, 30Amp Hr Rating
- Float Voltage - 55.35V DC = 2.30 VPC
- Temperature compensated charge - NO
- Highest battery temperature recorded 26°C
- Lowest battery temperature recorded 19°C
- % Loss in string conductance = 15%
- % Change for each 6 cell segment
  1) – 8% 2) - 20% 3) – 13% 4) – 16%
- String capacity = (Test scheduled for 5-99)

Site B: Description; OSP, South West, USA
Observation period; June, 1995 to Oct, 1998
Battery information – String #1*

- Manufacture date - September, 1993
- Installation date - Undocumented
- Design - 3 Cell VRLA, 160 Amp Hr Rating
- Float Voltage - 54.0/54.30V DC = 2.26 VPC
- Temperature compensated charge - NO
- Highest battery temperature recorded 43°C
- Lowest battery temperature recorded 4°C
- % Loss in string conductance = 13%
- % Change for each 6 cell segment
  1) –12% 2) -10% 3) –15% 4) –15%
- String capacity = 104% @ 25°C

NOTE: * We capacity tested Site B, String #1 in October, 1998. This five year old battery delivered 104% of its rated capacity under the manufacturers specified 3 hour load rate to 1.75 Volts Per Cell. String #2 at this site was form the same manufacturer and was the same age, but it had failed badly. Both battery strings were replaced in Oct., 98 as part of a site update. More details on that issue later.

Site C: Description; OSP, Southeast, USA
Observation period; Oct, 1995 to Feb, 1999
Battery information;

- Manufacture date - March, 1992
- Installation date - Undocumented
- Design - 2 Cell VRLA, 125Amp Hr Rating
- Float Voltage - 53.07 to 54.37V DC
- Temperature compensated charge - NO
- Highest battery temperature recorded 49°C
- Lowest battery temperature recorded 5°C
- % Loss in string conductance = 68%
- % Change for each 6 cell segment
  1) – 85% 2) - 59% 3) – 62% 4) – 66%
- String condition = Unserviceable (Failure documented 11/96. Capacity test results in February, 1998 showed string at <30% of rated capacity. These batteries were still in service as of 3/98
- String discharge capacity @ 25°C = <30%

Site D: Description; Customer Premise, NYC
Observation period; Nov., 1996 to Feb., 1999
Battery information;

- Manufacture date - January, 1995
- Installation date - April, 1995
- Design - 6 Cell VRLA, 80 Amp Hr Rating
- Float Voltage - 53.95V DC = 2.25 VPC
- Temperature compensated charge (?) - NO
- Highest battery temperature recorded 29°C
- Lowest battery temperature recorded 20°C
- % Loss in string conductance = 15%
- % Change for each 6 cell segment
  1) – 10% 2) - 20% 3) – 13% 4) – 16%
- String condition = Serviceable
- String discharge capacity (Scheduled 5-99)

III. Site analysis:

Site A; The batteries at Site A are being float charged at a voltage slightly above the recommended level. With relatively low site operating temperatures and relatively good battery health [3][4], we expect this battery to perform at an acceptable level. This conclusion is based on the stable conductance observed over the last 2-½ years.

Site B; This site presents a much different scenario than what we found at Site A. String #1 at this site was being monitored with conductance and a 15% conductance loss occurred over the 3-½ years of observation. This slight conductance loss in String #1 is a good indication that this battery' state of health has remained largely unchanged for when it was first observed. At this site however, there was a second matching battery string being charged in parallel, and this second string was not being conductance monitored failed badly. We found broken battery cases, erratic cell voltages and ***low*** conductance or ***no*** conductance observed.

Site B, String #2 was inside the rectifier compartment where operating temperatures were slightly higher than they were for String #1, which was mounted underneath the equipment cabinet. There were probably a combination of circumstances that contributed to the differences we observed in the two strings, but String #2 experienced what can be called a *catastrophic failure* based on it's physical condition. When several cells are actually broken open, there can't be much hope for battery performance. Voltage could be measured on the cells because String #2 was connected to the rectifiers, but several cells measured "0" conductance and "0" capacity when tested.

How long the battery had been in trouble is impossible to say because we did not have regular access to this site for visual inspections, and there was no conductance monitor installed to observe String #2. To our knowledge, there is no record of a voltage alarm being generated at this site. Luckily, no customer service interruptions were experienced even with the battery conditions as bad as we found them. The plant load is < 40 Amps and String #1 would have provided about 4 hours of reserve capacity based on our timed discharge capacity test results. This means the site was down to about 50% of its designed run time and maintenance was required.

Site C; Site C had the oldest battery string under observation for this study, and there is no doubt it is a critical failure. Over the 3- ½ years we have observed it, ***the string average conductance had fallen by 68%.*** This ***Ohmic change*** is well beyond what would be considered acceptable under the most lenient analysis criteria. We also observed rather random float voltage changes, suggesting the rectifiers may not be properly functioning, temperature-compensated units.

It became obvious back in November of 1996 that these batteries were in a failure mode. This conclusion was on the fact that this string had already lost an average of more than 50% conductance from what was observed a year and a half earlier when the monitor was installed. This is a radical loss of conductance for a relatively short period. As of this writing, this battery string is still in service and it could pose a safety risk. A new parallel battery string was installed at this site in late 1997 to make additional reserve battery capacity available. These new batteries do not match the original manufacturer or capacity rating of the string we have been observing. The broad discrepancy between these two strings' electrical condition could be an independent source of trouble. In addition, the wisdom of this battery mix and match practice is a topic for a separate debate.

Site D; These sample batteries are performing as expected under what looks like ideal conditions. A cool, stable operating environment combined with proper charge conditions should lead to life cycle performance very close to the manufacturers published levels for a battery in float service.

IV. What did we learn?

This type of site information simply confirms what most people involved in the battery business today already know. Consider the following:

1. Batteries (VRLA in particular) can change capacity/conductance rather quickly
2. Parallel strings may not experience parallel performance changes over time, even with similar operating conditions
3. High operating temperature and high charging voltages are two factors influencing battery life because they accelerate the processes directly related to premature VRLA battery failures.
4. The battery system must be able to sustain the site load for an acceptable period of time to fulfill it's primary mission

V. A changing world - What to do next?

With companies being bought, sold or traded almost daily, it becomes difficult to maintain focus on your core business objectives. These same problems persist in the now de-regulated power industry. You may have no control over what kind of facilities your company will acquire, but you still will be responsible for their operation and maintenance. These new sites must blend into your existing network and conform to your company's operating standards, which is no small task under the best of circumstances. To make a decision about what to do with a power plant, you need to have a grasp of the factors influencing the battery operation, which ones can be controlled or monitored and then reported as required.

Independent guidelines for battery operations and site analyses are available from the IEEE [5] [6] and other sources. These standards cover topics ranging from battery sizing, ventilation requirements, installation and maintenance for Vented and Valve Regulated Lead Acid batteries along with Nickel-Cadmium cells. You can call the IEEE at 1-800 678-4333 (USA and Canada) for information or to obtain copies of the current published standards. Information is also available from the Internet at: http://stdsbbs.ieee.org:70/0/pub/ieeestds.htm

When forming a plan of action, a site ranking system describing the level of service may be required. Local regulatory issues and special application issues will guide you in determining a priority system. Consult all the appropriate support documents for each application, and the IEEE guidelines are an excellent place to start when developing a plan. Before you monitor anything, a simple site survey might be the best place to start to identify operating conditions as they are.

Site Surveys: Keep it simple. If you spend the time to micro-analyze all of your sites, you may never have time to go home. Use a logical correction factor in your site calculation to fulfill the provisioning needs that will guarantee a "safety zone" of battery reserve capacity. This can be done without spending additional resources for capacity well in excess of the actual site requirements. The applicable IEEE documents [5][6] are a good place to start in the absence of specific company guidelines. Use this site survey information to quantify an overall plan and to help calculate your budget for battery replacements. These site surveys would naturally include an inventory of the existing site electrical activity and a forecast for growth.

Step 1. Ohmic battery testing:
An important tool that can help when performing site surveys is one of several Ohmic battery testers. Although the unit designs are unique, they are all designed to calculate an approximation of battery' state of health using an application of Ohms Law. Ohmic testers will help you quickly qualify the general condition of each battery in a system. Portable Ohmic Test equipment will save a tremendous amount of time while doing your site surveys. You may discover after this initial Ohmic test, there are serious battery problems requiring immediate action. Full capacity discharge tests or system rundown tests may be needed to guarantee the batteries are in acceptable condition. Any discharge capacity testing will take a significant amount of time in comparison to the Ohmic tests. The relative importance of each site, the availability of trained personnel and the equipment to do the discharge testing, crew schedules and other issues may limit what further testing will be done.

Once a battery string is determined to be serviceable through the best means at your disposal, installation of a full time battery monitoring system to track changes in system condition. Information available through various equipment monitors can include (but is not limited to) values like:

- Mid-point conductance
- Module Conductance
- String float voltage
- String mid-point voltage differential
- Pilot cell data (Temperature, Voltage)
- Battery float current
- Discharge performance test algorithms

Full time battery monitoring becomes particularly important given the number of premature VRLA battery capacity failures being reported. [3] Screening (testing) batteries in advance of monitoring is necessary to insure you have provided a minimal battery reserve capacity.

The point here is "Why monitor a battery already found below acceptable performance level?" Having a reliable ongoing indication of the available battery run time at any site is the obvious objective of monitoring.

Taking this idea one step further, it may be necessary to factor in additional reserve capacity based on site low temperature operating conditions. The battery manufacturers' published data tables will indicate the appropriate correction factor for low battery temperature. If you expect a minimum battery operating temperature of 5°C, for example, the battery manufacturers' temperature compensation tables will provide the formula for installing the appropriate battery capacity.

Step 2 – Analyze your data/define your future:
By documenting the site needs, you can come up with the business plan for success. [8] Using the site DC load alone to calculate available run time based on the battery manufacturers published capacity rating or "sticker value" is all you need to get started. Plan to share your calculated service needs with the personnel in your company responsible for contract purchasing. Also, keep all your equipment and battery vendors involved in this process. You will want to have the most current information and that should help improve conditions. Here is a case in point.

Some telecom sites we have recently observed have had in excess of 70 hours of reserve battery capacity installed, based on site conditions. This battery capacity was found in a site where the operating company's design profile called for 8 hours of run time. This would seem to be excessive, if for no other reason than the first cost of the installed batteries. You now have the ongoing cost to test, maintain and monitor the apparent excess of batteries that were installed. No matter how much physical space may be available, the suggestion here is to only install the batteries you will logically need for each application.

System designs: A perpetual problem in we encounter in field applications is difficult access to batteries for maintenance and test activity. Power systems must have sufficient room for battery maintenance or replacement when required. It is important to involve personnel outside the Power department to help resolve some of the service issues. Engineering shares much of the responsibility to help guarantee the products specified match the needs of the Network. Battery manufacturers need to apply what they have learned in the lab and in field studies to improve battery designs. [7] Equipment and cabinets should provide more thermally efficient designs for greater heat dissipation and improved ventilation. Power plant manufacturers also need to make temperature compensated chargers that conform to values generally recommended by the battery manufacturers. Compensated charging should improve battery life expectancy even under extremely stressful battery operating temperatures.

These are all things that will help improve your system reliability and improve cost control for your company and improve service on behalf of our customers. By selecting a simplified system design, you're purchasing department to help the Power Department become more cost effective. As fundamental as this may seem, it relates to every battery and equipment site we will deploy today and everything we do in the future.

All leaders in the power industry need to become advocate for battery awareness. It is unlikely you would be reading this paper if you were not involved in influencing decisions on power equipment and battery issues within your organizations. You must communicate relevant information to senior managers that this is serious business. Regardless of the budget limits, site constraints or anything else, we all share the responsibility to take improve the state of the art in power provisioning. There is a perpetual need for maintenance support, plan for it now! Lets focus on what can be done in the areas of improved product quality. We can all make a difference if we concentrate on the long-term benefits resulting from a combined effort on behalf of our paying customers.

We must ask the questions, "What is the cost (value) associated with building the appropriate level of battery protection?" On the maintenance issues, ask your self "What is the cost (liability) if I don't maintain and monitor those batteries?" Both customers and competitors are anxious to see how we bring this industry into the twenty-first century.

VI. Conclusions:

1. We documented that an installed ***conductance monitor*** was able to remotely provide an indication of the relative condition of a battery strings without discharge activity.

2. The state of health of two of the four reported battery' strings were capacity tested and proven to have failed capacity tests. The schedule for capacity testing was established by reading the conductance change over time.

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[1] Johnson Controls Form 41-7329 Rev. (10/94) Page 1
[2] EPRI TR-108826, Final Report, December 1997, pages 2-24 and 2-25
[3] D.O.Feder, M.Hlavac, T.G.Croda & K.S.Champlin. Proceeding of INTELEC 92,Vol. 2, pp. 218-233
[4] D.O.Feder, Proceeding of INTELEC 95, pp. 22-28
[5] IEEE Std. 484-1995, Installation and Maintenance of Flooded Batteries for Stationary Applications.
[6] IEEE-Std 1187-1996 Installation and Maintenance of Valve Regulated Lead Acid (VRLA) Batteries for Stationary Applications
[7] B.H.Dick, Power Quality Assurance article, Catalyst Technology Improves VRLA Battery Life, September, 1998, page 72 to 78
[8] M.Kniveton & A.I.Harrison, Impedance/Conductance Measurements as an Aid to Determining (Battery) Replacement Strategies, Proceedings of Intelec 98