Performance Testing Lead-Acid Stationary Batteries: Myths, Misunderstandings and Mistakes

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Abstract
In order to remain reliable, stationary batteries require care over their service life. This includes not only periodic inspections, but should also include performance testing when new as well as throughout its service life in accordance with the applicable industry recommended practice. There are facets of testing that continue to be misunderstood by those testing them. Mistakes are made as a result of myths, misunderstandings, lack of knowledge and proper training. Highlights of the Institute of Electrical and Electronics Engineers (IEEE) recommended practices 450-2010 for vented lead-acid (VLA) and 1188-2005 for valve regulated lead-acid (VRLA) batteries will be discussed. The paper will discuss several common misconceptions and myths relating to performance testing stationary batteries in an effort to raise personnel awareness when testing such systems.

Introduction
Both Acceptance and periodic Performance testing is part of industry recommended practices applicable to both VLA and VRLA batteries operated in stationary service. The author refers to performance testing as "the other part" of a complete battery maintenance program. Frequently, it is not performed for reasons ranging from the thought that such testing is unnecessary, too expensive and the notion that stationary batteries were never meant to be tested because it damages them. After all, we have internal ohmic tests to tell us capacity, right? Well, not really. Ohmic testing is one of a number of tools in the technician's toolbox. However, that, along with other maintenance checks and measurements provides information necessary to analyze and determine battery state of health. Capacity cannot be determined from these tests. For owners or service companies who *do* conduct performance testing in accordance with the applicable recommended practice, congratulations! Hopefully you are performing it correctly. As the paper title indicates, the paper will explore some of the technical "gotchas" that can get test technicians in trouble before and during tests. The type of testing discussed in this paper is single rate discharge tests conducted at manufacturer published rates. If you want to know what the capacity of a battery is, conduct a performance test. Of importance here is that it should be done correctly.

Myths

Myth #1 – Performance Testing Ruins the Battery

This is a common reason why some do not perform this test. Excessive/unnecessary testing, given enough cycles will certainly reduce battery life. When conducted in accordance with the applicable IEEE recommended practice, periodic performance testing is not considered to be excessive nor unnecessary. For example, for a vented battery tested in accordance with IEEE 450-2010, it would be tested at the factory or upon initial installation. This is called an Acceptance test. A Performance test of battery capacity should be made within the first two years of service in an effort to check for infant mortality issues. Throughout its service life, periodic Performance tests should be conducted as described in IEEE 450-2010. For such testing, intervals should not exceed 25% of battery's expected service life for the application. Once it reaches 85% of expected service life, or capacity has fallen more than 10% since the previous test, or capacity has reached 90% of rated, testing should be conducted annually until capacity reaches 80%. At that point, the battery should be replaced. In the practical world, this translates to but a few performance tests over the life of the battery.

To compare the recommended testing practice to battery capability, consider the following. Generally speaking, vented flat plate lead calcium batteries can deliver approximately 50 cycles to a depth of discharge of approximately 80%. Depending upon the manufacturer and model of battery, this correlates approximately to a 4 to 5 hour discharge at the corresponding published discharge current to 1.75 VPC (volts per cell). The calculated depth of discharge varies with battery types. An example of such a battery is one used for telecom or utility applications. Testing such a battery in accordance with IEEE 450-2010 would perhaps result in six discharges. Testing is frequently not conducted at the actual application time and rate; rather, it is performed at a shorter published time at the corresponding higher published current. Utility substation batteries are frequently performance tested at the 1 to 2 hour rate, which corresponds to a depth of discharge of approximately 50%. In this practice, the test time is shorter and fewer total AH (ampere-hours) are removed. This results in less wear and tear on the battery. As a bonus, this testing method requires reduced time on site compared to a full 8 hour performance test. The results gleaned from the shorter tests provide a reasonably good indication of how the battery will perform at the longer rate.

Myth #2 –Always Equalize Vented Batteries Before a Test

The above statement applies but in specific context, so definition is needed. Is this a new battery system or is it an existing system that is about to undergo a performance test? In the battery business, there has been too much over-generalization of many subjects, presumably in an effort to simplify or "dumb down" maintenance and testing procedures. After all it's just a battery; how hard can it be? Battery fundamentals and familiarization with industry recommended practices and procedures are important and should be understood.

Equalize Charge in the Context of Acceptance Tests

After a new battery is installed, and an acceptance test is going to be conducted, the *initial charge* should be carried out. Other names for this include freshening or commissioning charge. The intent is to ensure the battery will be fully charged and ready to test, especially if it has been in storage. Additionally noteworthy, it should be placed on float for no less than three days but not longer than thirty days before the test is performed. Battery manufacturers publish specific commissioning charge instructions in their IOM (installation, operation and maintenance manuals). These instructions should be read and understood prior to proceeding. The applicable IEEE recommended practice should be on hand also.

Equalize Charge in the Context of Performance Tests

In practical application, batteries are discharged directly from float while in normal service. Performing a test directly from float reflects maintenance practices. An example of poor maintenance includes prolonged battery operation at a float voltage that is below the minimum recommended setting, resulting in undercharged cells. Another is float operation at a temperature lower than recommended by the battery manufacturer. A battery should not be tested if it has not been under routine maintenance or its general condition is unknown. Connection overheating or a battery fire could result. If maintenance has lapsed, a detailed inspection should be undertaken in accordance the annual inspection criteria as outlined in IEEE 450-2010. Recorded readings should be reviewed and evaluated to verify the battery can be safely tested. This should not be a problem if the battery has a history of proper maintenance.

While on the topic of equalize charging, the notion that 72 a hour equalize charge is applicable to all batteries prior to an acceptance or performance test is erroneous. There may be confusion with the recommendation to allow a battery to *stand on float for 72 hours* after equalize or commissioning charging and before the actual test is performed. There is no universal time/voltage combination applicable to all vented batteries. Table 1 from a manufacturer instructions clearly illustrates this. The “72 hour equalizing rule” as some call it, should be filed in the urban legend category.

LEAD CALCIUM CELLS

Nominal Specific Gravity See Part 4, Sec. 1.3)	Maximum Average Volts Per Cell VPC (see note)	Time in Hours at maximum cell voltage
1.215	2.38	24 - 100
1.250	2.43	24 - 100
1.300	2.50	24 - 100

Table 1. A time table for a Calcium VLA battery initial charge voltage. Additional conditions to ensure full completion of the initial charge are required. Consult battery manufacturer manual for details.

Myth #3 – Equalize VRLA Batteries Prior to Performance Testing

Generally, VRLA batteries are not to be equalized before a performance test unless it is prescribed by the battery manufacturer. Consult the battery manufacturer as needed. In the case of the acceptance test, an initial charge may be required prior to testing.

Misunderstandings That Lead to Mistakes

A mistake frequently arises from a misunderstanding. The following section will blend these into several discussions.

Mistake #1 – Terminating a Performance Test When Battery Capacity Reaches 100%

A performance test should be stopped when the overall battery voltage reaches the final (end of discharge) voltage specified for the test, not just because it reaches 100% of the specified published time. In some cases the battery is above final voltage when it reaches 100% capacity. The argument from those making the practice of early termination is that there is no purpose in continuing the test because the battery already demonstrated 100% of its rating. The problem with this line of thinking is the test technician doesn't know the true capacity of the battery because the test was not run to the rated final voltage. Degradation will not be detected until capacity drops below 100%. When batteries are new it is not uncommon to see performance in excess of 100%. Capacity trending should begin with the acceptance test using that result as the benchmark. It is worth noting that not all VLA batteries will deliver 100% capacity when new. It can take two to three years to reach 100%. Check the data sheet footnotes for your particular battery.

Table 2 illustrates an example case. This battery was tested at the published one hour rate corresponding to 1.75 VPC final voltage. The battery consists of 58 cells. Final voltage should have been allowed to decrease to 101.5 V. Instead, the test was terminated in error when the capacity reached 100%. Battery voltage at that time was still above final at 103.4V.

Test Time: 01:00:00 **Battery Voltage:** 103.4 **Amps:** 226.7 **Kw:** 23.4

String: String 1

1 = 1.776	2 = 1.787	3 = 1.793	4 = 1.780	5 = 1.797	6 = 1.784
7 = 1.776	8 = 1.784	9 = 1.776	10 = 1.768	11 = 1.781	12 = 1.765
13 = 1.777	14 = 1.788	15 = 1.774	16 = 1.774	17 = 1.788	18 = 1.776
19 = 1.781	20 = 1.781	21 = 1.787	22 = 1.785	23 = 1.792	24 = 1.765
25 = 1.783	26 = 1.776	27 = 1.786	28 = 1.787	29 = 1.792	30 = 1.783
31 = 1.798	32 = 1.785	33 = 1.775	34 = 1.791	35 = 1.779	36 = 1.785
37 = 1.782	38 = 1.793	39 = 1.759	40 = 1.792	41 = 1.803	42 = 1.804
43 = 1.810	44 = 1.817	45 = 1.781	46 = 1.808	47 = 1.804	48 = 1.808
49 = 1.789	50 = 1.812	51 = 1.809	52 = 1.806	53 = 1.799	54 = 1.805
55 = 1.807	56 = 1.755	57 = 1.806	58 = 1.777		

Table 2. The test data shows the battery was over 100% capacity because voltage was not permitted to decrease to the required level.

Mistake #2 – Failure to Bypass Weak Cells

It is not uncommon for a cell or multicell unit to fail during a test. Depending on condition, failure can occur at any time during a test.

Not all test technicians are aware that options are available to them when imminent cell failure looms. One option is to simply terminate the test. The failing or failed cell (when approaching 1.0 volt or less) is replaced and the battery system is retested at a later date with the new cell or unit. Depending on the condition of the remaining cells, additional ones may fail during the follow-up test, which can create more problems. Option number two is to pause the test, (temporarily stop the discharge) bypass the cell with appropriate connectors then continue the test to the new specified final voltage, accounting for one less cell. This is permitted if cell failure occurs at a point in time during the test before 90%-95% of the expected test time has been reached. It is permitted once during a test. The downtime cannot exceed 10% of the total expected test time or 6 minutes, whichever is shorter, and this downtime shall not be included in the test discharge period when calculating battery capacity. However, if a cell is approaching failure past 90%-95%, continue testing to the specified final battery voltage for the test. These options are discussed in more detail in the applicable IEEE recommended practice.

Test technicians should avoid leaving a failing/failed cell in a battery prior to the 90%-95% decision time discussed above, especially if it occurs considerably early in the test; 1 hour into a 3 hour test for example. Doing so can significantly skew the overall demonstrated capacity of the battery, invalidating the test results.

Mistake #3 – Failure to Correctly Size Load Bank Cables

Load cable voltage drop between a battery and the load bank that is serving it should be carefully considered. Such is the case when a load bank will be required to operate at or near its maximum nameplate rating. For example, a manufacturer's line of dc load banks suggests the maximum voltage drop between the load bank and battery should not exceed 3.0 volts. Failure to correctly size cables can result in the inability of the system to achieve the required load current due to excessive voltage drop. Sourcing additional cables once the test crew is on site can be very time consuming and costly. Test technicians should have this sorted out prior to test day whenever possible.

A basic cable sizing example is provided below for a setup with a 450 ampere load and 50 feet between the load bank and battery under test. Copper wire is used.

1. Cable Size (CM) = 12.9 × loop conductor × load ÷ max drop
2. 12.9 × 100 × 450 amperes ÷ 3.0 v
3. Cable size = 193,500 CM (4/0 cable, 211,600 CM) – 1 conductor per polarity recommended

Should the cable size be known, the formula can be reworked to calculate the voltage drop for a given cable size as illustrated below.

1. Voltage Drop = 12.9 × loop conductor × load ÷ cable size (CM)
2. 12.9 × 100 × 450 amperes ÷ 133,100 CM (2/0 cable)
3. Voltage drop = 4.4 V with 1 conductor per polarity

Based on the paper text, this cable is too small to meet the need of the example test setup.

Mistake #4 – Terminating a Test When the First Cell Reaches Final Voltage

Terminating a test based on this misunderstanding results in an invalid test. The final voltage used as the terminating criteria is <u>overall</u> battery system voltage, not an individual cell voltage. During testing, cell voltage non-uniformity exists just as it does during float operation, due to slight differences in cell characteristics. At the conclusion of a test, some cells will be exactly at the final voltage while some will be above and some below. While terminating a test at a point when the first cell reaches final voltage may get one close, close doesn't count and it is not technically correct to do so. The test must be run to system final voltage to consider a test to be valid.

Once a test is complete, individual cell performance should be reviewed. Attention should be given to cells that performed at significantly or questionably lower capacity than expected. Individual cell capacity can be easily calculated with the same techniques used for overall capacity. The battery manufacturer should be consulted with concerns regarding cells that did not meet expectations. In specific cases replacement may be required.

Suggested Additional Reading

IEEE 450-2010 - *IEEE Recommended Practice for Maintenance, Testing, and Replacement of Vented Lead-Acid Batteries for Stationary Applications*

IEEE 1188-2005 - *IEEE Recommended Practice for Maintenance, Testing, and Replacement of Valve-Regulated*

Lead- Acid (VRLA) Batteries for Stationary Applications

R. Tressler, *Proper Commissioning Procedures for Lead-Acid Batteries, 18th Battcon*