BATTERY CAPACITY TESTING IMPLEMENTING IEEE AND NERC STANDARDS AND FIELD EXPERIENCE

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ABSTRACT

In order to remain reliable, stationary batteries require maintenance and care over their service life. Large number of tests have been performed and described on these topics: visual inspections, specific gravity float voltage, float current measurement, internal resistance test, capacity test, etc. Although all these tests are recommended by the standards, the battery capacity test is the only ones that accurately determines the true capacity of the battery and where is the battery on its predictable life curve. This paper provides a summary of the capacity test defined by the IEEE and NERC standards for the lead acid batteries, focusing on initial conditions, site preparation, test duration, rate of discharge, temperature effect, and other tests that can be performed with load banks in order to find out the state of its health. This paper also shares a description of the measurement techniques for the battery capacity test and monitoring of an individual cell condition to detect the weak cells. It also describes and discusses several common misconceptions and myths relating to capacity testing, and how to not get sidetracked.

INTRODUCTION

Stationary lead-acid batteries play an increasing role in the industry today by providing power and back-up energy during emergencies. When an emergency situation occurs it is essential that the battery systems perform as designed, or the substation may be left unprotected, considering that the batteries provide power to the protection and control equipment. IEEE and NERC are active in the development of standards for battery testing. Although many test methods can be performed to estimate the condition of the battery, the discharge test at specific time intervals and specific discharge rates are presented as the necessary tests, and the only method that can measure the real capacity of the battery. At the end it decides where the battery is on its predictable life curve. The capacity test types recommended by IEEE standards are: Acceptance, Performance, and Modified Performance tests. Nowadays the capacity tests are not performed because of the belief that this type of testing is too expensive, requires a lot of time, and it damages the battery. Most battery users today apply the internal resistance measurements in order to determine the battery state of health and save time. This approach is not wrong. However the real capacity cannot be decided from this test. This paper describes certain initial conditions, which should be met before the discharge tests, as well as how to save the time required by the discharge testing using the load bank for internal resistance measurements. The type of testing discussed in this paper is the constant current discharge test along with the load bank and external load, as well as the discharge test using modified load profiles.

ACCEPTANCE TEST

An acceptance test of the battery capacity should be performed at a manufacturer's facility or after the initial installation on a site. The test should meet a specific discharge rate and duration according to the manufacturer's rating or to purchased battery specifications. The main purpose of this test is to define the baseline capacity for trending purposes. Battery strings can have less than rated capacity after the acceptance test, but in no case should any cell have less than 90% of its specified capacity.

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PERFORMANCE TEST

The most commonly used capacity test is the Performance Test. It is a controlled constant-current or constant-power discharge test of a battery until reaching the specified final voltage. This type of the test should be made within the first two years of service, in order to find whether the battery meets manufacturer's specifications. Batteries should undergo additional performance tests periodically. It is recommended the time interval between the tests should not be greater than 25% of the expected service life time. During the performance testing**,** the constant current or constant power approach may be used. The constant current or power parameters for different periods of time are specified by the battery manufacturer. Before every test start, it is necessary to define the end point cell voltage and the discharge current for the specific end voltage. The appropriate discharge current depends on the amount of required time for discharge as well as the capabilities of the test equipment. Using an additional load bank with an external current measurement option will significantly expand control of load possibilities especially if there is either an external load deployed or the regular battery load. Using this approach the total test time can be reduced. After the test completion, the battery capacity result should be adjusted to 25 degrees centigrade. It is important to emphasize that correction factor vary by a battery manufacturer.

MODIFIED PERFORMANCE TEST

The Modified Performance test is the battery capacity test using intervals of steady current values simulating a duty cycle. This allows the performance test to be accomplished in a minimum amount of time, while still demonstrating the high rate capability of the battery to meet the duty cycle requirements. In order to perform this test with different loads it is necessary to use the load banks capable of changing the load profiles during the entire test. There are three types of the Modified Performance test.

Modified Performance test type 1

Type 1 test comprises of the two rates: a short high-rate discharge followed by a discharge at the normal rate for the performance test. The value for the high rate discharge is the largest current load of the battery duty cycle, or the published 1 minute rate divided by the aging factor.

Modified Performance test type 2

This type is used in case the battery has more complex duty cycle. The discharge includes all peak loads of the duty cycle that are above the normal performance test rate, while the performance test rate is adjusted so that no more than 80% of the capacity is removed during the duty cycle.

Modified Performance test type 3

This test can be used for applications that have the peak loads near the end of the duty cycle.

If any of the above test types has been used, it should continue to be used during the entire service life to provide consistent trending information. Load banks that can create different load profiles necessary for Modified Performance tests can also be used for internal resistance measurements.

TEST PREPARATION

A test preparation is important to perform the test correctly. Before the test starts, it is necessary to prepare the equipment to comply with the safety standards. After that, it is important to visually inspect the cell connections are in a proper condition as well as the charger has been disconnected. The load connected to the battery needs to be adequately backed up, or the current taken by the load needs to be included in the discharge rate.
It is important to emphasize the test preparation and conditions before its start can affect the test results. Having that in mind, it is important to check the key parameters such as the cell voltage, float voltage, and

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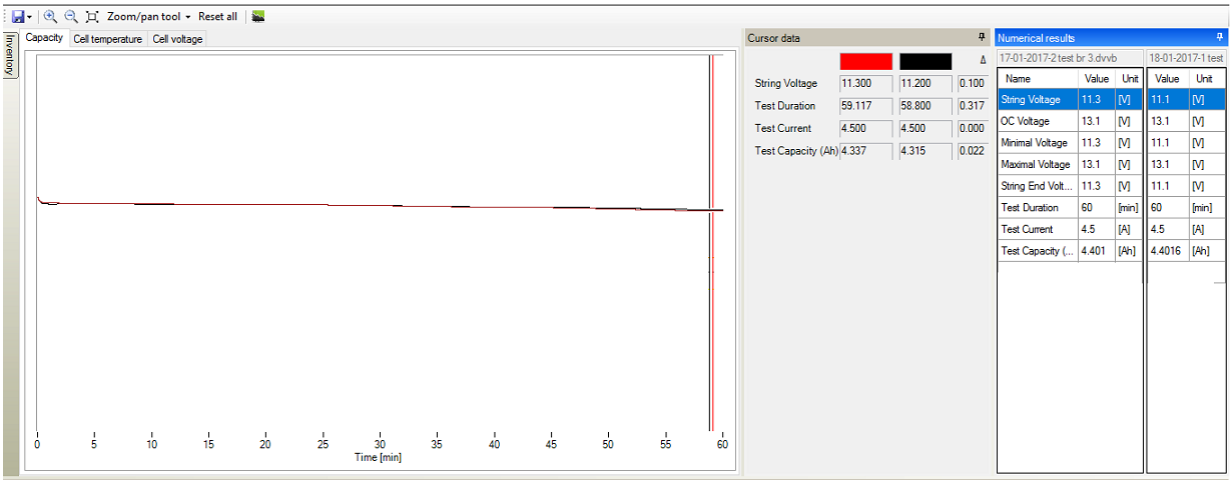
electrolyte (cell) temperature before the test starts. Once the initial conditions are met, load unit and additional systems may be connected.

MYTHS AND MISUNDERSTANDINGS RELATED TO CAPACITY TESTING

In battery testing, especially capacity tests, there are some facts that are misunderstood. Mistakes are made as a result of myths, misunderstandings, and lack of training and experience.

Myth 1. Capacity testing ruins the battery, and it is expensive

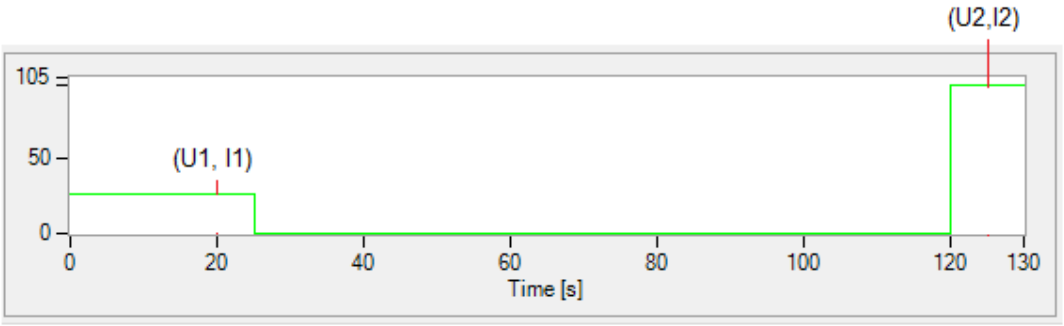
This myth creates confusion among the test professionals. Excessive charging and discharging, with too many cycles will reduce the service life. However, when conducted in accordance with the applicable standards and manufacturer's recommendations, the capacity testing will not reduce the battery service life and the consideration that this test is not needed is wrong.
The effect of the performance test on a battery was analyzed on the Powerfit S312/7S battery. The discharge test was performed with higher discharge rate and reduced test time. The graph in the Figure 1 illustrates the test results collected from the battery with manufacturer declared five years of service. After being subjected to five discharge tests, the voltage values and the capacity levels at the last test were unchanged compared to the results of the first test. This confirms that five more discharge cycles will not ruin the battery.



Measured battery voltage as a function of time in five discharge tests on Powerfit S312/7S Figure 1

Besides the opinion that this kind of a test ruins the battery, the capacity test is not performed since it is considered as expensive, and the load bank is replaced by the hand held instruments for internal resistance measurements. The main reason is that the internal resistance would tell us the battery state of health. Although the internal resistance does correlate with a capacity, it is not a direct correlation. A capacity cannot be determined using this kind of a test. The internal resistance indicates there is a problem and this data needs to be confirmed with additional measurements, such as the capacity testing. For the team members that are involved in a battery testing, the capacity testing using load banks is recommended. In addition, internal resistance can be tested using a proper load bank which provides different load profiles settings. In order to measure the internal resistance using a load bank, it is necessary to establish a specific discharge characteristic and establish the two points. After 20 s discharge, at a defined current, the voltage is read and this provides the first point. Then, the discharge is interrupted and the battery is left in an open circuit state for 2 up to 5 minutes. After the five seconds in the second discharge interval with a higher current level, the voltage value is recorded again. This gives the second point as shown in the Figure 2.

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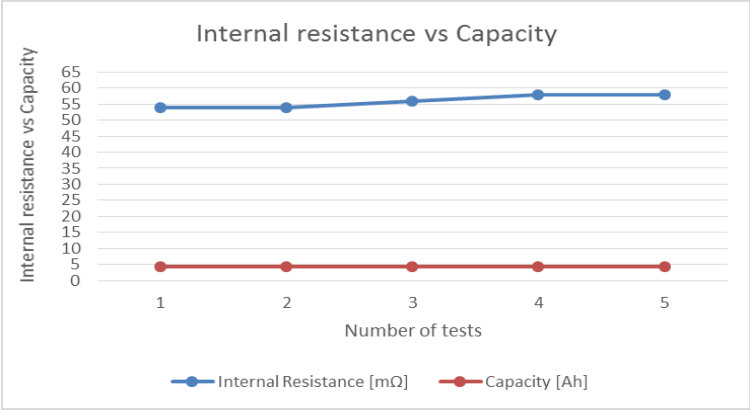


Load profiles for internal resistance measurements using load banks
Figure 2

The internal resistance is calculated using the following formula as per **IEC 60896-21**:

$$R_i = \frac{U_1 - U_2}{I_2 - I_1}$$

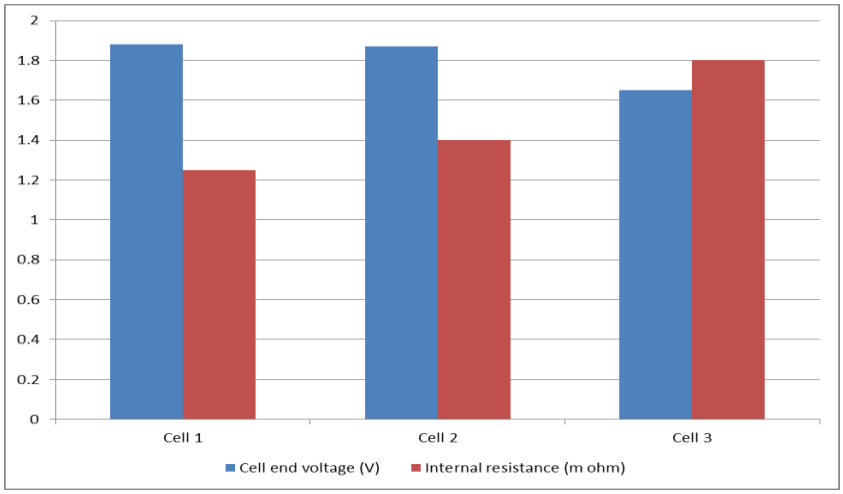
Measurements based on this method were done on a Powerfit S312/7SR batteries while fully charged. The resistance did not changed in five tests as well as the capacity as shown on the figure 3.



Internal resistance vs capacity on Power fit S312/7SR battery
Figure 3

Additional tests were done on the Sonnenschein 2EPzV 200 battery. The battery was subjected to the capacity test in order to determine week cells in the string. After the discharge test the battery was recharged and subjected to the internal resistance test according to the above mentioned test method with load bank in order to see the differences in resistance between the cells that passed capacity test and the cells which failed the capacity test. Cell voltages during two discharge intervals were measured with Battery Voltage Supervisor system (cell by cell scanner). The differences in internal resistance on cells with better capacity and on cells with bad capacity are show on the figure 4. The cell with lowest cell voltage at the end of the capacity test had the highest internal resistance.

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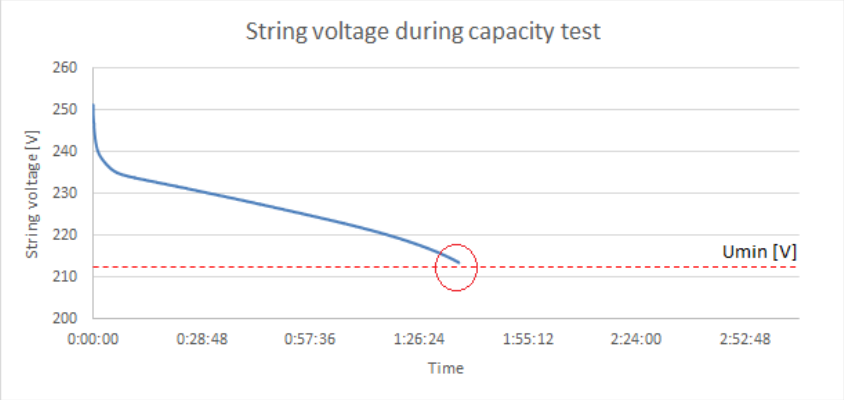
Differences between internal resistance on cells with higher capacity and failed cell
Figure 4

Myth 2. Battery needs to be equalized before a test

This statement depends on whether the battery system is new or it is in an existing system that is about to undergo a performance test. When a new battery is installed and the acceptance test is to be performed, a commissioning charge including an equalize charge should be performed. In that case the battery will be fully charged and ready for the test. In addition to that, a battery should be placed on float for at least three days. In everydays practice batteries are tested from a float state.
Battery manufacturers publish their recommendations for a charging procedure in their installation, operation and maintenance manuals. Prolonged battery operation outside the manufacturers float voltage limits will reduce the life expectancy. For example, VRLA batteries do not need to be equalized before performance test unless it is recommended by the manufacturer.

Myth 3. Stop the test when the first cell reaches cell-end voltage

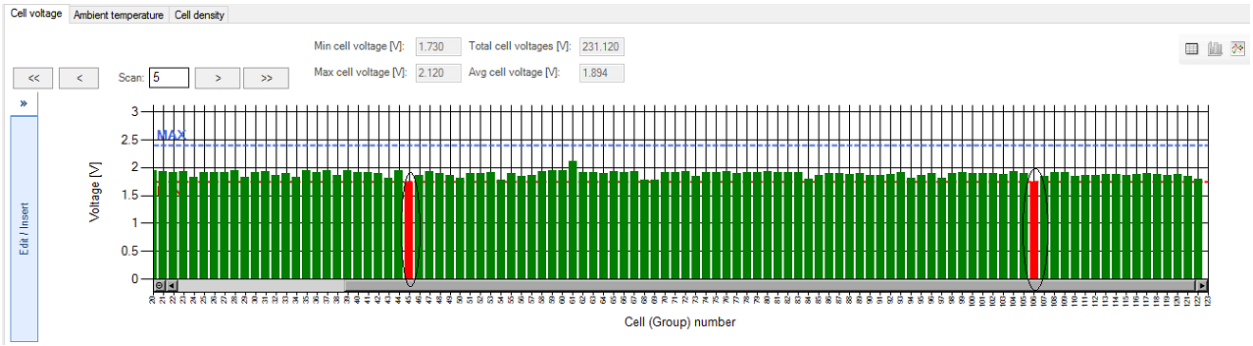
During the performance test it is not uncommon for a cell or a few of them to fail before the end of the test. Terminating a test as soon as the first cell fails may result in incomplete or wrong test results. The total string voltage should be used as a test terminating criteria. The example of the string that should be replaced is shown in the Figure 5.



Total string voltage on the battery that needs to be replaced
Figure 5

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However, a test person should immediately bypass a week cell except the test has run 90-95 % of its course in which case the weak cell can remain in the string until the end of the test. During a test a cell voltage non-uniformity is present; some cells are above the end voltage value, some are below. Terminating the test when one cell reaches end voltage will not allow us to find other damaged cells in the string; which is the main reason for the test. A detection of the two week cells is presented in the figure below.



Voltages of individual cells during the test
Figure 6

During the discharge test, one test team member should be prepared to bypass the cells. The bypass can be done by pausing the test, then bypassing the cell with appropriate connectors. All safety precautions should be followed during this procedure. The string voltage needs to be recalculated and the test continued with the new end-voltage value taking into account one cell less. The maximum allowed time to finish the bypassing process is six minutes or 10% of the total expected test time, and it should not be counted in the total test time.

EFFECT OF TEMPERATURE ON DISCHARGE TEST

The temperature has a big influence on the cell performance. As the temperature of the cell increases, the internal resistance decreases and the chemical reaction increases what improves (increases) the capacity of the battery. However, keeping the battery warmer then recommended, will cause a higher level of active material shedding, gassing, and grid corrosion that in turn would reduce the service life. This includes ambient and cell temperature. Battery manufacturers always publish recommended operating temperatures for their batteries. If the operating temperature of the battery system is above or below recommended, a correction factor needs to be applied after the test. The table with temperature factors can be found in IEEE Std 450-2010 for Vented Lead Acid batteries.

TEST PROCESS

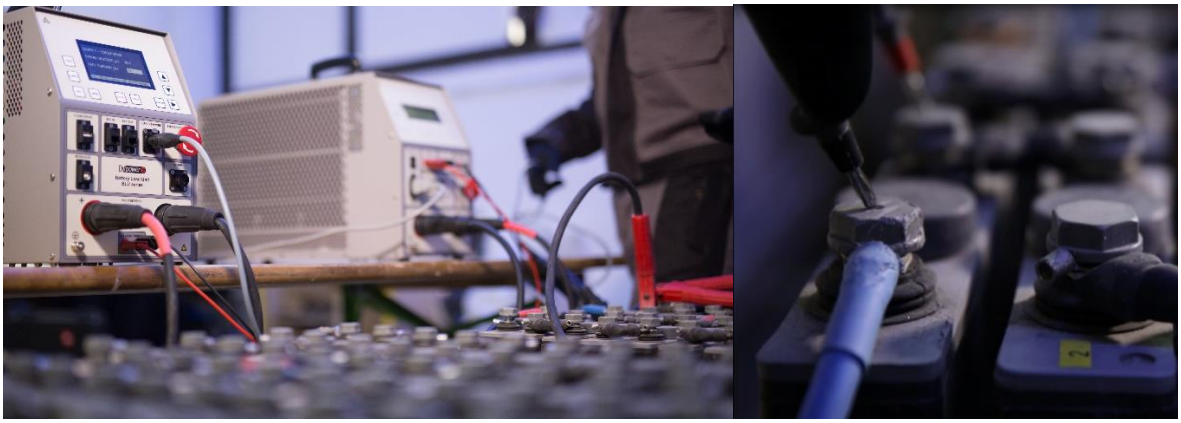
Once the initial conditions are meet, the load unit and other necessary test equipment needs to be connected and setup properly. The first step is to define the test current, end voltage, and the test duration. These parameters are found in the manufacturer's published data and recommendations. The battery installation used for testing had 126 cells and the string voltage of 252 V. The manufacturer's recommendations for the discharge test of this battery are shown in the Table 1.

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Table 1: Manufacturer published ratings at 20 C

Part number	Vpc	10 min	15 min	30 min	45 min	1 h	2 h	3 h	4 h	5 h	6 h	8 h	10 h	20 h
NGA6021000HS0FC	1.90	442	431	405	387	357	278	239	199	168	146	119	100	60.3
NGA6021000HS0FC	1.87	560	546	509	454	413	324	280	217	187	160	130	109	65.5
NGA6021000HS0FC	1.85	665	613	561	499	449	334	275	231	198	171	137	114	67.6
NGA6021000HS0FC	1.83	692	673	609	539	483	369	293	244	209	179	145	118	68.6
NGA6021000HS0FC	1.80	815	764	648	591	524	379	308	258	217	190	149	124	71.7
NGA6021000HS0FC	1.75	936	890	773	648	556	400	320	270	224	201	154	127	71.7
NGA6021000HS0FC	1.70	1066	1025	878	751	655	421	326	272	226	202	154	127	71.7
NGA6021000HS0FC	1.65	1175	1160	972	762	698	426	326	276	226	202	154	127	71.7
NGA6021000HS0FC	1.60	1310	1279	1054	799	729	426	326	276	226	202	154	127	71.7

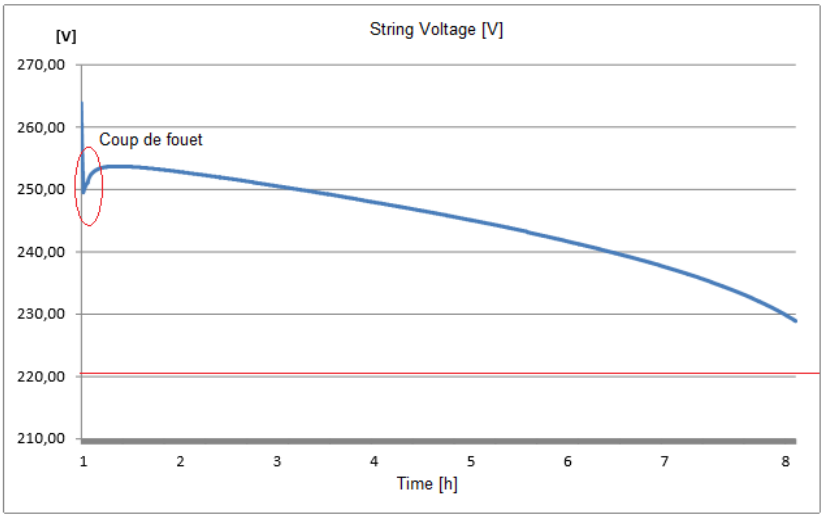
It is important to emphasize that current values are not adjusted for temperature. After completing the test and calculating the battery capacity it is necessary to perform a temperature compensation.
It is advantageous to use a powerful load bank or a load bank with an external current measurement feature, to measure and to include in the test the current that has been withdrawn from the battery by regular or any other additional connected load.
The load unit along with extra load unit was used in order to increase loading capability as shown in the Figure 7



Connection of Load bank and resistive external load to the battery
Figure 7

The terminal voltage was measured during the entire test as a function of time, and the battery should be discharged until it reaches the minimum terminal voltage, or once the total test time has been reached.

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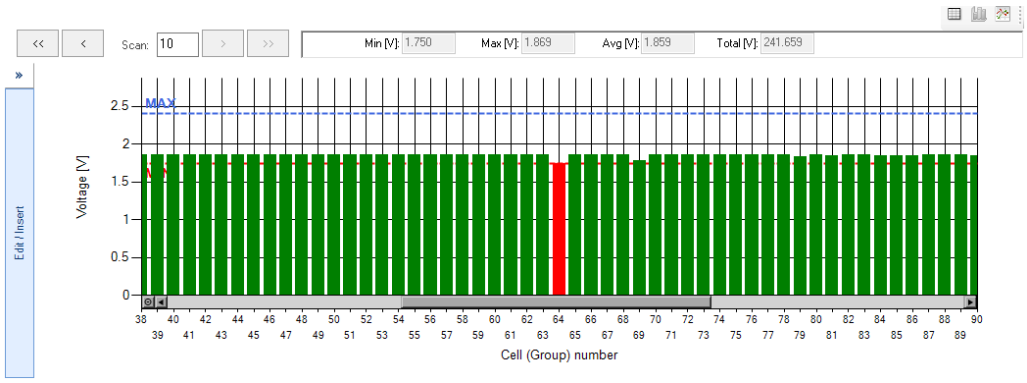


String Voltage as a function of time
Figure 8

Coup de fouet" phenomenon shown in the Figure 8 represents a dip in the voltage drop present on a fully charged battery at the beginning of the test. This drop in the voltage and the maximal voltage after the recovery are dependent on the battery age, discharge rate, float voltage, and other operating conditions. Due to that partial discharge with controlled load discharge will cause the Coup the fouet. It can be considered as a useful tool in determining the battery state of health.

During the entire discharge test, it is important to monitor a behavior of the cells within the string by measuring the cell voltages at least three times during the test. One measurement should be taken at the beginning of the test and the others at specified intervals. The sample rate should be more frequent when the voltage starts to decrease faster. This approach makes it easier to spot a bad cell and predict failures well in advance.

Individual cell voltages can be measured manually by using a handheld voltmeters or using an automated monitoring system. Voltages in this particular test were measured using the battery voltage recorder (cell by cell scanner) and voltage values of each cell scan is illustrated in the Figure 9.



Voltage of each cell with warning and stop limits
Figure 9

Note that in case of one cell voltage drops below the end voltage, the test should not be stopped and restarted once the failing cell was replaced, especially if it occurs early in the test. For example, if performing the 8-hours test, the week cell has to be bypassed within 6 minutes and the test continued. The general rule is a test interruption should be 10% of the test time if the test is interrupted for a longer

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time period and the string retested again, depending on the condition of remaining cells, some of them may fail and create more problems.

CAPACITY CALCULATION METHODS

The battery capacity is usually expressed in ampere – hours (Ah). However, the capacity at the end of the test is always expressed in a percentage of the manufacturer's published capacity. IEEE standards define the two methods for capacity determination. Once one test method has been chosen, for trending purposes it should be used during the battery's entire service life.

Time adjusted method

In the time adjusted method, the test current is kept constant as defined in the manufacturer's published table as a function of the selected test time duration. The battery capacity is calculated after the completion of the test by using the published performance data at 68˚F. This method is recommended for the test whose duration is longer than 1 hour.
The capacity in % is calculated as the ratio of an actual test discharge time to a published discharge time.

$$C\,\% = \frac{(T_a\, x\, 100)}{T_m x\, K_t}$$

C – Capacity at a specific temperature recommended by the manufacturer.
Ta – Actual time duration of the test until reaching the specified string end voltage
Tm – Manufacturer's rated time to reach the string end voltage
Kt – Temperature correction factor as per the IEEE standard.

Rate adjusted method

This method is recommended for performance or acceptance tests whose duration is one hour or less. There are two options of this method based on the discharge rate for testing: adjusting the manufacturer's recommended rating for the end of life condition or using the full recommended rate.
The adjusted manufacturer's rate method is preferred since testing an aged battery at a high rate may result in a short runtime. In this method, a time duration is kept constant and the rate is adjusted based on the derating factor in order to simulate the end of life condition (80% of the rated capacity).

Following this, from the Table 1, for a 15 min test and derating factor of 0.8, the rate needs to be adjusted from 764 A to 611 A. The test needs to be conducted with 611 A for 15 minutes until the end voltage is reached. The capacity is calculated using the following formula:

$$C\,\% = \frac{(X_a\, x K_c) x\, 100}{X_t}$$

C – Capacity at the specified temperature
Xa – Actual rate used for the test
Kc – Temperature correction factor as per the IEEE standard
Xt – Manufacturer's provided rating for time to reach the specified end voltage

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REPLACEMENT CRITERIA

The recommended practice is to replace the battery if its capacity is below 80% of the manufacturer rating. Following the test, it is necessary to review the battery sizing to conclude if the remaining capacity is sufficient for the battery to perform intended function. A capacity of 80% indicates the battery (cell or string) rate of deterioration is increasing even there is still a capability to support the load. Additional characteristics such as abnormality of the cell temperature and the cell voltage are often determinants for complete battery or cell replacements. The cell voltage is a good indicator for further investigation and cell replacement. In case we use replacement cells, it is important to ensure they have electrical characteristic compatible with the existing cells and they should be tested before installation. In case that only one or a few cells need to be replaced, the battery manufacturer should be consulted.

CONCLUSION

One of the main goals in the battery testing area, besides learning the real condition of the battery, is to reduce the test time. Several techniques and test systems are used today in order to achieve this goal. If we take a look at the battery manufacturer's publications, there are two parameters provided in these documents that a user should be referred to. These parameters are the capacity and the internal resistance. The battery capacity is the only proven way to judge the condition of the battery during the entire service life and it does not depend on the measurement equipment that is being used. The internal resistance measurement technique is not standardized and the techniques are proprietary. This paper offers the three general conclusions.

1. When conducted according to the applicable IEEE recommended practice and following the manufacturer's maintenance instructions, the periodic performance testing will not ruin the battery and cannot be considered as excessive or unnecessary. Using load banks with extended features enables users to increase a loading capability, reduces a test time, and in addition, creates less wear and tear of the battery.

2. A load bank that enables creating different load profiles can be used for internal resistance measurements, in order to observe significant changes in a battery condition. Depending on the degree of a change, a capacity test interval can be planed.

3. According to regulations set forth by NERC and IEEE, the battery capacity testing is recommended and should be performed properly. It is important to emphasize that all generation as well as transmission companies must be compliant with these regulations to avoid penalties.

Considering all the above, it is highly recommended that users involved in battery testing have a load bank available.

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BIOGRAPHY

Armin Fazlic is an application engineer at DV Power, Sweden. He earned his B.SC and M.Sc. EE degrees at the University of Sarajevo, Bosnia And Herzegovina. He is engaged as a technical support engineer for Middle East. After receiving his M.Sc., he has been working as a product manager for the battery testing instruments, including the Battery Load Unit – BLU series, one of the most advanced load banks in the market. He is involved in testing of the company's entire battery product portfolio, as well.

Velibor Vidić, B.Sc.E.E. is born in Sarajevo 1982. He works as an engineer at Electric Power Research and Development Center (IRCE a.d.) in East Sarajevo since 2007. He earned his B.SC degrees at the University of East Sarajevo, Bosnia and Herzegovina in 2006. He as engaged as a test engineer for testing transformers, motors and batteries .

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