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Advanced Nuclear Technology: Final Test Results on 80% Service Test and Implementation Plans

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ABSTRACT

Current practice within the nuclear power industry is to use performance discharge tests for condition monitoring to determine when a battery has reached 80% of its rated capacity, which is considered the end of its service life. A service test is now used every refueling outage to verify that a battery can satisfy its design basis function as defined by the battery duty cycle. A modified performance test is used at intervals of one-fourth the qualified life—typically every five years—to satisfy the requirements of the service and performance tests at these intervals. These types of battery discharge tests are described in detail in IEEE 450-2010.

The proposed 80% service test would be used each refueling outage in place of the normal service test. The proposed test would envelop the duty cycle for most batteries and would not be subject to change. In addition, it would replace both types of performance tests for condition monitoring. The duty cycle for the proposed test consists of a first step of 80% of the rated 1-minute rate for the first minute followed by a second step of 80% of the published rating to the specified terminal voltage for the remaining duration of the duty cycle. In addition to verifying that the design basis functions are met each outage, a percent of rated capacity value will be calculated for use in condition monitoring and trending. Inputs for this capacity calculation include the initial battery electrolyte temperature and the terminal voltage at the end of the 80% service test. The capacity trending would be used to identify the onset of degradation and to confirm that the battery meets or exceeds the qualified condition of 80% of rated capacity. Use of the 80% service test could also facilitate the qualification of batteries for advanced nuclear plants.

Proof-of-concept testing at the 4-hour and 72-hour rates has been completed on three sets of batteries. Results from this testing demonstrate that a percent-capacity value can be calculated based on the voltage at the end of the duty cycle. This indicates that the 80% service test could be an acceptable substitute for the normal performance tests used for condition monitoring on existing and advanced nuclear plants.

This report provides the results of the conceptual testing and describes required changes to the various industry standards and processes to implement the 80% service test for Class 1E batteries in nuclear plants.

Keywords

Battery qualification
Condition monitoring
Lead-acid battery
Performance test
Safety-related battery
Service test
Surveillance tests

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1
DESCRIPTION OF 80% SERVICE TEST

The proposed 80% service test was first introduced in an earlier EPRI report [1]. According to IEEE 450-2010 [2], a *service test* is a test of the as-found condition of the battery's capability to satisfy the battery design basis duty cycle. In nuclear plants, there may be more than one duty cycle involved for various design scenarios. Therefore, the test duty cycle would be the most limiting duty cycle based on the magnitude and duration of the load steps as well as the minimum voltage requirements for the most critical step.

In general, the capacity removed from the battery during a service test is no more than 70% of its rated capacity for the duty cycle duration, and it can be less than 50%. This can be illustrated from the battery sizing methodology described in IEEE 485-2010 [3] using two examples. For the first case, with a minimum electrolyte temperature of 70°F (21°C), full aging allowance of 25%, and minimum recommended design margin of 10%, the combined sizing correction factor is 1.43 (1.04 x 1.24 x 1.10). The uncorrected sizing factor can be calculated as the reciprocal of this factor, or 0.7 (1/1.43), which when converted to a percentage is 70%. Similarly, a more extreme case may have a minimum electrolyte temperature of 40°F (4°C), full aging allowance of 25%, and total design margin of 25%. The combined sizing correction factor would be 2.03 (1.30 x 1.25 x 1.25), resulting in an uncorrected sizing factor of 0.493 (1/2.03) or 49.3%. Industry experience indicates that when less than 80% of the rated battery capacity is removed during testing, the capacity results can be inconsistent over time.

In addition, the current service test duty cycle varies over time because of load changes—usually increases—throughout the service life of a battery. Therefore, the current type of service test is not suitable for use in providing consistent percent-capacity data for use in condition monitoring. Using a discharge rate of 80% of the published rate for a given duty cycle duration will provide consistent results for use in identifying the onset of battery degradation.

Proposed 80% Service Test Profile

The duty cycle profile for the proposed test is 80% of the published 1-minute rate for the first minute followed by 80% of the published rating to the specified terminal voltage for the remainder of the duty cycle. Figure 1-1 shows a typical 4-hour service test duty cycle with an 80% service test profile also shown for comparison.

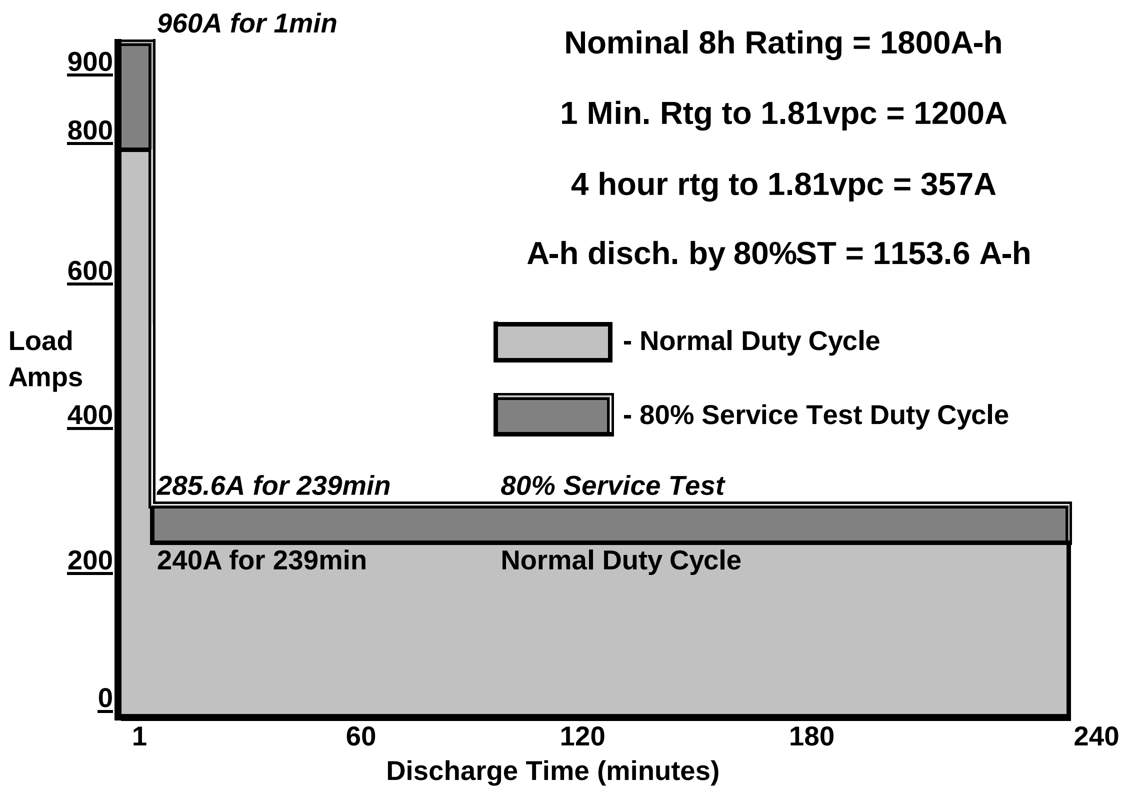

Figure 1-1
80% Service Test Versus Normal Service Test

As shown in Figure 1-1, the duty cycle for the 80% service test clearly bounds the normal service test duty cycle in both rate and time as required. This ensures that the as-found capability of the battery to satisfy its design function is verified each refueling outage. For an as-found test, no equalizing charge is given, no temperature correction is made to the discharge rates, and all battery connection resistance measurements are taken—but no corrective actions are taken unless there is a possibility of permanent damage to the battery. These requirements are described in more detail in IEEE 450-2010. All of these service test requirements are met by the proposed test.

Comparison of Discharge Ampere-Hours

For the normal service test shown in Figure 1-1, the number of ampere-hours (A-h) discharged is calculated as follows:

$$Ahd = \frac{(1m \times 800A + 239m \times 240A)}{60m/h} = 969\ A\text{-}h \qquad \textbf{Eq. 1-1}$$

For the 80% service test, the number of ampere-hours discharged is calculated as follows:

$$Ahd = \frac{(1m \times 960A + 239m \times 285.6A)}{60m/h} = 1153.6\ A\text{-}h \qquad \textbf{Eq. 1-2}$$

In this case, the ampere-hours discharged by the 80% service test are 19% higher than for the normal service test. This difference accounts for the temperature correction factor and design margin.

Maintenance Process Using the 80% Service Test

There will be several changes to the present maintenance practices during refueling outages. In addition to verifying the capability of the battery to satisfy its design function, battery capacity must be determined for use in condition monitoring. Procedure changes will be needed to capture the percent capacity each outage and establish trending to identify the onset of degradation and pending battery replacement. These functions are currently based on performance testing.

Service tests and modified performance tests are to be performed in the as-found condition. This means that the battery must not be equalized just before the test and that the intercell connection resistances can be measured, but no corrective actions are allowed unless there is a risk to personnel safety. As a result, there can be a wider variation in capacity values than seen when the battery condition is equalized and connections reworked prior to testing. This capacity variation is already experienced with the use of modified performance testing, but it needs to be recognized with the use of the 80% service test as well.

The 80% service test is designed to envelop or bound the worst-case duty cycle for the plant. In effect, the aging correction factor of 125% is fully credited with this test, and the end-of-life condition is 80% of rated capacity. This must remain true for the complete service life of the battery. The battery sizing calculations must demonstrate that these conditions are maintained for the life of the battery.

Battery terminal voltage measurements must be taken to the same extent as with any service test, but the voltage at the end of the duty cycle is even more critical. This voltage measurement along with the initial average electrolyte temperature will be used to calculate the percent-capacity value.

2
CAPACITY DETERMINATION: 80% SERVICE TEST

The question has been raised as to whether an accurate and repeatable percent-capacity value can be determined using the results from a service test. This section presents the technical justification for using the proposed 80% service test to determine capacity. A comparison to modified performance tests will be made and the actual capacity calculation methodology presented.

Similarities Between 80% Service Test and Modified Performance Tests

Referring to Section 6.5 [2], which describes the modified performance test, the following similarities to the 80% service test can be identified:

- The discharge bounds the currents in the duty cycle for both tests.
- The initial conditions for both tests are identical.
- Either test can be used in place of the normal service test at any time.
- Batteries sized according to IEEE 485 are acceptable if their tested capacity is 80% or greater.
- Jumpering (that is, bypassing) of cells during either test is not allowed.
- There are some important differences (described next) using the Type 1 modified performance test for the comparison.

Differences Between 80% Service Test and Type I Modified Performance Test

The first part of the 80% service test is similar to a Type 1 modified performance test; however, there are also differences to be considered. After the high rate discharge, the Type 1 modified performance test is continued at the full rated performance test discharge to end voltage, with the **ending time** being measured. The ending time and the initial electrolyte temperature are used to calculate the percent capacity using the time-adjusted method from Section 7.4.2 [2]. After the high rate discharge, the 80% service test is continued at 80% of the full rating for the duty cycle duration, with **end voltage** being measured. The end voltage and the initial electrolyte temperature are used to calculate percent capacity using the rate-adjusted methodology from Section 7.4.3 [2]. The test discharge rate is not adjusted for temperature for either type of test. Rather, the temperature adjustment is made in the capacity calculation.

Differences Between 80% Service Test and Type 3 Modified Performance Test

The duty cycle portion of the 80% service test is identical to a Type 3 modified performance test. However, after the duty cycle portion is completed, the Type 3 modified performance test is continued at the full rated performance test discharge to end voltage, with the **ending time** being measured. These differences must be factored into the capacity calculation method.

Percent-Capacity Calculation for the 80% Service Test

The duty cycle will remain constant for the service life of the battery. In Figure 1-1, the duty cycle consists of the first minute at 960 amperes followed by the remaining 239 minutes at 285.6 amperes. Both ratings are based on the selected end voltage of 1.81 volts per cell (VPC) average for this example. As calculated previously (see Equation 1-2), the number of ampere-hours discharged for the 80% service test in Figure 1-1 is 1153.6. The two other parameters needed for the capacity calculation are average end voltage and initial electrolyte temperature. The average end voltage is used to determine the rated ampere-hours for the given test duration. These data are used in the following capacity equation (Equation 2-1), similar to those used for the Type 3 modified performance test described in Annex I.3 [2]. (Note: Table L.2 is the extended version of Table 2 provided in Annex L [2].)

$$\%Capacity = \frac{K_C \times \sum I_N \times T_N}{RtdA - h} \times 100 \qquad \textbf{Eq. 2-1}$$

Where:

K_C is the temperature correction factor from Table L.2 [2]
I_N is the discharge current in amperes for section N
T_N is the duration of section N in hours
N is the section number for each portion of the discharge test
RtdA-h is the rated A-h to duty cycle duration for the actual end voltage of test

Using the example from Figure 1-1 and assuming an initial electrolyte temperature of 90°F (32.2°C) and an actual end voltage of 1.90 VPC for the test, the capacity calculation is the following:

- The temperature correction factor for 90°F (32.2°C) read from Table L.2 is 0.94.
- The rated capacity in ampere-hours at the 4-hour duration to 1.90 VPC at 77°F (25°C) is read from the published data as 271 A x 4 h = 1084 A-h.
- The number of ampere-hours discharged during the 80% service test calculated in Equation 1-2 equals 1153.6.

The percent capacity is now calculated as follows:

$$\%Capacity = \frac{0.94 \times 1153.6}{1084} \times 100 = 100\% \qquad \textbf{Eq. 2-2}$$

This illustrates one percent-capacity calculation method for the 80% service test. The similarity to the rate-adjusted performance test methodology can be shown by adjusting the terms in Equation 2-2 by dividing both numerator and denominator by 4 hours, which is the test duration. This results in the following equation:

$$\%Capacity = \frac{0.94 \times 288.4}{271} \times 100 = 100\% \qquad \textbf{Eq. 2-3}$$

The capacity calculation formula from Section 7.4.3 [2] is shown next. This formula is located in Section 7.3.2.2 in the 2002 version of IEEE 450.

$$\%Capacity = \frac{X_a \times K_C}{X_t} \times 100 \qquad \textbf{Eq. 2-4}$$

Where:

X_a is the actual rate used for the test

X_t is the published rating for time t

t is the time of test to specified terminal voltage

K_C is the temperature correction factor (see Table L.2 [2])

Comparing the terms between this rate-adjusted formula and Equation 2-3, the actual rate used for the test would be 288.4 amps. Referring to Figure 1-1, 80% of the 4-hour rating of the battery is 285.6 amps. The difference between these two values is the ampere-hours removed by the first-minute peak spread across the 4-hour duration. The published rating for a time of 5.93 hours to specified terminal voltage of 1.90 VPC is 271 amps, which matches the value in Equation 2-3 and the definition of X_t given in the conditions for Equation 7.3.2.2. Therefore, the capacity calculation method for the 80% service test is basically equivalent to the calculation methods used for the Type 3 modified performance test and the rate-adjusted performance test.

In the initial 80% service test proposal, the Type 3 modified performance test capacity calculation method was used. In fact, the first test report (EPRI report 1023622 [4]) used this method. After reviewing the test results, it was determined that the rated-adjusted methodology was more suited for use in the 80% service test calculation. The first-minute peak load of the duty cycle is important for bounding the worst-case duty cycle in actual service but has little difference in the overall percent capacity for trending. A separate rated-adjusted capacity calculation for the first-minute peak load can be used for trending high rate performance. Both the first-minute capacity and the overall battery capacity calculations will use Equation 2-4 as shown above.

In addition to verifying that the design basis functions are met during each outage, the terminal voltage at the end of the 80% service test and the initial electrolyte temperature would be used to calculate an equivalent percentage of rated capacity for use in condition monitoring. This capacity trending would be used to identify the onset of degradation and to confirm that the battery meets or exceeds the qualified condition of 80% of rated capacity. In this way, both functions can be fulfilled using the 80% service test throughout the service life of the battery.

3

PROOF-OF-CONCEPT TESTING

As with any technical proposal, the final proof is confirmation by actual testing. A summary of this conceptual testing is provided next.

Three nominal, 12-volt vented lead acid battery strings, representing existing and future nuclear plant applications, were discharge tested. Initial electrolyte temperatures ranged from 75 to 80°F (23.9 to 26.7°C), and end voltages ranged from 1.75 to 1.90 volts per cell average.

The discharge testing was performed using automatic battery discharge test equipment. All tests were fully documented with test equipment records and other documentation as required. Test procedures were in accordance with IEEE 450 and battery manufacturer instructions. Test procedures were written by each testing contractor and approved by the principal investigator prior to the start of testing.

The basic sequence for each test consisted of the following steps:

1. Conduct an 80% service test consisting of 80% of the 1-minute rating followed by 80% of the rating for the duty cycle duration (4 or 72 hours). No discharge rate adjustment for temperature is to be used; the temperature correction is done in the capacity calculation. On some test sequences, the discharge was continued at the second discharge rate until the end voltage was reached.
2. Record the initial electrolyte temperature prior to the start of each test, the first-minute discharge rate in amperes, the minimum, or coup de fouet, voltage during the first minute, the remaining discharge rate in amperes, the end voltage at the end of the duty cycle, and the time to end voltage of the extended discharge, when used. These data were recorded every 10 to 15 seconds for later reference.
3. Recharge the battery, and verify that it is fully charged in preparation for the next sequence.

Normal, time-adjusted performance tests were used for comparison. They were conducted before and after the 80% service test sequences.

Three testing contractors were used for these tests; they provided fully documented test reports for the record. Section 4 of this report summarizes the results and records the conclusions of the overall conceptual testing effort.

A typical duty cycle diagram for the 80% service test is shown in Figure 3-1 for reference.

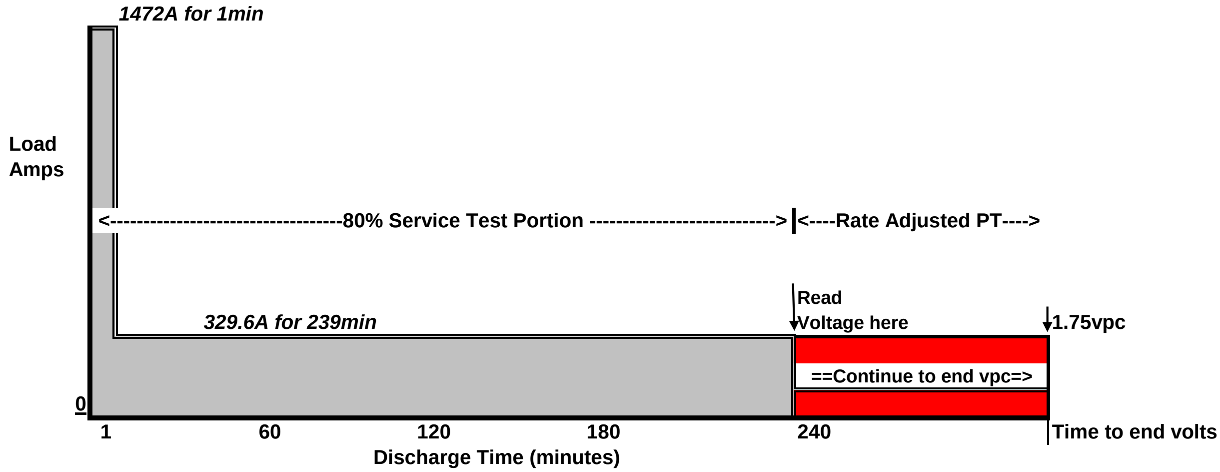

Figure 3-1
Proof-of-Concept Test Duty Cycle Example (4 hours to 1.75 VPC)

4
FINAL TEST RESULTS

The critical data measured and recorded during the testing were the initial electrolyte temperatures, the discharge rates, the voltage at the end of the service test, and the time to rated end voltage, when required. These data are shown in Tables 4-1 through 4-5.

Measured Test Data Results

4-Hour 80% Service Test Measured Data

Table 4-1
GNB Cell Model NCN-27

Parameter	1.75 VPC	1.81 VPC	1.86 VPC	1.90 VPC
Initial temperature (°C)	24.82	24.89	23.89	25.37
First-minute discharge rate in amps (Xa1)	1477.5	1045	728.6	499.3
Minimum VPC during coup de fouet (first min.)	1.793	1.840	1.882	1.917
Remaining discharge rate in amps (Xa2)	329.89	306.89	273.20	234.66
Measured average end voltage at 240 min.	1.872	1.893	1.915	1.939
Minutes to extended discharge end volts (t)	312	322	333	339

Table 4-2
C&D Cell Model LCR-25

Parameter	1.75 VPC	1.80 VPC
Initial temperature (°C)	25.5	25.5
First-minute discharge rate in amps (Xa1)	1437	1111.5
Minimum VPC during coup de fouet (first min.)	1.807	1.844
Remaining discharge rate in amps (Xa2)	313	295
Measured average end voltage at 240 min.	1.882	1.898
Minutes to extended discharge end volts (t)	325	334

Note: No 4-hour service tests were run on the Enersys Cell Model GC-17M.

72-Hour 80% Service Test Measured Data

Table 4-3
GNB Cell Model NCN-27

Parameter	1.90 VPC	1.85 VPC	1.81 VPC	1.75 VPC
Initial temperature (°C)	22.78	23.44	23.91	24.00
First-minute discharge rate in amps (X_{a1})	499.00	756.20	1036.52	1459.58
Minimum VPC during coup de fouet (first min.)	1.915	1.891	1.857	1.810
Remaining discharge rate in amps (X_{a2})	22.135	25.928	26.960	27.953
Average end voltage at 72 hours	1.950	1.929	1.922	1.913

Table 4-4
C&D Cell Model LCR-25

Parameter	1.75 VPC	1.80 VPC
Initial temperature (°C)	25.5	25.5
First-minute discharge rate in amps (X_{a1})	1438	1111
Minimum VPC during coup de fouet (first min.)	1.800	1.840
Remaining discharge rate in amps (X_{a2})	27	26
Average end voltage at 72 hours	1.909	1.917
Minutes to extended discharge end voltage (t)	5664	5761

Table 4-5
Enersys Cell Model GC-17M

Parameter	1.81 VPC	1.75 VPC
Initial temperature (°C)	24.39	23.44
First-minute discharge rate in amps (X_{a1})	820	1122.5
Minimum VPC during coup de fouet (first min.)	1.86	1.80
Remaining discharge rate in amps (X_{a2})	24.2	24.8
Average end voltage at 72 hours	1.916	1.907

Capacity Calculation Results

The measured data were converted to values for use in the capacity calculations. The capacity calculations used the rated-adjusted methodology described above. These values along with other pertinent data and results are summarized in Tables 4-6 through 4-15. Alternative calculations were done on the C&D batteries using the Type 3 Modified Performance Test equation and are included in Appendix A.

4-Hour 80% Service Test Capacity Calculation Results

Table 4-6
First-Minute Capacity Calculation: GNB Cell Model NCN-27

Parameter	1.75 VPC	1.81 VPC	1.86 VPC	1.90 VPC
Temperature correction factor (K_C)	1.002	1.001	1.011	0.996
First-minute discharge rate in amps (X_{a1})	1477.53	1045.01	728.62	499.30
Rated amps for first-minute discharge (X_{t1})	1425.2	1027	729.3	535.6
Calc. percent capacity for first minute (%C1)	**103.9%**	**101.9%**	**101.0%**	**92.8%**

Table 4-7
First-Minute Capacity Calculation: C&D Cell Model LCR-25

Parameter	1.75 VPC	1.80 VPC
Temperature correction factor (K_C)	1.000	1.000
First-minute discharge rate in amps (X_{a1})	1437	1111.5
Rated amps for first-minute discharge (X_{t1})	1333	1051
Calc. percent capacity for first minute (%C1)	**107.8%**	**105.7%**

Note: The first-minute capacity results will be used for evaluating high rate capability. The percent capacity for trending used for condition monitoring is a separate calculation based on the valley discharge interval.

Table 4-8
Trending Capacity Calculation: GNB Cell Model NCN-27

Parameter	1.75 VPC	1.81 VPC	1.86 VPC	1.90 VPC
Temperature correction factor (K_C)	1.002	1.001	1.011	0.996
Remaining discharge rate in amps (X_{a2})	329.89	306.89	273.20	234.63
4-hr rated amps to end VPC at 240 min. (X_{t2})	329.8	303.8	273.3	234.0
Calc. percent capacity for trending (%C2)	**100.2%**	**101.1%**	**101.1%**	**99.9%**

Table 4-9
Trending Capacity Calculation: C&D Cell Model LCR-25

Parameter	**1.75 VPC**	**1.80 VPC**
Temperature correction factor (K_C)	0.994	0.994
Remaining discharge rate in amps (X_{a2})	313	295
4-hr rated amps to end VPC at 240 min. (X_{t2})	280.3	254.6
Calc. percent capacity for trending (%C2)	**111%**	**115.2%**

72-Hour 80% Service Test Capacity Calculation Results

Table 4-10
NCN-27 First-Minute Capacity Calculation

Parameter	**1.90 VPC**	**1.85 VPC**	**1.81 VPC**	**1.75 VPC**
Temperature correction factor (K_C)	1.023	1.016	1.011	1.010
First-minute discharge rate in amps (X_{a1})	499.00	756.19	1036.52	1459.58
Rated amps for first-minute discharge (X_{t1})	546	682.5	911.4	1287
Calc. percent capacity for first minute (%C1)	**93.5%**	**112.6%**	**115.0%**	**114.5%**

Table 4-11
LCR-25 First-Minute Capacity Calculation

Parameter	**1.75 VPC**	**1.80 VPC**
Temperature correction factor (K_C)	1.000	1.000
First-minute discharge rate in amps (X_{a1})	1438	1111
Rated amps for first-minute discharge (X_{t1})	1390.5	1081.8
Calc. percent capacity for first minute (%C1)	**103.4%**	**102.7%**

Table 4-12
GC-17M First-Minute Capacity Calculation

Parameter	1.81 VPC	1.75 VPC
Temperature correction factor (K_C)	1.006	1.017
First-minute discharge rate in amps (X_{a1})	820	1122.5
Rated amps for first-minute discharge (X_{t1})	713	993.1
Calc. percent capacity for first minute (%C1)	**115.7%**	**115%**

Table 4-13
NCN-27 Trending Capacity Calculation

Parameter	1.90 VPC	1.85 VPC	1.81 VPC	1.75 VPC
Temperature correction factor (K_C)	1.023	1.016	1.011	1.010
Remaining discharge rate in amps (X_{a2})	22.135	25.928	26.960	27.953
72-hr rated amps to end VPC (X_{t2})	22.30	25.59	26.69	27.32
Calc. percent capacity for trending (%C2)	**101.5%**	**102.9%**	**102.1%**	**103.4%**

Table 4-14
LCR-25 Trending Capacity Calculation

Parameter	1.75 VPC	1.80 VPC
Temperature correction factor (K_C)	0.994	0.994
Remaining discharge rate in amps (X_{a2})	27	26
72-hr rated amps to end VPC (X_{t2})	25.7	24.5
Calc. percent capacity for trending (%C2)	**104.3%**	**105.2%**

Table 4-15
GC-17M Trending Capacity Calculation

Parameter	1.81 VPC	1.75 VPC
Temperature correction factor (K_C)	1.006	1.017
Remaining discharge rate in amps (X_{a2})	24.2	24.8
72-hr rated amps to end VPC (X_{t2})	22.76	23.8
Calc. percent capacity for trending (%C2)	**107%**	**106%**

Comparison of Results

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 components/connections may be identified during this portion of the test.

First-Minute Results Comparison

Table 4-16
First-Minute Capacity Comparison

Cell Model	Type of Test	1.75 VPC	1.80/1.81 VPC	1.85/1.86 VPC	1.90 VPC
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 range of capacity values in the data, which may be due to changes in the test sequencing and procedures. In practice, this measurement may provide a qualitative measure of cell/battery integrity after a consistent basis for the measurement is formed.

4-Hour Results Comparison

Table 4-17
NCN-27 4-Hour Trending Capacity Comparison

Parameter	1.75 VPC	1.81 VPC	1.86 VPC	1.90 VPC	Special 1.75 VPC
Percent capacity for 80% service test (%C2)	100.2%	101.1%	101.1%	99.9%	100.2%
Percent capacity from initial 4-hr perf. test (%PT)	100.6%	100.6%	100.6%	100.6%	100.6%
Percent difference: (%C2 - %PT)	**-0.4%**	**0.5%**	**0.5%**	**-0.7%**	**-0.4%**

Note: Special test was run at 80% of rated 4-hour rate to end voltage.

Table 4-18
LCR-25 4-Hour Trending Capacity Comparison

Parameter	1.75 VPC	1.80 VPC
Percent capacity for 80% service test (%C2)	111.0%	115.2%
Percent capacity on initial 8-hr perf. test (%PT)	107.3%	107.3%
Percent difference: (%C2 - %PT)	**3.7%**	**7.9%**

The percent-capacity values for these 4-hour 80% service tests are within 0.7% of the percent capacity of the initial 4-hour performance test, excluding the test involving a charging anomaly. This confirms that the 80% service test can deliver accurate percent-capacity values for use in condition monitoring at the 4-hour rate. The 4-hour testing was designed to simulate duty cycles for existing nuclear plants.

72-Hour Results Comparison

Table 4-19
NCN-27 72-Hour Trending Capacity Comparison

Parameter	1.90 VPC	1.85 VPC	1.81 VPC	1.75 VPC
Percent capacity for 80% service test (%C2)	101.5%	102.9%	102.1%	103.4%
Percent capacity on performance test (%PT)	101.2%	101.0%	101.0%	100.2%
Percent difference (%C2 - %PT)	**0.3%**	**1.9%**	**1.1%**	**3.2%**

Note: Three 8-hr performance tests were used: initial, intermediate, and final.

Table 4-20
LCR-25 72-Hour Trending Capacity Comparison

Parameter	1.75 VPC	1.80 VPC
Percent capacity on 80% service test (%C2)	104.3%	105.2%
Percent capacity on performance test (%PT)	102.4%	102.7%
Percent difference: (%C2 - %PT)	**1.9%**	**2.5%**

Note: Two 8-hr performance tests were used: initial and final.

Table 4-21
GC-17M 72-Hour Trending Capacity Comparison

Parameter	1.81 VPC	1.75 VPC
Percent capacity on 80% service test (%C2)	107%	106%
Percent capacity on performance test (%PT)	111.7%	103.3%
Percent difference: (%C2 - %PT)	**-4.7%**	**2.7%**

Note: Two 8-hr performance tests were used: 1st to 1.81, 2nd to 1.75 VPC.

The percent-capacity values for these 72-hour 80% service tests are within 4.7% of the percent capacity of the corresponding benchmark performance test capacity. These results indicate that the 80% service test can deliver percent-capacity values but that more refinement is needed for use in condition monitoring at the 72-hour rate. The 72-hour testing was designed to simulate long duration duty cycles for the passive design nuclear plants.

5
PLANS FOR IMPLEMENTATION

Implement 80% Service Test for Non-1E Batteries at Existing Plants

Because the results for the 4-hour tests were within 0.7% of the results from conventional performance tests, implementation of the 80% service test for the non-1E batteries should be considered. Some nonnuclear plants have already started using the test as part of their maintenance programs. As with anything new, lessons will be learned along the way, and it would be helpful to capture those lessons at some of the nuclear plants.

Revise IEEE 450 to Address Maintenance

An annex for each of these documents will be needed to describe the 80% service test and its use in satisfying both service test and performance test functions. A proposed annex for IEEE 450 covering vented lead acid (VLA) battery maintenance is included as Appendix B.

Revise IEEE 535 [5] to Address Qualification

Because the qualified condition of 80% of rated capacity will be demonstrated each refueling outage using the 80% service test, consideration should be given to using condition monitoring as an adjunct to qualified life as discussed in IEEE 323 [6] and 1205 [7]. This approach needs to be explored and the necessary changes made to IEEE 535 [5].

A revision to IEEE 535 is in balloting now that includes a description of the 80% service test as part of the modified performance testing to be done during the aging process.

Revise Standardized Technical Specifications

The 80% service test is a specific type of service test allowed with the current version of the standardized technical specifications for verifying that the battery meets its design function. It is not explicitly named as such but meets the current description. However, the current version allows only performance test or modified performance test results to be used for condition monitoring. This is in concert with the current versions of the maintenance requirements in IEEE 450 and other documents. Therefore, a revision will be required to allow the use of the 80% service test for condition monitoring.

6 REFERENCES

1. *A Proposed 80% Service Test to Satisfy the Duty Cycle and to Trend Battery Capacity*. EPRI, Palo Alto, CA: 2010. 1021179.
2. ANSI/IEEE Standard 450-2010, IEEE Recommended Practice for Maintenance, Testing, and Replacement of Vented Lead-Acid Batteries for Stationary Applications.
3. ANSI/IEEE Standard 485-1997 (R2003), IEEE Recommended Practice for Sizing Lead-Acid Batteries for Stationary Applications.
4. *1E Battery 80% Service Test.* EPRI, Palo Alto, CA: 2010. 1023622.
5. ANSI/IEEE Standard 535-2006, IEEE Standard for Qualification of Class 1E Lead Storage Batteries for Nuclear Power Generating Stations.
6. ANSI/IEEE Standard 323-2003, IEEE Standard for Qualifying Class 1E Equipment for Nuclear Power Generating Stations.
7. ANSI/IEEE Standard 1205-R2007, IEEE Guide for Assessing, Monitoring, and Mitigating Aging Effects on Class 1E Equipment Used in Nuclear Power Generating Stations.

A

ALTERNATIVE CAPACITY CALCULATIONS FOR C&D BATTERIES

As an alternative approach to benchmarking capacity for the 80% service test, the test results from the C&D test sequences were used with the Type 3 Modified Performance Test (MPT) equation (Equation 2-1 in Section 2) to derive another set of capacity values. This was done to support the evaluation of this calculation method versus the rate-adjusted method.

Input data for these calculations were taken from Tables 4-2 and 4-3 in Section 4.

Table A-1
LCR-25 4-Hour Trending Capacity Comparison (Using Type 3 MPT)

Parameter	1.75 VPC	1.80 VPC
Percent capacity for 80% service test (%C2)	109.3%	115.2%
Percent capacity on Type 3 MPT (%MPT)	111%	112%
Percent difference: (%C2 - %MPT)	**1.7%**	**3.2%**

Table A-2
LCR-25 72-Hour Trending Capacity Comparison (Using Type 3 MPT)

Parameter	1.75 VPC	1.80 VPC
Percent capacity on 80% service test (%C2)	104.3%	105.2%
Percent capacity on Type 3 MPT (%MPT)	107%	107.8%
Percent difference: (%C2 - %MPT)	**-2.7%**	**-2.6%**

This approach was considered in view of the Type 3 MPT already included in the current versions of IEEE 450 and the standardized technical specifications.

B

PROPOSED IEEE 450 ANNEX

The 80% service test is a special type of the service test discussed in Clause 7.6. In addition to verifying that the battery can meet its duty cycle, this special test can also determine battery capacity for use in trending. This trending will be used to identify the onset of battery degradation. The duty cycle for many service tests may remove no more than 50–70% of rated capacity. However, the duty cycle for the 80% service test consists of 80% of the 1-minute rating for the first minute followed by 80% of the published rating to the specified terminal voltage for the remaining duration. The recommended process, presented next, should be used to verify that a specific duty cycle is bounded by the 80% service test.

a. Verify that the full aging margin of 25% (aging correction factor of 1.25) is used in the battery sizing calculation. If not, the 80% service test is not appropriate.
b. Verify that the highest 1-minute step load is less than 80% of the 1-minute published rating to the specified terminal voltage.
c. Verify that the peak steps of the duty cycle are less than or equal to 80% of the published rating to the specified terminal voltage for the remaining duty cycle duration.

If all of these conditions are satisfied, the 80% service test may be used.

Methodology

1. Determine the published 1-minute rating of the battery to the specified terminal voltage. Calculate 80% of this rating for use as the initial test discharge rate.
2. Determine the published rating to the specified terminal voltage for the full duration of the service test duty cycle. Multiply this rating by 80% to determine the adjusted end-of-life test discharge rate.
3. Set the first-minute discharge rate for the value found in Step 1 and the second discharge rate to the value found in Step 2. The discharge time for the second step will be the duty cycle time period in minutes minus 1 minute.

   Note: The service test stops on time, not voltage.
4. Record the battery terminal voltage at the minimum coup de fouet point during the first minute and just before the end of the first-minute discharge. After adjusting the test discharge current to the second rate, record the battery terminal voltage and the individual cell voltages periodically until the end of the duty cycle duration is reached.

   It is critical to record the battery terminal voltage at the end of the test with the load still applied; therefore, closely monitor the battery terminal voltage during the last 15 minutes of the test to ensure that the battery terminal voltage at the end of the test is captured while the load is still applied.
5. To be acceptable, the battery terminal voltage at the end of the first minute and at the end of the test must be greater than or equal to the specified battery terminal voltage.

6. Using the final battery terminal voltage recorded in Step 4 and the duty cycle duration, determine the corresponding published discharge rating in amperes.
7. Determine the capacity using rate-adjusted formula 7.4.3.5. The actual rate (X_a) used for the test is the discharge used for the second part of Step 2. The published rating (X_t) for time to specified terminal voltage is the value determined in Step 6. The temperature correction factor (K_c) is the rate-adjusted value, not the time-adjusted value.

The capacity calculation ignores the additional capacity removed by the first-minute discharge step.

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