

Battery Capacity Testing with Constant-Resistance Loads

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Abstract

Constant-resistance loads are relatively simple to construct using correctly sized power resistors connected either in series or series parallel. This paper explores the use of constant-resistance loads for battery capacity testing and provides data to demonstrate whether such a method is viable.

IEEE battery testing standards discuss establishing a baseline capacity after installation of the battery and then utilizing the same load test procedure to trend the capacity change over the lifetime of the battery. This would be possible with a constant-resistance load. However, a methodology would have to be established using constant-resistance loads to determine the percent capacity (and subsequently the rate of deterioration and the end of life) using the battery manufacturer's existing constant current data. This paper will propose such a test methodology and provide data to demonstrate the viability of the method.

Introduction

IEEE Standards for testing and determining battery capacity such as IEEE Std 450 for VLA (Vented Lead-Acid), IEEE Std 1188 for VRLA (Valve Regulated Lead-Acid) and IEEE Std 1106 for NiCad (Nickel-Cadmium) batteries refer to all tests being done with either constant current or constant power test loads. Most battery manufacturers have in fact published the performance of their batteries at constant current and/or constant power. However, limited work has been done using constant-resistance loads in determining battery capacity.

According to Ohm's law, current varies in direct proportion to the voltage, given a constant resistance. So when using constant resistance loads for testing battery capacity, as the voltage decreases so does the load current. This effect makes the interpretation of results using fixed resistance much more difficult in comparison to the much easier method using constant current loads. In UPS applications with constant power loads, as the voltage decreases the current increases. Because this is well characterized in applications, most battery manufacturers have determined their cells performance based on constant power. Where constant power values are not available estimated average voltages are often employed to convert constant power to estimated constant current load values. This paper will investigate whether similar techniques using average current is possible to aid in characterizing capacity based on constant-resistance loads.

Method

The first step was to compare the capacity of several batteries by using both constant current and constant-resistance loads. Two different battery types were selected for this test. One was a nominal 100Ah vented lead acid (VLA) battery, which we will designate battery X. The other a nominal 240Ah vented nickel cadmium battery, designated battery Y.

Background

Battery X

This is a battery which is 3 – 4 years old that is showing significant positive plate growth probably due to overcharge or other abuse. As a mature battery the capacity may have peaked. During the tests the battery had been operated in a controlled environment between 20 – 30°C. All individual cell voltages were measured to be within the manufacturer’s recommended operating limits. The battery is a lead-calcium alloy design consisting of 60 cells for a 130Vdc system. Constant voltage charging was used to charge the battery. Float voltage setting: 130.8Vdc (2.18Vpc), Equalize voltage setting: 139.8Vdc (2.33Vpc). All electrolyte levels were within the max/min electrolyte level lines of the cells. Specific gravity of a pilot cell was checked to verify manufactures requirements.

Battery Y

This is a new battery and therefore needed several charge-discharge cycles to stabilize the capacity. The battery was operated in a controlled environment between 20 – 30°C. All individual cell voltages were measured within the manufacturer’s recommended limits. The battery is a pocket-plate design consisting of 40 cells for a 48Vdc system. Constant voltage charging was used to charge the battery. Float voltage setting: 56.8Vdc (1.42Vpc), Equalize voltage setting: 62Vdc (1.55Vpc). All electrolyte levels were within the max/min electrolyte level lines of the cells.

Test Method

Before each discharge test the batteries were equalize charged and put on float charge for a minimum of 72 hours until the float current stabilized. Two (2) or three (3) different discharge rates were chosen for each battery. See Table 1 below:

Table 1

Battery	Discharge rate(time)	Battery end voltage	Cell end voltage
X	1 hour	105Vdc	1.75Vpc
X	4 hour	105Vdc	1.75Vpc
X	8 hour	105Vdc	1.75Vpc
Y	3 hour	40Vdc	1.00Vpc
Y	5 hour	40Vdc	1.00Vpc

Constant current discharges were performed at each discharge rate to establish a baseline battery capacity. After this, the same procedures were used to stabilize the capacity before performing the constant-resistance capacity tests.. During discharge tests individual cell voltages were monitored to ensure no cell voltage reversed or dropped to a critical level. Battery capacity was calculated based on the time to reach the overall battery end voltage.

Equipment

1. The constant current discharge load used for the constant current testing was manufactured by Eagle Eye, model: LB-48/125-100, rated 100Amps, 48/125Vdc.
2. The constant-resistance load consisted of series or series parallel 1.02 ohm stainless steel wound resistors on a ceramic core. Approximate wattage per resistor was 1,000 watts. The resistors were mounted in a well ventilated enclosure. An 850 cfm fan was placed in the bottom of the enclosure blowing up from the bottom onto the resistor network to provide consistent cooling.
3. Shunt, 50mV/150A, 0.25% accuracy

- 4. Data logging with a Sendyne SFP101, measurement acquisition-control and communication interface. Measured and recorded mV drop across the resistive shunt. All data was recorded at 1.0 second intervals.

Results

Determining average discharge current

The Manufacturer's constant current values were used in testing to determine baseline capacities. In order to make a comparison of the constant resistance capacities to the baseline values required a method to calculate average current over the discharge period. Since the discharge current curves are not linear for the constant resistance discharges, several techniques were investigated to find the best average values for the discharge current.

Essentially the constant resistance discharge current curve mirrors the discharge voltage curve. See the Figures 1A and 1B below. For the VLA battery the current curve is relatively flat with a drop at the end of discharge (Figure 1-A). The NiCad battery shows a distinctive drop at the beginning and end of the current curve and flat during the main discharge (Figure 1-B).

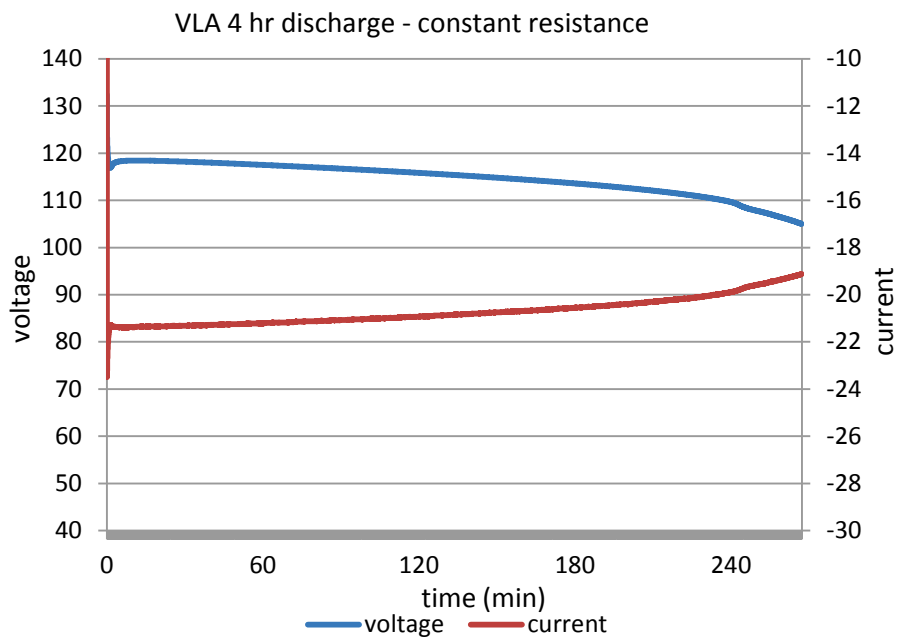


Figure 1-A

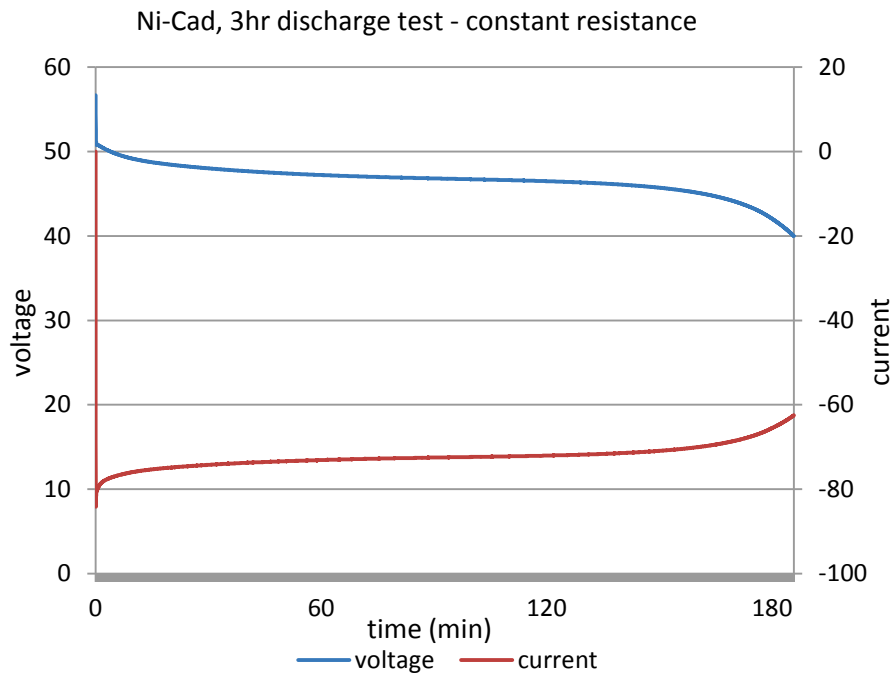


Figure 1-B

Several techniques were used to obtain the best value of the average of the discharge current, (e.g. analysis of variance, integration of the sum of the curves or using the median of the time axis). The result of these different methods for determining the average current resulted in differences in the final capacity determination of 0.3% from the average. Based on this small variation, the final decision was to use the average of the individual current values logged every 1 second during the discharge.

Discharge data comparison

For both battery technologies, discharge capacity tests were performed using the time adjusted method. The NiCad battery tests were performed at the 5 hour (nominal rating) and the 3 hour discharge rates. This avoided the higher discharge rates where the float effect has more influence. For the VLA battery three discharge tests were performed; one at the 8 hour (nominal rating), the 4 hour rate and the 1 hour rate. The manufacturer’s published performance data was used for the constant current testing to determine the baseline capacity for each test. The constant resistance loads were calculated to be as close as possible to the constant current published performance data using estimated average discharge voltages. Table 2 below shows the constant current discharge test values used and the average constant resistance current values calculated from the logged test data.

Table 2

Battery	Test run time	CC current (Amps)	Average CR current (Amps)
X-VLA	1 hour	72.0	75.2
X-VLA	4 hour	21.78	20.7
X-VLA	8 hour	13.4	13.5
Y-NiCad	3 hour	78.0	72.25
Y-NiCad	5 hour	42.7	43.95

The test capacity results comparing the constant current results to the constant resistance results are summarized below in Table 3.

Table 3

Battery	Test run time	Battery temp. constant current °C	Battery temp. constant resistance °C	Test end voltage (Vpc)	% capacity constant current (CC)	% capacity constant resistance (CR)	% difference from baseline (CC) capacity
X-VLA	1 hour	27.3	26.9	1.75	113.2	119.1	5.2%
X-VLA	4 hour	22.9	22.8	1.75	102.7	106.7	3.9%
X-VLA	8 hour	26.5	29.0	1.75	118.3	120.0	1.5%
Y-NiCad	3 hour	22.3	22.1	1.00	98.4	94.7	-3.8%*
Y-NiCad	5 hour	26.0	22.3	1.00	96.7	98.0	1.4%

* The 3 hour constant resistance discharge value for the NiCad battery appears to be an anomaly and the battery was probably not at 100% state of charge prior to discharge. Clearly, this data point needs to be retested.

Battery temperature was measured at the beginning of each test. Where appropriate the capacity temperature factor as referenced in IEEE450 and IEEE1106 was used to adjust the final capacity result.

Since battery manufacturers use various types of curves or tables to represent the performance of their batteries at specific discharge times and rates, a simplified procedure was needed to determine the discharge times of the average constant resistance loads. Typical curves representing discharge time vs Amps per positive plate (fan curves) are represented in IEEE Std 485, Appendix C. For nickel-cadmium batteries typical discharge tables are available for performance (in Amps) vs time.

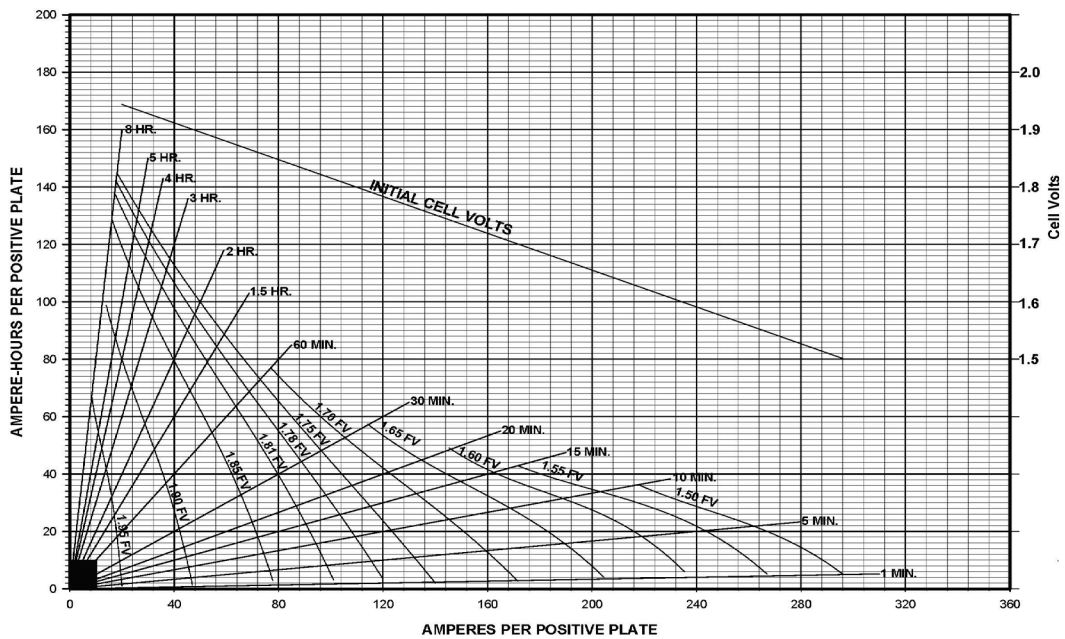


Figure 2. Typical fan-curve from IEEE Std 485, Appendix C⁴

As can be seen from the above fan-curve (Figure 2), both these relationships of Amps per positive plate and Performance (Amps) vs time are non-linear making it a tedious process to generate new curves or data for a specific average test load. Appendix A of IEEE Std 1115 implies that discharge times between K_t factors can be linearly interpolated. So if we can demonstrate linearity for both batteries between discharge times and K_t factors we should be able to use a simple linear interpolation procedure for determining the discharge time for our average test load.

The rated discharge time for each load either constant current or constant resistance was determined by the following procedure:

1. The discharge performance for each battery at different discharge times (t_n) was used to calculate a capacity factor (K_t) (ref.IEEE485/1115).

$$K_t \text{ factor} = \frac{\text{Ah capacity}}{\text{performance at } t_n}$$

2. These K_t factors were then plotted against the discharge time. As can be seen from the Figures 3-A and 3-B below, the relationship between the K_t factor and discharge time is nearly linear as expressed by the linear regression analysis trend line plot and R^2 coefficient (goodness of fit determination).

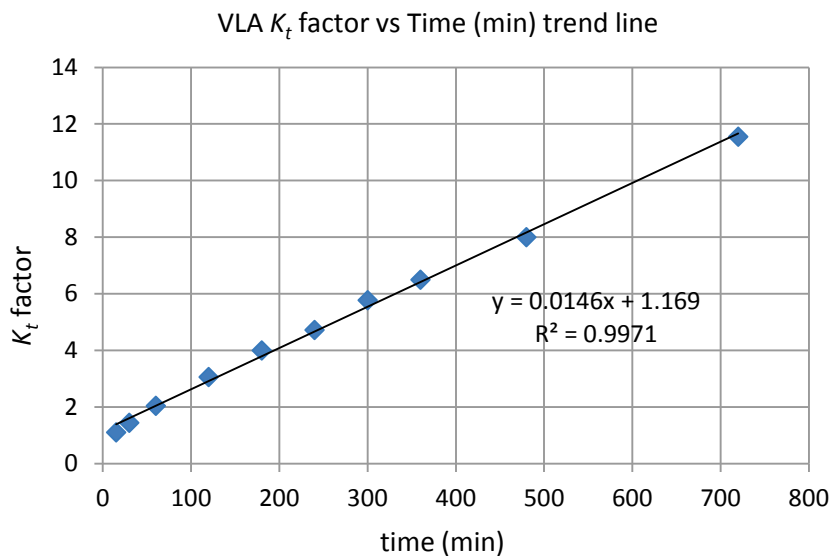


Figure 3-A

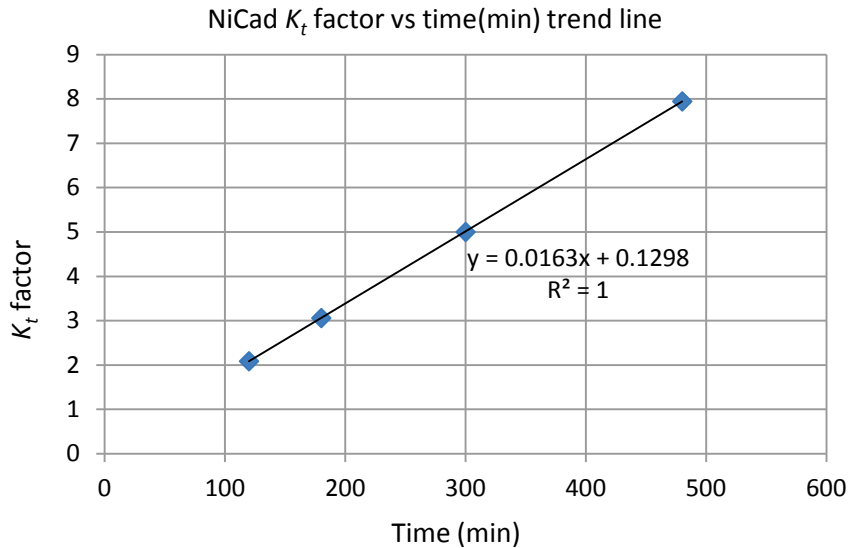


Figure 3-B

3. For a particular average discharge current a K_t factor was calculated.
4. The rated discharge time t is determined for a calculated K_t factor. Where discharge time t falls between two times (t_1 and t_2) for which related K_t factors are available (K_{t1} and K_{t2}), the time t is calculated for the calculated K_t factor by interpolation using the following formula.

$$t = t_1 + \frac{(t_2 - t_1)(K_t - K_{t1})}{(K_{t2} - K_{t1})}$$

5. The time adjusted percentage of capacity was calculated from IEEE450/1106 using the rated time determined above:

$$\% \text{ of nominal capacity} = \left[\frac{\text{Time to end voltage}}{(\text{Rated time}) \times (\text{Temperature correction factor})} \right] \times 100$$

Conclusions

In all cases, the capacity measured by constant resistance is greater than that measured by constant current. This is due to the fact that the current drops off as the voltage decreases. The amount of this deviation is discussed and graphically represented in the graphs below where the constant current and constant resistance curves are overlaid onto a single graph for both the VLA and Ni-Cad batteries.

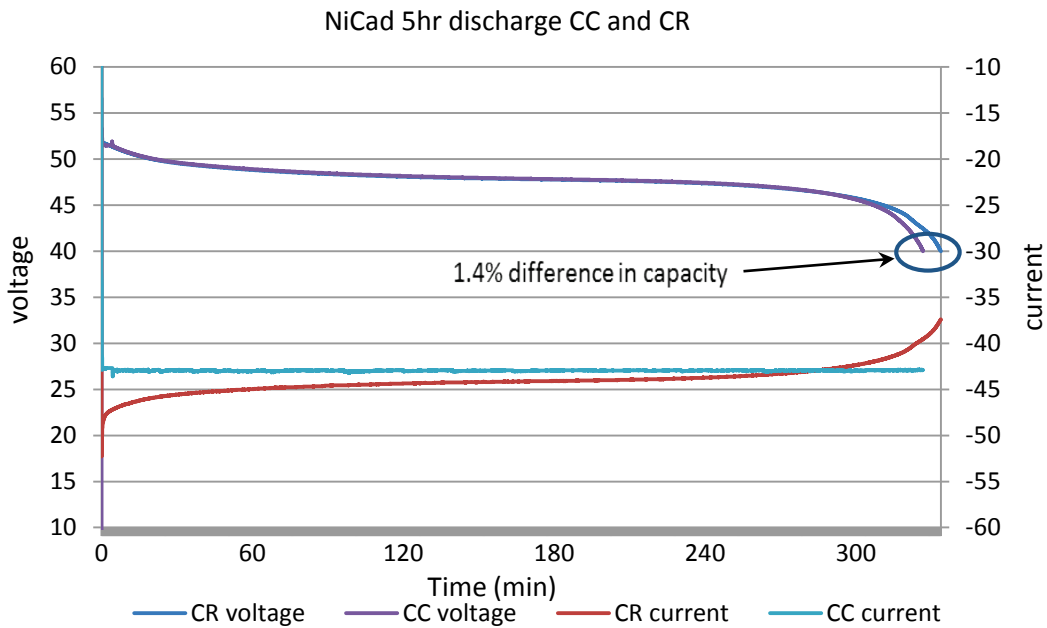


Figure 4

Figure 4 above shows the tested Ah capacity differences for the constant current and constant resistance tests of the Ni-Cad battery at the 5hr discharge rate.

- Constant current discharge: The time to the end voltage of 1.00Vpc is 321.68 minutes at 42.7 Amps. The calculated percentage of nominal capacity is 96.7%.
- Constant resistance discharge: The time to end voltage of 1.00Vpc is 326.67 minutes at 43.95 Amps average discharge load. The calculated percentage of nominal capacity is 98.0%.
- The difference in capacity is +1.4% from the baseline capacity.

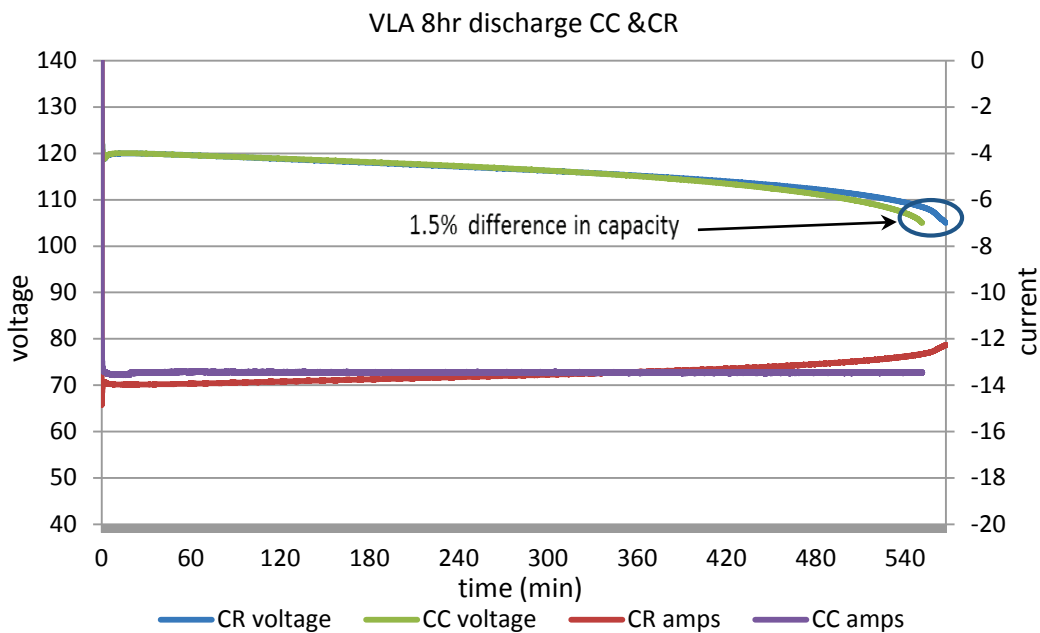


Figure 5

Figure 5 above shows the tested Ah capacity differences for the constant current and constant resistance tests of the VLA battery at the 8hr discharge rate.

- Constant current discharge: The time to the end voltage of 1.75Vpc is 551.2 minutes at 13.4 Amps. The calculated percentage of nominal capacity is 118.3%.
- Constant resistance discharge: The time to end voltage of 1.75Vpc is 567.5 minutes at 13.5 Amps average discharge load. The calculated percentage of nominal capacity is 120.0%.
- The difference in capacity is +1.5% from the baseline capacity.

As the discharge test time decreases the percent deviation from baseline increases. From Table 3 above the percentage difference of the constant resistance capacity from the baseline constant current capacity for the VLA battery is graphed in Figure 6. This shows a clear relationship between time of discharge and percentage deviation of the capacity from the baseline.

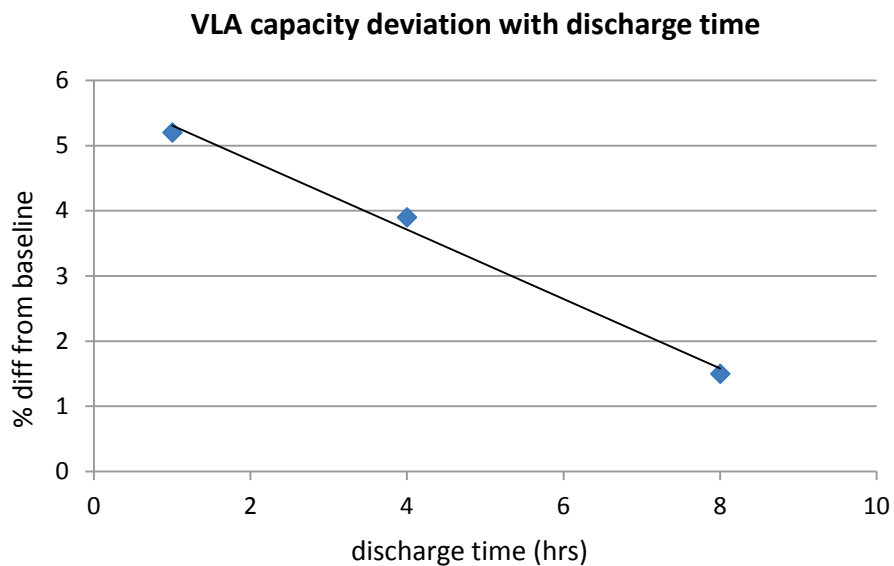


Figure 6

These percentage differences in capacity determination are fairly small, particularly for the longer discharge times. As long as these differences in percentage of capacity are understood and accounted for, it is possible to determine overall capacity and capacity trending for battery replacement using constant resistance testing.

On-going testing is continuing to validate the conclusions of this paper. In addition the capacity determination by the constant current or constant resistance method has some inherent variability which is dependent on many factors, i.e., equipment, operator, environment, etc. Future testing will try to establish typical variation in the capacity measurement process.

These tests were conducted with batteries with healthy cells and the possible effects of voltage drops due to weaker cells was not investigated. However, individual cell voltages were monitored during the tests. If any cell voltage approached zero volts, it would be bypassed in accordance with procedures specified in IEEE Std 450.

Other techniques for dealing with the resistance drop near the end of the discharge test, such as switching in an additional constant-resistance load were not considered for this paper. The intent was to quantify the effects of a single fixed constant-resistance load on the determination of battery capacity.

The advantages of constant resistance testing are logistic and economic where a user has a large number of sites, where portability of test loads is limited or prohibitive, or economies of scale prohibit purchase of large numbers of constant current test loads.

References

1. IEEE Std 450-2010, Recommended Practice for Maintenance, Testing and Replacement of Vented Lead-Acid Batteries for Stationary Applications
2. IEEE Std 1188-2005, Recommended Practice for Maintenance, Testing and Replacement of Valve-Regulated (VRLA) Lead-Acid Batteries for Stationary Applications
3. IEEE Std 1106-2015, Recommended Practice for Maintenance, Testing and Replacement of Vented Nickel-Cadmium Batteries for Stationary Applications
4. IEEE Std 485-2010, Recommended Practice for Sizing Lead-Acid Batteries for Stationary Applications
5. IEEE Std 1115-2014, Recommended Practice for Sizing Nickel-Cadmium Batteries for Stationary Applications