Final Test Results on the 80% Service Test and a Path Forward

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Introduction

The concept of a new type of service test was proposed at Battcon in 2010[1]. Initial test results for the proposed 80% Service Test were presented at Battcon 2012[2]. The remaining conceptual testing has been completed and test results have been evaluated.

Currently within the electric power industry and especially at nuclear plants, performance discharge tests are used for condition monitoring, and service tests are used to verify a battery meets its design duty cycle. These types of battery discharge tests are described in detail in IEEE 450-2010[3]. With some modifications to the service test duty cycle and to the condition monitoring methodology, some of these discharge tests can be eliminated by the proposed 80% Service Test.

The proof-of-concept testing described in the earlier Battcon paper[1] consists of 4-hour and 72-hour discharge tests on nominal 12 volt strings of vented lead acid batteries representing existing and future nuclear plant applications. Conventional performance tests were done to provide percent capacity comparisons. The load profile consists of a high first minute peak at 80% of rating followed by a lower stable discharge at 80% of rated current for the remainder of the duty cycle duration.

This paper presents the final conceptual test results and a path forward to support implementation of this test in non-nuclear and nuclear generating station applications.

Summary of Test Processes

Three different battery models were used, consisting of a nominal 12-volt string using six cells connected in series. Standard intercell connectors were used. Automatically-controlled battery discharge equipment was used in each of three separate test locations. Laboratory grade instrumentation was used for measuring and recording the test data. Critical data was recorded at least every 30 seconds.

After the receipt inspection, a complete set of initial readings were taken. The cells were given a boost charge and place on float prior to starting the test sequences. Initial time-adjusted performance tests were run to establish the benchmark capacity.

Four-hour 80% Service Tests were run to simulate batteries used in the existing nuclear plants. Seventy-two hour 80% Service Tests were run to simulate batteries used in the passive design nuclear plants. A variety of final voltages were used to simulate the range of voltages seen in the field.

The battery models used and their nominal ratings are given below.

Table 1 - Models Tested and Nominal Ratings

Manufacturer	Model	Nominal 8 hr. A-h Rating
Exide/GNB	NCN-27	1944
C&D	LCR-25	1800
Enersys	GC-17M	1540

The various test sequences are summarized in Table 2 below.

Table 2 - Test Sequences Run on the Different Models

Test Description	NCN-27	LCR-25	GC-17M
Performance Test	4-hr to 1.75VPC	8-hr to 1.75 VPC	---
First 4-hr 80% Service Test	To 1.75 VPC	To 1.75 VPC	---
Second 4-hr 80% Service Test	To 1.81 VPC	To 1.80 VPC	---
Third 4-hr 80% Service Test	To 1.86 VPC	---	---
Fourth 4-hr 80% Service Test	To 1.90 VPC	---	---
Performance Test	8-hr to 1.75 VPC	8-hr to 1.75 VPC	8-hr to 1.81 VPC
First 72-hr 80% Service Test	1.90 VPC	To 1.75 VPC	1.81VPC
Second 72-hr 80% Service Test	1.85 VPC	To 1.80 VPC	1.75 VPC
Third 72-hr 80% Service Test	1.81 VPC	---	---
Fourth 72-hr 80% Service Test	1.75 VPC	---	---
Performance Test	8-hr to 1.75 VPC	8-hr to 1.75 VPC	8-hr to 1.75 VPC

Note: 80% Service Tests prefixed by “To” were run to the stated final voltage. Others were stopped at end of the duty cycle.

All of the performance tests were done using the time-adjusted methodology from IEEE 450[3]. Some of the 80% Service Tests were stopped at the end of the duty cycle as would normally be done. However, some tests were continued to final voltage to provide another capacity value for comparison purposes. Testing on the NCN-27 cells was done first and the initial results reported in an earlier Battcon paper[2]. This paper is the first report on testing of the other two battery models.

Capacity Test and Calculation Methods

The normal time-adjusted method[3] was used for the baseline performance tests. Some variation was used in the test duration and final voltage to facilitate comparison with the capacity values derived from the 80% Service Test. Several capacity calculation methods have been considered for use with the 80% Service Test[2]. Several factors have been considered in this process including the following general industry practices[3].

1. The same capacity testing method should be used throughout the life of the battery (Clause 6.2)[3].
2. The performance tests should be similar in duration to the service test (Clause 6.3.a)[3].
3. The rate-adjusted performance test can be run at the end of life (80%) rate (Clause 7.4.3.2)[3].
4. In either method, the performance test is carried to final voltage, unlike the 80% Service Test.

For simplicity and consistency, the time-adjusted method was initially considered due its prevalence in the industry. The standard time-adjusted method cannot be used with 80% Service Test since the discharge is not carried to final voltage, as discussed in the original proposal paper[1]. However, the calculation method used for the Type 3 Modified Performance Test was considered, to account for the total discharge capacity in ampere-hours removed during the test. The dilemma then became what rated capacity was to be used for comparison since the discharge did not go to final voltage and the discharge rate used was only 80% of the full rating. The mathematical manipulation of the equations in the first paper[1] indicated the rate-adjusted method may best fit the 80% Service Test. With either method, the 80% Service Test satisfies the second factor in the list above in the sense that the 80% Service Test always stops at the end of the duty cycle and this voltage will be used to calculate capacity. The 80% Service Test is definitely consistent with the rate-adjusted method in being run at 80% of the published rating as indicated by factor 3 above.

In the second paper,[2] a two-part rated-adjusted capacity calculation method was introduced. This method calculated the first minute and remaining duration capacities separately and then combined them using a proportioning process to combine them into one percent capacity value. After further consideration, the decision was made to keep the capacities for these two divergent rates separate for trending purposes. The first-minute capacity data will be evaluated along with the other service test results, and the remaining duration capacity will be used for trending for aging.

One other consideration in using the rate-adjusted method is related to determining a benchmark capacity at some point in the service life of a battery. For example, if there is a downward trend in capacity using the 80% Service Test capacity, then the next test can be continued at the same rate until final voltage is reached. This data can then be used to verify the earlier trend using the rate-adjusted method without having to do another time-adjusted performance test.

Now we will review the use of the rate-adjusted capacity calculation formula for the 80% Service Test.

Rate-Adjusted Capacity Calculations

The rate-adjusted capacity calculations were done using formula (2) in Section 7.4.3.5 of IEEE 450[3].

$$\%Capacity = \frac{X_a \times K_C}{X_t} \times 100$$ *Formula (2)*

Where: *X_a = actual rate used for the test,*
X_t = published rating for time t,
t = time of test to specified terminal voltage,
K_C = temperature correction factor (see Table 2)[3].

There are two variations in using this formula in the capacity results shown below. For calculating capacity for the 80% Service Test, the time, *t*, for the test is always the same as the duty cycle duration. The voltage measured at the end of the test is used to determine the published rating, *Xt*, for use in the calculation. This variation will be the one most commonly used for the 80% Service Test. When it is desired to obtain another full capacity value for trending, then the test will be carried to rated final voltage and the formula will be used in the more tradition fashion.

Comparison of Test Results

The critical data measured and recorded during each test sequence were the initial electrolyte temperatures, the discharge rates, the voltage at the end of the service test (240 minutes) and the time to rated end voltage. This data was converted as required and entered into the rate-adjusted capacity calculation formula to determine a percent capacity for the first-minute, the remaining discharge period, and the full extended period to end voltage when used. The four-hour test results are summarized in the table below. The test sequences proceeded from left to right with respect to time.

Some general comments may be helpful before beginning the detailed comparison of the test results. The first minute portion of the test is designed to assess the integrity of the internal grid structure and connections. High resistance internal components and connections may be identified during this portion of the test.

First Minute Results Comparison

Table 3 - First Minute Capacity Comparison

Cell Model	Type of Test	1.75VPC	1.80/1.81VPC	1.85/1.86VPC	1.90VPC
NCN-27	**4-hr ST**	104%	102%	101%	93%
	72-hr ST	115%	115%	113%	94%
LCR-25	**4-hr ST**	108%	106%	---	---
	72-hr ST	103%	103%	---	---
GC-17M	**72-hr ST**	115%	116%	---	---

There is a wide spread in the capacity values of these results. This measurement can provide a qualitative measure of cell/battery integrity for now. Future enhancements in measurement techniques can provide a more consistent basis for better trending. This is one area for further research and refinement.

Four-Hour Results Comparison

Table 4 - NCN-27 4-Hour Trending Capacity Comparison

Parameter	1.75 VPC	1.81 VPC	1.86 VPC	1.90 VPC
% Capacity from Initial 4-hr Performance Test (%PT)	100.6%	100.6%	100.6%	100.6%
% Capacity for 80% Service Test (%ST)	100.2%	101.1%	101.1%	99.9%
% Difference: (%ST - %PT)	**- 0.4%**	**0.5%**	**0.5%**	**- 0.7%**

This initial series has the smallest variation in capacity. The performance test was run at four hours the same as the service tests. This is in agreement with the second industry practice listed above.

Table 5 - LCR-25 4-Hour Trending Capacity Comparison

Parameter	1.75 VPC	1.80 VPC
% Capacity from Initial 8-hr Performance Test (%PT)	107.4%	107.4%
% Capacity for 80% Service Test (%ST)	111.0%	111.2%
% Difference: (%ST - %PT)	**3.6%**	**3.8%**

The percent capacity values for the four-hour 80% Service Tests are within 0.7% of the percent capacity of the initial four hour performance test. This confirms that the 80% Service Test can deliver accurate percent capacity values for use in condition monitoring at the four hour rate. The larger variation, when compared to the initial eight hour performance test, is attributed to the difference in durations of eight versus four hours. The four hour testing was designed to simulate duty cycles for the existing nuclear plants.

72-Hour Results Comparison

Table 6 - NCN-27 72-Hour Trending Capacity Comparison

Parameter	1.90 VPC	1.85 VPC	1.81 VPC	1.75 VPC
% Capacity on Performance Test (%PT)	101.2%	101.0%	101.0%	100.2%
% Capacity for 80% Service Test (%ST)	101.5%	102.9%	102.1%	103.4%
% Difference (%ST - %PT)	**0.3%**	**1.9%**	**1.1%**	**3.2%**

Note: Three 8hr Performance Tests used: Initial, Intermediate and Final

Table 7 - LCR-25 72-Hour Trending Capacity Comparison

Parameter	1.75 VPC	1.80 VPC
%Capacity on Performance Test (%PT)	102.4%	102.7%
% Capacity on 80% Service Test (%ST)	104.2%	105.1%
%Difference: (%ST - %PT)	**1.8%**	**2.4%**

Note: Two 8hr Performance Tests used: Initial and Final

Table 8 - GC-17M 72-Hour Trending Capacity Comparison

Parameter	1.81 VPC	1.75 VPC
% Capacity on Performance Test (%PT)	109.9%	103.3%
% Capacity on 80% Service Test (%ST)	106.8%	106.0%
% Difference: (%ST - %PT)	**- 3.1%**	**2.7%**

Note: Two 8hr Performance Tests used: 1st to 1.81, 2nd to 1.75vpc

The percent capacity values for these seventy-two hour 80% Service Tests are within 3.2% of the percent capacity of the corresponding benchmark performance test capacity. These results indicate the 80% Service Test can deliver percent capacity values but more refinement will be needed for use in condition monitoring at the seventy-two hour rate. The 72-hour testing was designed to simulate long duration duty cycles for the new passive design nuclear plants.

Going forward, the normal performance tests would not be used for benchmarking capacity. The intent is to run the 80% Service Test continued to end voltage as the factory acceptance test and, thereafter, only run 80% Service Tests to end time through the remainder of the battery service life. When a performance test is needed to verify capacity, the 80% Service Test would be continued to end voltage.

Summary and Observations

The test sequences run at the higher end voltages provide some insights into the practical application of the 80% Service Test for those plants using higher end voltages.

The four hour results in particular provide percent capacity data with reasonable resolution that could be used for condition monitoring. Some less critical applications could be used as test beds for the 80% Service Test and would be very helpful going forward. Additional 72-hour testing is needed to confirm the resolution on the capacity results and to gather additional extended data points at 72 hours and beyond for the higher end voltages.

The smaller differences in capacity are associated with the first 4-hour test sequences where a 4-hour performance test was used as the benchmark. As differences in durations diverge to 8 hours for the performance test and 72 hours for the service test, so do the differences in capacity. This divergence was expected but will not have an effect in actual practice since the same durations will be used throughout the service life of each battery.

One observation concerning the 80% Service Test approach to condition monitoring may be of interest. Each successful test verifies the battery meets its design function and also proves the battery delivers at least 80% of rated capacity as required for continued operation. This is a definite addition to normal service test results.

Path Forward

The completion of conceptual testing is the first step in a process leading to full implementation of the 80% Service Test for Class 1E applications in nuclear plants. This process can take ten years or longer. The steps provided below outline a process to full implementation.

1. Several non 1E batteries with ages in the 10 to 20 year range should be selected for testing to determine the effect of aging upon the 80% Service Test capacity results. It is preferred to use similar models to those used in this initial testing. One option would be locating several plants willing to perform one or more 80% Service Tests on their aged non 1E batteries. Another option would be locating some aged batteries for testing by the original manufacturer or an independent testing company. The goal is to extend the range of test results using aged cells.

2. Another approach to gathering test data on aged cells would be to conduct an industry survey to locate service test results with sufficient documentation to support the project. Presumably, the full test records for the service life of several batteries could be mined for service and performance test results.

3. Once sufficient data is collected, then changes could be proposed to IEEE 450 and other battery maintenance documents. Changes to the Technical Specifications and other regulatory documents would also be required.

4. To complete the process, IEEE 535[4] covering qualification of Class 1E batteries must be revised to support the use of the 80% Service Test to determine capacity in lieu of performance tests. This change sets up the process to qualify any new batteries for new or existing nuclear plants. One advantage to using the 80% Service Test is the qualified condition of 80% of rated capacity is verified at the end of each service test without the need for performance tests. This qualified condition would be used as an adjunct to the qualified life used in the current qualification process.

References

1. Floyd, K, Barry, K, "*A Proposed 80% Service Test to Satisfy the Duty Cycle and to Trend Battery Capacity,"* proceedings of Battcon 2010.
2. Floyd, K, Barry, K, "*Initial Test Results Proposes 80% Service Test – One Test Covers Duty Cycle and Trends Capacity", proceeding of Battcon 2012.*
3. IEEE Standard 450-2010 *IEEE Recommended Practice for Maintenance, Testing, and Replacement of Vented Lead-Acid Batteries for Stationary Applications.*
4. IEEE Standard 535-2006 *IEEE Standard for Qualification of Class 1E Lead Storage Batteries for Nuclear Power Generating Stations.*

Acknowledgements

The assistance of Al Williamson of C&D Technologies and Jason Zerbe of Enersys is acknowledged in conducting the last two sets of tests.