WHEN THINGS GO WRONG AT THE ACCEPTANCE TEST: A CASE HISTORY

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ABSTRACT

The need for a properly prepared and executed acceptance test is a vital phase of any successful stationary battery installation. A battery that that passes this all-important test essentially places the period at the end of sentence that reads; "The battery system performed in accordance with the system design criteria". That having been stated, why are such tests seemingly so frequently incorrectly performed? The case history described in this paper involves a classic mission-critical installation involving multiple UPS systems and over two thousand valve regulated lead-acid cells. During the initial acceptance test, battery systems that should have performed in excess of the expected run time were failing miserably, one test after the other. The ambient temperature was 77° F. The AC load current and voltage that were measured and employed in the AC load calculation were found to be within the performance specification for the UPS modules. A battery performance specification was on hand and the end-of-discharge voltage was programmed into the UPS. The UPS modules were functioning correctly according to the manufacturer. By all accounts, the battery systems should have performed as expected. Why they did not is the focus of this paper. It is the authors' intention to bring to light what can, and does occur when multiple parties are involved in the installation and testing of batteries. This paper goes further to discuss how much effort was put into investigating the causal factors that resulted in the seemingly lackluster battery performance. Information will be presented that illustrates how the situation reached this point. The end user was demanding the replacement of all cells. In the end, however, cool heads prevailed, and remedies were made to the satisfaction of the equipment owner.

SYSTEM CONFIGURATION OVERVIEW

The final selection of equipment included five UPS systems, each consisting of an 1100 kva UPS module. Each UPS module is supported by 2 strings of 240 cells of 20 year, VRLA cells in parallel.

THE PLAYERS

Sometimes, the more entities that become involved in a large installation, the more difficult it becomes to collect the facts and make a determination as to why something did not work as intended. This was such a case. They consisted of the general contractor, the equipment owner, the electrical contractor, the UPS manufacturer and the battery manufacturer. Each entity had several representatives involved on site and another fifteen or so that ultimately became involved.

IN THE BEGINNING

This particular project was plagued with problems from the start. The battery was manufactured in late fall and delivered to the installation site in January the following year. There, they sat until mid-May of that year until someone came to the conclusion that perhaps the battery should receive a freshening charge. While that decision had been made, it took 2 more months for it to actually take place. By this time, it was mid-July. The last time the battery had a charge was at the factory in October, the year prior. The battery has been on open circuit for 10 months. The storage time was this long due to the fact that the battery was delivered too early; way too early. The UPS had yet to be installed, so there was no power with which to perform a freshening charge. A full court press was established to get the battery systems installed as well as the UPS and the associated wiring. By the time November rolled around, the batteries were finally installed, wired to the UPS and ready to go. Or were they?

THE ALL-IMPORTANT COMMISSIONING CHARGE

It is important to note that a battery manufacturer's installation, operating and maintenance instructions should be followed for many reasons, particularly, when it comes to commissioning procedures and establishing a full state of charge. It is especially important that it is carried out when the battery is to undergo an acceptance test. Generally, it is quite costly to repeat testing operations, especially when it involves a large number of cells. Extension of load bank rentals and the requirement to keep test, witness and technical test personnel on site can easily add many thousands of dollars in labor to complete the work. In the end, back charges began to roll in, followed by the customary battle over who was to pay these fees and who was responsible for the problem. As you may have already surmised, there was a problem with the commissioning charge. Some of the systems received one, more not. The reasons as to why the batteries did not receive this charge are still not fully understood. But the reality was that the batteries, some fully charged, some not, were about to be tested against a performance specification. The results were not good.

THE PERFORMANCE SPECIFICATION

The UPS modules are rated 1100 kva with a .8 power factor. The resultant AC load is 880 kilowatts. The battery was required to provide 9 minutes of support at full load to an end cell voltage of 1.67 volts per cell at 77°F. measured at the UPS. More specifically, the battery performance specification was written using verbiage that prohibited any cell voltage from falling below 1.67 volts. However, referring to IEEE recommended practice 1188-1996[1], when conducting a performance test, an average voltage per cell is calculated. It has been generally accepted when the overall battery voltage is at or above that specified at the end of the test time, the battery has passed. Nonetheless, the average-versus-specific individual cell voltages at the end of the test were frequently subjects of discussion.

THE FIRST TEST

The first round of acceptance tests was conducted and the results were quite unacceptable. Only one of the batteries met the performance specification of 9 minutes. Table 1 illustrates actual times were well below the required time of 9 minutes. The batteries that made the higher times were typically those that received a commissioning charge, although still below recommended charge time. Upon completion of these tests, the first of many phone calls and emails followed from the contractor responsible for the project. Needless to say, all involved were not happy with the test results. Could all the batteries be defective?

System	Run Time (minutes) to 1.67
1	08:37
2	05:39
3	06:49
4	11:11
5	08:12

Table 1
First test results

Fact Finding Mission Begins

A fact finding mission began and an investigation was launched into the reason why batteries that should have performed well, had performed so badly. The UPS manufacturer was one of the first to be contacted by the general contractor, who wanted answers as to the nature of the alleged battery failure. One of the first things learned was that none of the batteries received a proper pre-test inspection. What is frequently referred to as an "IEEE certification inspection" was not conducted prior to the first tests. The recommended procedures are outlined in IEEE 1187-1996[2]. Neither cell voltages, nor connection resistance measurements were taken. State of charge was also not verified before the tests were conducted. Basically, these cells were installed, placed on float and tested to a specification that they simply could not meet. Only a couple of the systems received a commissioning charge, and, for a period of time, that could not be confirmed. For all practical purposes, this test and its results were invalid.

Corrective Actions

Before a re-test of the systems could be performed, a few things had to be fixed. First, a full set of connection resistance measurements had to be made and recorded. This was done, and the results of this exercise indicated well over 400 connections (17%) were outside the IEEE 1187-1996[2] recommended maximum values.

High resistance connections were re-made and their resistances all fell into line with the others. Another corrective action that was required was to give all cells the proper attention regarding the requisite commissioning charge. The battery manufacturer advised that the battery would be considered fully charged when the voltage of the lowest cell in each string stopped rising over a three hour period with readings taken hourly and while at the commissioning charge voltage potential. This method was recommended because float current measurement instrumentation was not available.

Storage Concerns

Given the poor test results, there was substantial concern as to whether the batteries would pass the re-test. Considerable focus and discussion relating to the storage history of the cells prior to installation became, at times, a hot topic. As a rule, the manufacturer recommends that the battery receive a freshening charge if it is not going to be installed within 6 months. However, many, including some battery manufacturers, acknowledge that the 6 month charge interval that some consider a hard and fast requirement is, in fact, actually a guideline. The maximum time in storage can be extended if the storage environment is conducive to a lower rate of self discharge, typically a lower storage temperature. This was supported by the battery manufacturer. Such was the case for a considerable portion of this battery's storage time. As it turns out, in the end, the extended storage time many thought a problem, was not a problem at all. Next phase – re-test the battery.

THE SECOND TEST

After much discussion, it was agreed that all the battery systems would be re-tested. With a full commissioning charge, cells verified for proper state of charge, and corrected connection resistance problems and a full set of ohmic measurements, the batteries were again ready to go. However the second set of test results was nearly a mirror image of the results from the first test. By this time, everyone was scratching their heads as to why these cells failed again so badly.

Investigation Continues

After two series of tests, the soon-to-be equipment owner was not at all happy with the way things were going. No one could blame them. The batteries were still heavily suspect and the storage time issue was again raised, this time as the likely cause of all the heartburn. Net Status: The general contractor and the UPS manufacturer were on the hook for whatever it took to correct the problem.

At this point, the project files were opened and the UPS company's service personnel on site began a detailed look into the job overall specification, and battery specification; and~~,~~ performance requirements were double-checked. Several inches of files were examined. A troubling thing that was found was the reference to end cell voltage specification. The customer specification stated that at no time could any cell be below 1.67 volts at the end of the test. The UPS company performance documents stated that the battery would provide the required support time to an end cell *average* of 1.67 volts per cell or 400.8 volts overall battery voltage. Essentially, the latter means that as long as the overall battery voltage was at or above 400.8 volts at 9 minutes, the battery passed muster. Clearly, the battery performance was so below expectations that every possible cause needed to be considered. This item was duly noted, but it was not going to help with the problem at hand. There was a major discrepancy here and the answer was about to be uncovered.

Voltage Drop

In its guide specification, the UPS manufacturer recommends a maximum drop of two volts between the UPS and the battery. During the second series of tests, overall battery voltage was measured, both at the battery as well as at the DC input to the UPS. In all systems, approximately four volts of drop were noted between the two points; double that recommended. When this was realized, expected performance was again compared to actual performance. The consensus was that an additional two volts of drop was not the sole cause of the problem. However, when the third series of tests were performed, the voltage drop would be duly noted and the end-cell shutdown voltage controls at the UPS would be adjusted accordingly to take this into consideration.

BATTERY “B”

As searching through the files continued, a major piece of the puzzle was found. Another specification, with a later date than the original had been submitted. Here, it was learned that the battery that was originally specified for the application could not be delivered in sufficient time, so a different battery, “Battery B” was sized, specified, approved and furnished. Herein lays the crux of the performance problem. While approval had been granted to use “Battery B” in place of “Battery A”, revised documentation never made it to the right people. The replacement battery was sized in the same manner just as the original battery, “Battery A”, but with one major difference. The specified end cell voltage for “Battery “B” was 1.63 volts per cell, not 1.67. When batteries are being tested at high rates, such as a UPS application, an end cell voltage difference of 1.67 versus 1.63 is a considerable one.

Once all concerned were made aware of this, the UPS and battery manufacturer, as might be expected, sought and received approval to re-test the battery a third time to prove its theory that the incorrect end cell voltage was the primary cause of the poor performance. All were in agreement that the opportunity to change the end cell voltage and retest the batteries was a good idea. In effect, the battery had been tested a first time at a low state of charge and a second time to the wrong specification. The voltage drop concern was also addressed, and the end-voltage control adjustment in the UPS was set to 388 volts. Doing so would allow the battery to discharge to 392 volts, or 1.63 volts per cell average.

THE THIRD AND FINAL TEST

The batteries were allowed to recharge overnight at float potential and the final test was scheduled for the next day. All operating parameters and battery condition was checked prior to the discharge. The batteries were ready to undergo scrutiny once again. Load banks were brought on line, the loads verified and instrumentation was ready.

The following corrections factored into the results illustrated in Table 2. 1) The battery was brought to a full state of charge. 2) All connection resistances that were outside recommended values had been corrected. 3) The end-cell voltage was correctly identified and UPS adjustments made accordingly. 4) Along with the correct end-cell voltage, the observed voltage drop from test 2 was taken into account in the final adjustment in item 3.

Table 2 illustrates the performance improvement for all five systems after readjusting the UPS to the correct end cell voltage and allowed to recharge overnight. Each subsequent test resulted in a run time well in excess of the customer requirement of nine minutes to end voltage. The result was that all systems performed in excess of the required nine minutes.

System	First Test Run Time to 1.67	Final Test Run Time to 1.63	Net Change
1	08:37	11:45	+03:08
2	05:39	12:02	+06:23
3	06:49	11:40	+04:51
4	11:11	12:36	+01:25
5	08:12	13:08	+04:56

Table 2
First and final tests compared

SUMMARY, CONCLUSIONS, RECOMMENDATIONS

The situation that occurred here is not unique. Problems arise frequently when battery installation and tests are being performed. One of the more significant concerns at times such as this is the seemingly large number of people that get involved a project. Considerable confusion occurs once comment and direction from numerous sources are aimed in the direction of the responsible party or parties. There was considerable misunderstanding, poor communication, finger-pointing and false assumptions made. This ultimately led to invalid tests, unwanted re-tests, erroneous data and considerable expense that went well into the six-figure range. The recommendations below are made as a result of the events that occurred at the site that is the subject of this paper.

The authors have been involved in similar situations that can, at times be very difficult to deal with. In most cases, the source of trouble is not the battery at all. The following are but a few of many considerations that must be given attention from receipt of the battery all the way to the testing phase of the job.

1. Pay close attention to the specifications. All parties must be working from the latest revisions. Do all the parties agree with provisions in the specification?

2. Don't get the batteries before they are needed. If it is determined they will have to be stored for more than the time recommended by the manufacturer, contact the appropriate support department at the factory level.

3. Many sites of the sort discussed in this paper treat the batteries the same as infrastructure equipment. This attitude results in batteries that are installed, fouled with construction dust and forgotten.

4. Measure and record all cell-to-cell and detail connection resistances in accordance with the battery manufacturer's and/or industry recommendations. Correct all deficiencies before proceeding. The installation cannot be considered complete until this, and other requisite pre-test tasks have been performed.

5. Follow the manufacturer's instructions regarding initial charge of the battery. The acceptance test will be invalid if the battery is not brought to a full state of charge. Testing is expensive. Do it right the first time.

6. Understand, to the best extent possible, those who are responsible, as well as those with simply an interest in an acceptance test and its results. In other words, learn who's who.

7. Ongoing communication between parties is essential, especially in situations when there are several organizations and many people involved, especially when a change in specification or problem occurs.

REFERENCES

1. IEEE 1188-1996 – IEEE Recommended Practice for Maintenance, Testing and Replacement of Lead-Acid (VRLA) Batteries for Stationary Applications, Section 7.4, page 8.
2. IEEE 1187-1996 – IEEE Recommended Practice for Installation Design and Installation of Valve-Regulated Lead-Acid Storage Batteries for Stationary Applications, Section 6.2.2, paragraph j)

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