

A Comparison of Calculated Battery Capacity Using the Current IEEE 450 Method and a Proposed Alternate Method For High Rate Discharge Applications

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Abstract

There is an on-going debate within the battery industry today regarding the correct method for calculating the capacity of a battery in a high-rate discharge application, such as an Uninterruptible Power Supply (UPS) battery plant. The contention is that the end-of-life requirement is for the battery to provide 80% of the published rate for 100% of the time as suggested through IEEE 485-1997 'Recommended Practice for Sizing Lead-Acid Batteries for Stationary Applications.' However, when the battery is tested in accordance with IEEE 450-1995, 'Recommended Practice for Maintenance, Testing, and Replacement of Vented Lead-Acid Batteries for Stationary Applications', the end-of-life measurement is when the battery provides 100% of the published rate for 80% of the time. It is argued that the existing method in IEEE 450 will suggest that the battery is apparently aging more rapidly than it actually is aging. The capacity calculation method in IEEE 450 is not consistent with the end-of-life requirement set forth in the sizing criteria found in IEEE 485.

This paper will show calculations based on the present method in IEEE 450 and a proposed alternative method, including the resulting difference in the calculated capacity, for flooded lead acid and valve regulated batteries in high-rate discharge applications.

Introduction

In performing a comparison between the two methods, it is necessary to ask *What is the motivation for this exercise?* Is it purely an academic interest? Is the disparity such that the method used will provide misleading or incorrect information?

The possible implications of a difference in the calculated capacity of a battery due to the method used goes beyond an inconsistency between two published industry standards.

The performance of annual load testing and the subsequent calculation of battery capacity are used by many to proactively manage their stationary battery plant. In a critical power application, this information is essential not only in planning against the replacement of the battery, but also in providing a degree of comfort that the system will perform to its maximum potential if required to do so.

This proactive approach is quite evident in mission critical businesses relying on Uninterruptible Power Systems (UPS). In the application of an UPS the potential impact from the failure of a battery could have a significant financial impact to the business enterprise. Many businesses are adopting this proactive approach in the support of their UPS battery plants and are including annual load testing as part of an aggressive maintenance program.

An UPS battery is by design intended for a High Rate Discharge. For the purposes of the comparison between the present and proposed methods, batteries associated with UPS load tests were selected. The analysis compares test data for different discharge rates between 5 minutes and 1 hour, 20 minutes.

Test Procedure

Before we compare the data, it is important to review the test methodology used. A typical method for testing an UPS battery includes the following:

- 1) Isolate the critical load. This may be accomplished by placing the load on a *Maintenance Bypass* source. This *Bypass* is a wrap around path to the UPS.
- 2) Place a resistive load bank on the output of the UPS.
- 3) Establish full load on the UPS. For example an UPS module rated 150 kVA, 120 kW would be loaded to its maximum capacity of 120 kW.
- 4) While monitoring the battery, including overall DC voltage, current and individual cell voltages, fail the AC input to the UPS.
- 5) During the battery discharge, the overall DC voltage, current and individual cell voltages are monitored and the data recorded for later analysis.

6) The test is terminated either when the UPS reaches its pre-set shutdown voltage or by restoring the normal input.

The load may not necessarily be at the full load rating of the module. Performing a load test at less than the rated capacity of the system is sometimes employed and is often referred to as a *Performance Test*. The procedure outlined above will remain essentially the same. The length of the discharge may be longer than at full load. On this point it should be noted that the UPS may shutdown at a higher voltage during a prolonged battery discharge. This provision is often available where Valve Regulated Lead Acid (VRLA) batteries are used to assure that the battery is not discharged for a prolonged period.

Data Analysis

Existing Method for Calculating Capacity

The existing method for calculating the capacity as per IEEE 450 is based on the following formula:

$$\% \text{ Capacity at } 25^{\circ}\text{C (77}^{\circ}\text{F)} = [T_a/T_s] \times 100$$

where

- T_a is actual time of test to specified terminal voltage
- T_s is rated time to specified terminal voltage

Procedurally this includes the following:

- A) Average the kW load applied to the battery for the duration of the load test. This is essentially the product of the measured battery terminal voltage and current averaged over time.
- B) Calculate the kW per cell (or monoblock). The average measured kW for the battery is then divided by the number of cells in the string.
- C) Adjust the average kW per cell for the initial electrolyte temperature. The method presented in IEEE 450 recommends using a Temperature Correction Factor to adjust the discharge power rate prior to testing. It is suggested that the power rate should be **divided** by the temperature correction factor to determine the test load. In AC testing of UPS battery systems the measured load is adjusted **after** the completion of the test. The average measured kW is **multiplied** by the Temperature Correction Factor. Battery Capacity is calculated based on the adjusted power rate.
- D) The calculation is the actual *Time* at the adjusted test rate divided by the rated *Time* for the load applied. The manufacturers discharge tables for the battery model are used to determine the published time at the adjusted rate to reach system end voltage (ex. 1.67 VPC). This may require interpolating for times that are not provided in the tables.

The following sample calculation sheet illustrates this procedure.

Capacity Calculation Sheet

BATTERY CAPACITY CALCULATIONS									
CONFIGURATION		VOLTAGE		TEMPERATURE		BATTERY TEMPERATURE		CORRECTION	
BATTERY TYPE	CELLS PER STRING	YCB	LCB	77	77	Battery Temperature Deg. F.	1	Temperature Compensation Coefficient	200.0
BATTERY NAME	2887	YCB	LCB	77	77	Temperature Compensation Coefficient	1	Temperature Compensation Coefficient	200.0
Number of parallel strings of cells	12	YCB	LCB	77	77	Temperature Compensation Coefficient	1	Temperature Compensation Coefficient	200.0
0:00	1680	310.3	517.8 kW	Rated Discharge at	10	Minutes	200.0	Average Watts/Cell	
0:30	1684	308.4	526.1 kW	Watts/Cell	600	Seconds	LOW		
1:00	1782	307.7	525.7 kW	Rated Discharge at	3	Minutes	200.0		
1:30	1711	306.3	524.8 kW	Watts/Cell	300	Seconds	200.0		
2:00	1721	304.2	523.5 kW	Rated Discharge at	1011.00	Minutes			
2:30	1721	302.2	523.3 kW	Watts/Cell					
3:00	1741	300.7	523.3 kW	Rated Discharge at	1.71	Minutes			
4:00	1782	298.8	523.3 kW	Watts/Cell					
4:30	1783	298.6	523.3 kW	Rated Discharge at	22.72	Minutes			
5:00	1774	294.8	523.3 kW	Watts/Cell					
5:30	1796	292.5	523.3 kW	Rated Discharge at	271.68	Minutes			
6:00				Watts/Cell					
6:30				Rated Discharge at	250.00	Minutes			
7:00				Watts/Cell					
7:30				Rated Discharge at	62.80	Minutes			
8:00				Watts/Cell					
8:30				Rated Discharge at	1.71	Minutes			
9:00				Watts/Cell					
9:30				Rated Discharge at	22.72	Minutes			
10:00				Watts/Cell					
10:30				Rated Discharge at	271.68	Minutes			
11:00				Watts/Cell					
11:30				Rated Discharge at	250.00	Minutes			
12:00				Watts/Cell					
12:30				Rated Discharge at	62.80	Minutes			
13:00				Watts/Cell					
13:30				Rated Discharge at	1.71	Minutes			
14:00				Watts/Cell					
14:30				Rated Discharge at	22.72	Minutes			
15:00				Watts/Cell					
15:30				Rated Discharge at	271.68	Minutes			
16:00				Watts/Cell					
16:30				Rated Discharge at	250.00	Minutes			
17:00				Watts/Cell					
17:30				Rated Discharge at	62.80	Minutes			
18:00				Watts/Cell					

Figure 1

Proposed Method for Calculating Capacity

The proposed method suggests that a discharge curve should be constructed for the cell under test. The curve is constructed for a predetermined end voltage. The curve is plotted using the manufacturers published discharge tables for the cell model.

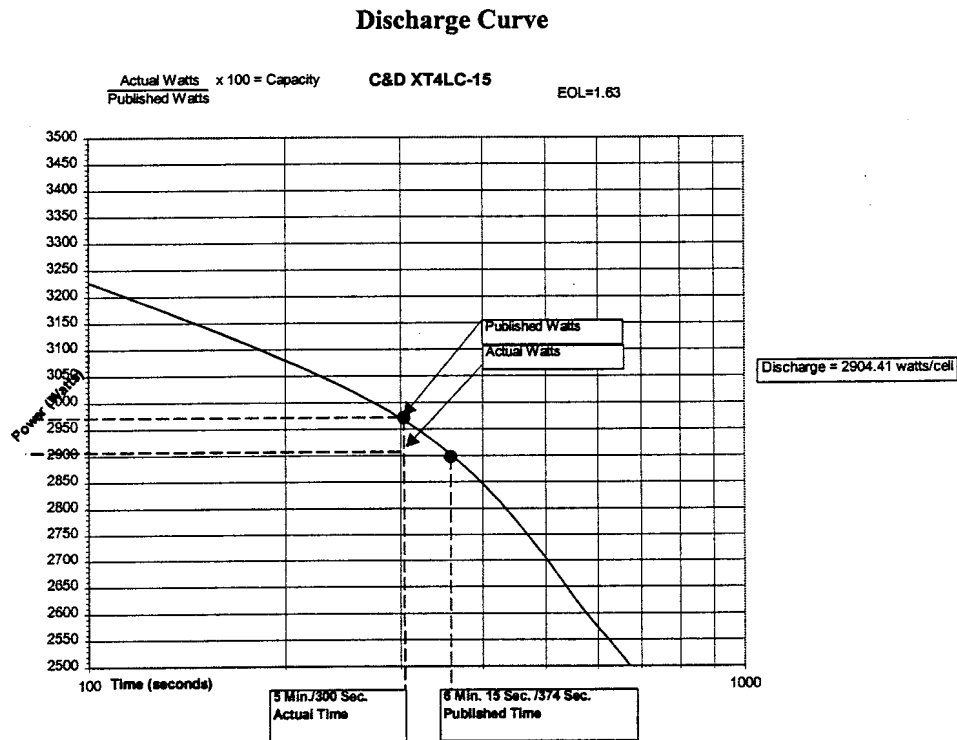
Using the steps outlined in A) through C) above, the adjusted discharge rate is calculated for the capacity calculation using the curve as follows.

- a) A horizontal line representing the adjusted discharge rate (*Watts*) is drawn to an intersection on the curve. This line may extend beyond the curve or fall short of the curve depending on the actual discharge time.
- b) If the horizontal line stops on the curve, the capacity is 100%. A vertical line drawn from the point of the curve representing the adjusted rate to an intersection on the x-coordinate (*Time*) will yield the published time to the selected end voltage.
- c) If the horizontal line falls short of the curve a vertical line is erected up to an intersection on the discharge curve. A second horizontal line is drawn from the intersection point to the vertical scale representing *Watts*
- d) If the horizontal line extends beyond the curve, a vertical line is erected down to an intersection on the discharge curve. A second horizontal line is drawn from the intersection point to the vertical scale representing *Watts*

The calculated capacity is the *Watts* (W_a) identified with the actual run time divided by the *Watts* (W_t) derived from the discharge curve multiplied by 100.

$\% \text{ Capacity} = [W_a/W_t] \times 100$, where temperature compensation has been factored into the 'actual' Watts.

The following graph depicts a discharge curve constructed in this manner.



Comparative Analysis

A comparative analysis was performed of several Flooded Lead Acid and VRLA batteries. The following table represents four (4) Flooded and three (3) VRLA batteries chosen for different discharge rates from a nominal 5 minutes to 1 hour, 20 minutes. The data is organized in ascending order for the Actual Time recorded for each test sequence.

Capacity Calculations Using Existing Method

Flooded	Time (Min.)		Capacity
	Published Time	Actual Time	
C&D XT4LC-15	6.3	5.5	87%
C&D XT2LCP-25	12	10.5	88%
EXIDE 4DX-17B	9.9	12.5	126%
C&D XT1LC-35	28.52	30	105%
C&D XT4LCP-13	31.2	32	103%
<hr/>			
Valve Regulated Lead Acid	Published Time	Actual Time	Capacity
C&D LS6-50	13.5	12	89%
JC UPS12-370	14.2	15	106%
JC UPS12-310FR	64.4	80	124%

Table 1

Capacity Calculations Using Proposed Method

Flooded Cell	Power (Watts)		Capacity
	Published Watts	Actual Watts	
C&D XT4LC-15	2967	2906	98%
C&D XT2LCP-25	3725	3644	98%
EXIDE 4DX-17B	2720	2962	109%
C&D XT1LC-35	3820	3926	103%
C&D XT4LCP-13	1240	1265	102%
<hr/>			
Valve Regulated Lead Acid	Published Watts	Actual Watts	Capacity
C&D LS6-50	176	167	95%
JC UPS12-370	340	355	104%
JC UPS12-310FR	80	102	128%

Table 2

Calculated Capacity Comparison

Battery Model	Existing Capacity Calculation Method	Proposed Capacity Calculation Method	Percent Deviation
Flooded			
C&D XT4LC-15	87%	98%	- 11%
C&D XT2LCP-25	88%	98%	- 10%
EXIDE 4DX-17B	126%	109%	+ 17%
C&D XT1LC-35	105%	103%	+ 2%
C&D XT4LCP-13	103%	102%	+ 1%
Valve Regulated Lead Acid			
C&D LS6-50	89%	95%	- 6%
JC UPS12-370	106%	104%	+ 2%
JC UPS12-310FR	124%	128%	- 4%

Table 3

The data suggests that the calculated capacity for the Flooded cells and VRLA batteries at the five and ten minute rate is significantly different between the two methods. However, the calculated capacity using the existing method produced battery capacities greater than the proposed method in four (4) of the samples. The calculated capacity for the Exide battery was significantly greater using the existing method. A review of the curve developed for this cell indicates a very steep slope related to the Watts vs. Time computation.

Differences in the calculated capacity of 1 to 2 percent may be due to inaccuracies in the interpolation or curve construction process.

It was expected that a convergence in the calculated capacity for each method should occur for the low rate discharges exceeding one hour. The data suggests that the disparity is less as the discharge rates decrease.

Conclusion

The test data indicates that there is a difference in the calculated capacity of a battery between the existing and proposed methods for high rate discharges. The difference is more evident in discharge rates less than 30 minutes. The curve construction related to the proposed method may yield results that are counterintuitive to the expected figures. Since the curve is constructed from the manufacturers supplied discharge data, these unusual results could be due to discrepancies in the data provided. This is particularly true where an interpolation is the primary source for the curve construction.

Additional comparative analysis is indicated. Manufacturers data should include both tabular and graphical information to help resolve potential inaccuracies.

There still exists a school of thought that in a UPS application, the point when the battery can no longer support the rating of the system for 80% of the specified time is when the battery should be considered for replacement. Therefore the calculation of battery capacity may be a moot point. As noted above, some calculation is still required to adjust the load for temperature. It is also clear that given the above method of testing, the actual load on the UPS may vary significantly due to factors such as the output voltage setting on the UPS and the test personnel's ability to adjust the resistive load bank.

Other arguments contend that where the *Existing Method* for capacity calculation is used, an allowance should be made for the sizing calculations, which allow an aging factor and must not be overlooked when performing such calculations. Often the testing company does not have that information at hand.

Now that we have explored an alternate method for calculating battery capacity, the industry has produced an atmosphere of doubt in the testing methodology and the conclusions of individuals using the existing method. A consensus is mandatory to not only address an inconsistency in the present standards, but to also alleviate these doubts and provide direction for those conscientious users who seek to effectively manage their critical systems.

Bibliography

IEEE Std. 450-1995. IEEE "Recommended Practice for Maintenance, Testing and Replacement of Vented Lead-Acid Batteries for Stationary Applications."

IEEE Std. 485-1997. IEEE "Recommended Practice for Sizing Lead-Acid Batteries for Stationary Applications."

Acknowledgements

Brian Thornton of Power Engineering, Inc., for help in organizing and analyzing data.

Jim McDowall, SAFT America, for input on the contents of this paper.