DISCHARGE TESTING: WHAT, WHY, AND WHEN EXPLAINED

Tom Carpenter
NERC/SERC Reliability Program Manager
TVA Nuclear
Chattanooga, TN

Lesley Varga, P.E.
Ret. Business Owner
Santa Fe, NM

Abstract

Standby batteries are used to provide emergency backup power when the normal power supply is lost. They are expensive to design, install, and maintain and they wouldn't be there if they weren't needed. In many cases they are the last line of defense in preventing a catastrophic, sometimes even life shattering event. As such, it is imperative they work properly when needed.

There is some confusion within the industry on the need for discharge tests - what type, what constitutes one, how are they performed, and their effect on the battery. The confusion is exacerbated by the number of new people in the field. This paper covers the IEEE Standards (Std.) 450 (VLA), 1188 (VRLA), and 1106 (Ni-Cd) recommended discharge tests. The below topics are presented to dispel some of the myths that exist around discharge testing and provide an argument for why discharge testing should be performed despite the costs and schedule impacts.

Introduction

Discharge tests are controlled, monitored, intentional temporary removals of some of the stored energy in a battery. The purpose of the tests varies depending on the type, but in general, they are used to verify the battery can perform its intended function and to determine where the battery is on its Life-Capacity curve, see Figures 2, 3, & 4.

There are many tools that propose to show a battery's condition (i.e. its State of Health "SOH") – the primary one being internal ohmic meters. These tools do a good job of providing an overall view of the SOH. However, there is lots of evidence to show that they can provide false negatives (i.e. show the battery to be bad when it's actually okay) and, much worse, false positives (i.e. show the battery to be good when it's actually not). As such, the industry recognized standards on stationary standby batteries, IEEE Std. 450, 1188, and 1106 recommend performing discharge tests as the only way to truly know the battery's capacity and SOH.

Types of Discharge Tests

There are two types of discharge tests – Service and Performance. The Performance tests are broken into three categories – Acceptance, Performance, and Modified Performance. These tests are described below.

Service Tests

Service tests were presented in the first published IEEE Std. 450 in 1972 as a means to determine if the battery will meet the design requirements of the connected load. Originally the standard was written and used primarily for Class 1E batteries at nuclear power generating stations.

Today, IEEE Std. 450-2020 defines a Service test as, a test of a battery's ability, in an "as found" condition, to satisfy the duty cycle. The "as found" condition means that no pre-conditioning of the battery (e.g. equalizing, connection cleaning, etc.) is done to improve the test results unless there is a personnel safety hazard or possibility of permanent damage to the battery. This test shows how the battery would perform in an actual event and also provides information the on the battery's maintenance program. This test does not provide battery capacity information.

The battery duty cycle, sometimes referred to as a "Load Profile", shows the loads and timeframes for those loads that the battery is expected to carry during a loss of normal power event – see Figure 1.

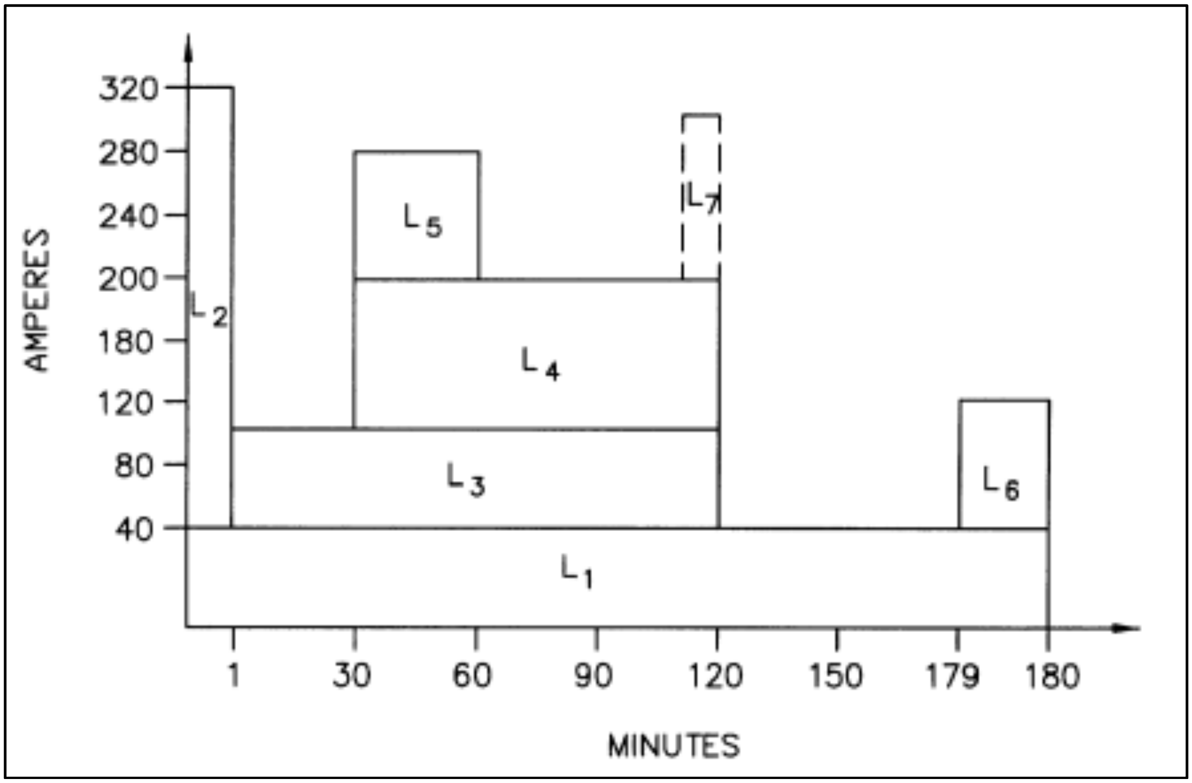

Figure 1: Battery Duty Cycle example from IEEE Std. 485-2020

During the test, the discharge current is adjusted up and down as needed to match the profile. If the battery voltage does not drop below the minimum acceptable voltage either during or by the end of the test, the battery passes the Service test. The minimum acceptable voltage, sometimes referred to as the minimum discharge voltage, is the voltage below which the battery cannot adequately supply the loads, i.e. the minimum voltage that any connected load needs for proper operation accounting for any voltage drop between the battery and the load.

Acceptance Test

IEEE Std. 450-2020 defines an Acceptance test as, a capacity test performed on a new battery to determine if it meets the purchase specifications or manufacturer's ratings. An Acceptance test is just a Performance test that is performed at the manufacturer's facility prior to shipping or upon initial installation, prior to being placed into service. It ensures that the battery will perform as expected. Generally, a vented lead-acid battery is expected to have at least 90% capacity when new and will then rise over the first few years before it starts to decline; see Figure 2. Valve regulated lead acid (VRLA) batteries typically ship at 100% capacity or greater and will remain there until it starts to decline; see Figure 3. Nickel Cadmium (Ni-Cd) batteries have a different life capacity curve and generally have a linear decline in capacity as they age with no sudden drop; see Figure 4.

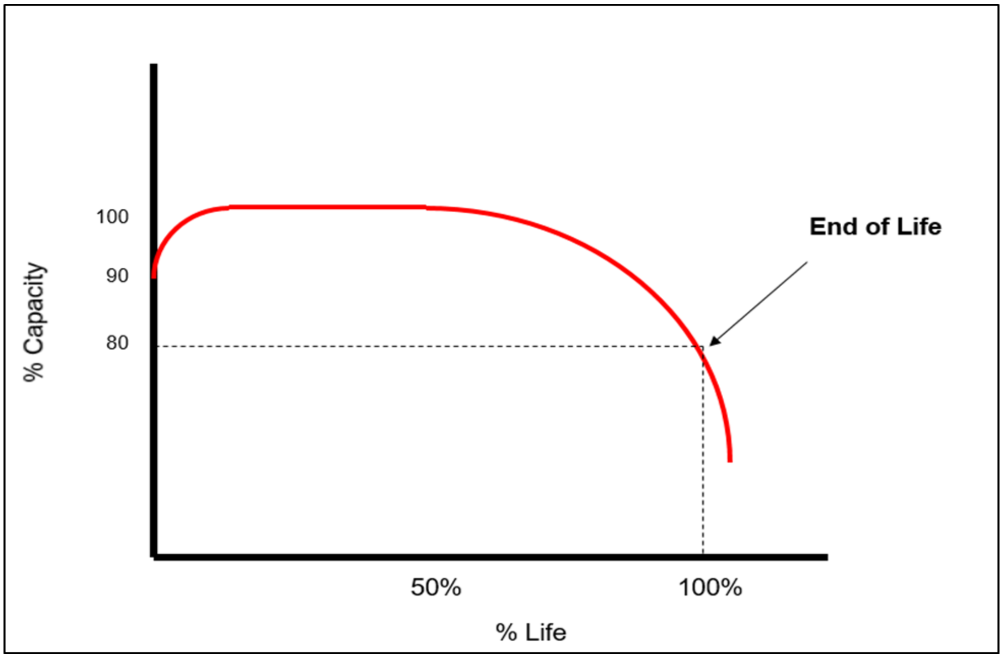

Figure 2: Typical Vented Lead-Acid Life-Capacity Curve

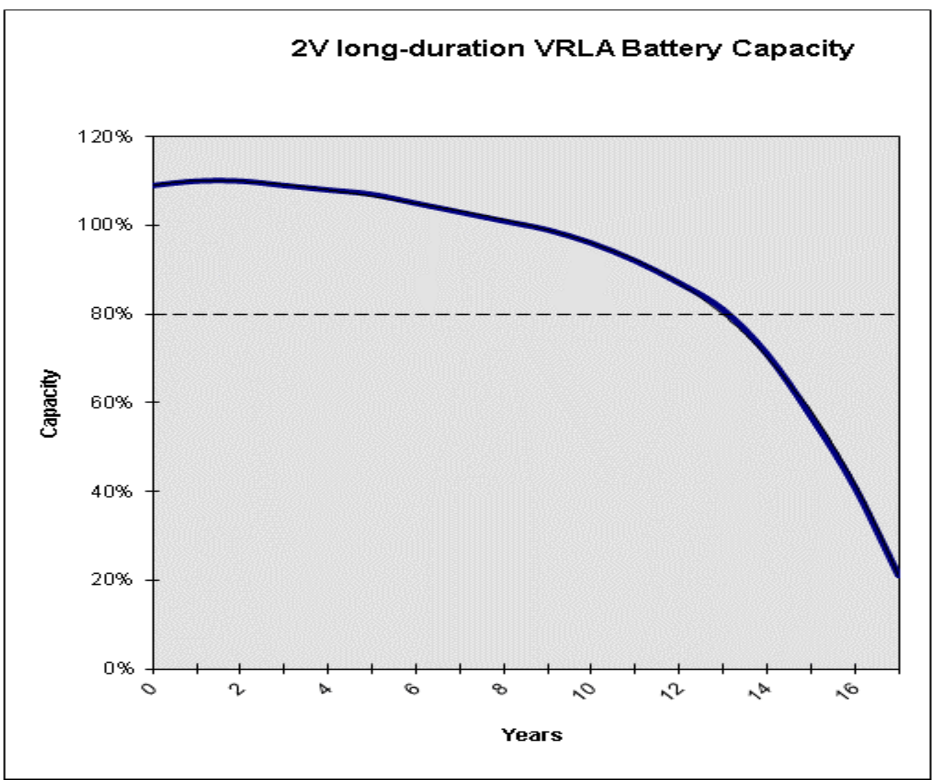

Figure 3: Typical Valve Regulated Lead Acid Life Capacity Curve

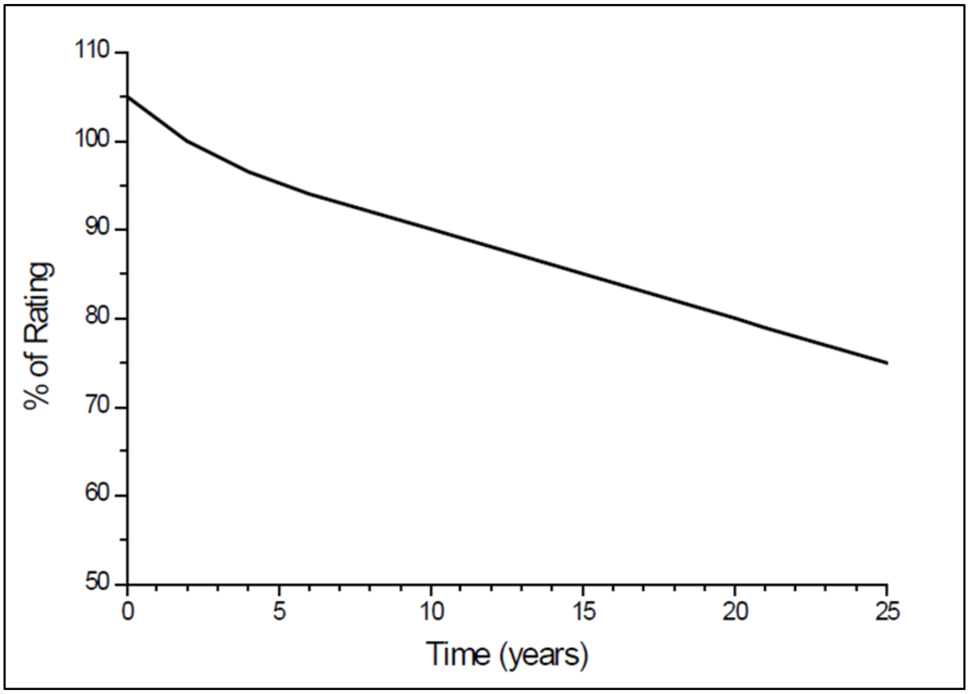

Figure 4: Typical Ni-Cd Life-Capacity Curve from IEEE Std. 1106-2015

Performance Tests

IEEE Std. 450-2020 defines a Performance test as a constant-current or constant-power capacity test made on a battery after it has been in service. In a constant-current test, the discharge current is maintained at a constant value throughout the test. In a constant-power test, the discharge current is increased as the battery voltage drops, thereby maintaining a constant power load throughout the test. Once begun the test continues until the battery voltage reaches a pre-determined end voltage.

The discharge rate, time, and end voltage are taken from manufacturer's data tables or curves. See Figure 5.

Discharge Rates in Amperes* to 1.75Vpc at 25°C (77°F)**

		Minutes			Hours						
Cell Type	NOM Ah Cap.[1]	1	15	30	1	1.5	2	3	4	5	8
2GC-09M	875	717	670	549	410	331	279	216	178	153	109
2GC-11M	1020	877	809	666	496	398	335	258	211	180	128
2GC-13M	1140	1029	938	775	576	461	386	294	240	204	142
2GC-15M	1225	1173	1056	875	650	517	431	326	264	223	153
2GC-17M	1540	1404	1306	1072	788	627	524	398	324	275	192
2GC-19M	1630	1564	1431	1172	859	681	566	428	347	293	204
2GC-21M	1695	1721	1548	1266	924	729	604	454	366	308	212
2GC-23M	1745	1878	1658	1354	984	773	638	476	382	321	218
GC-25M	2260	2104	1870	1535	1137	908	760	580	473	403	282
GC-27M	2360	2231	1987	1633	1207	962	804	612	497	422	295
GC-29M	2450	2351	2099	1726	1275	1014	846	641	520	440	306
GC-31M	2515	2466	2205	1814	1338	1062	884	667	539	455	314
GC-33M	2560	2576	2306	1897	1398	1107	919	691	556	468	320
GC-35M	3085	2772	2487	2052	1523	1217	1020	781	640	545	386
GC-37M	3200	2874	2595	2146	1597	1277	1069	817	667	568	400
GC-39M	3300	2970	2696	2235	1667	1333	1116	851	693	589	413
GC-41M	3385	3065	2794	2323	1737	1389	1162	883	717	608	423
GC-43M	3470	3149	2890	2409	1805	1444	1207	916	742	627	434
GC-45M	3550	3245	2994	2503	1879	1503	1255	948	766	646	444

Figure 5: Example Discharge Table for EnerSys GC-M cells

Modified Performance Tests

IEEE Std. 450-2020 defines a Modified Performance test (MPT) as a test, in the 'as found' condition, of battery capacity and the ability of the battery to satisfy the duty cycle. MPTs are a combination of a Service test and a Performance test in that they perform a battery discharge using a constant current (Performance test part) and add in areas of increased current to bound the duty cycle (Service test part). As such, they can be used in lieu of either one at any time. There are three types of MPTs, designated Type 1, Type 2, and Type 3. These are clearly described in Annex I of IEEE Std. 450-2020.

Type 1 - has a short, high-rate discharge current at the beginning and then drops to a lower constant current for the remainder of the test. This is often used for those applications where there is a high inrush current at the beginning followed by a constant lower current for the remainder of the duty cycle. Note that the test duration and values must fully encompass the duty cycle. As the initial inrush portion of the test removes very little energy from the battery, it is ignored in the capacity calculation and, therefore, it must be a very short duration - typically limited to 1 minute. This test can be used in situations where the exact duty cycle may be unknown but there is a desire to confirm the battery and conduction path can provide a high rate discharge. See Figure 6.

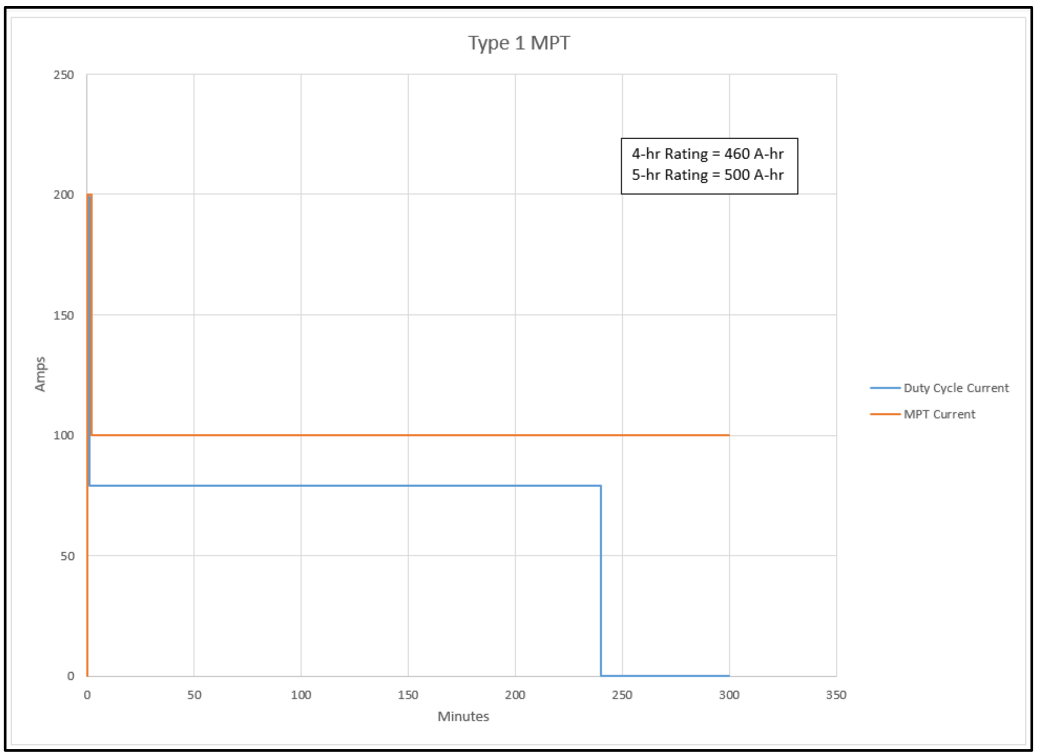

Figure 6: Type 1 Modified Performance Test

Type 2 - uses the standard Performance test current and then increases the current at the times in the duty cycle where the required current goes above that of the Performance test. Note that for this test to work, the Performance test duration must be adjusted such that no more than 80% of the battery's rated capacity is removed during the duty cycle time (portion) of the test. This can generally be done by multiplying the duty cycle duration by 1.25 and then using this as the base for the Performance test current. Calculating the battery's capacity is a little more arduous using this method as the energy removed in each section of the test must be determined and then all added together before dividing by the manufacturer's rating for the base discharge time. See Figure 7.

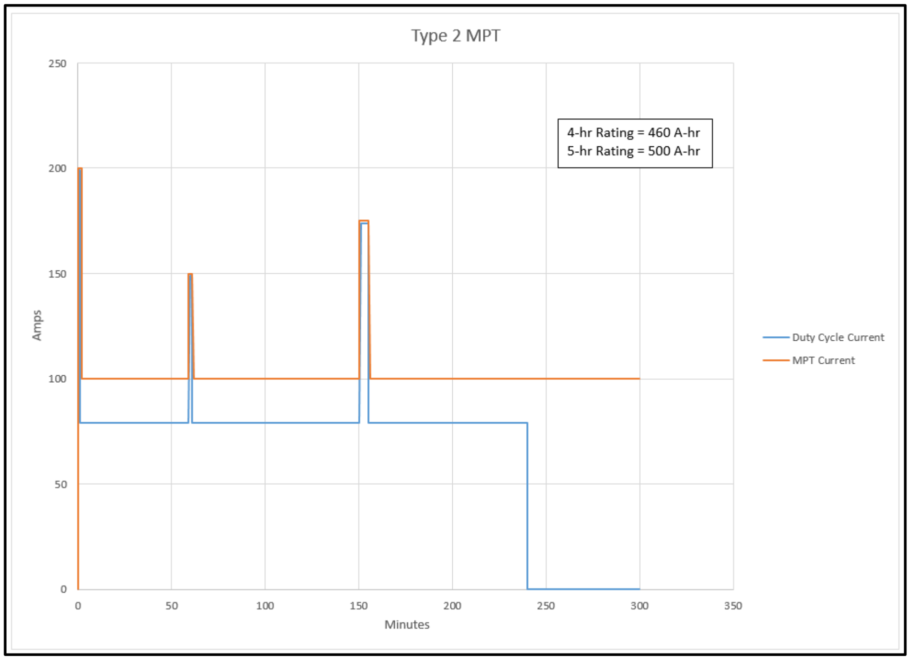

Figure 7: Type 2 Modified Performance Test

Type 3 - is a standard Service test followed immediately by a Performance test. While this test can take a long time to perform, it covers duty cycles where there is a large current draw at the end. As with the Type 2 test, calculating the battery's capacity is a little more arduous as the energy removed in each section of the test must be determined and then all added together before dividing by the manufacturer's rating for the base discharge time. See Figure 8.

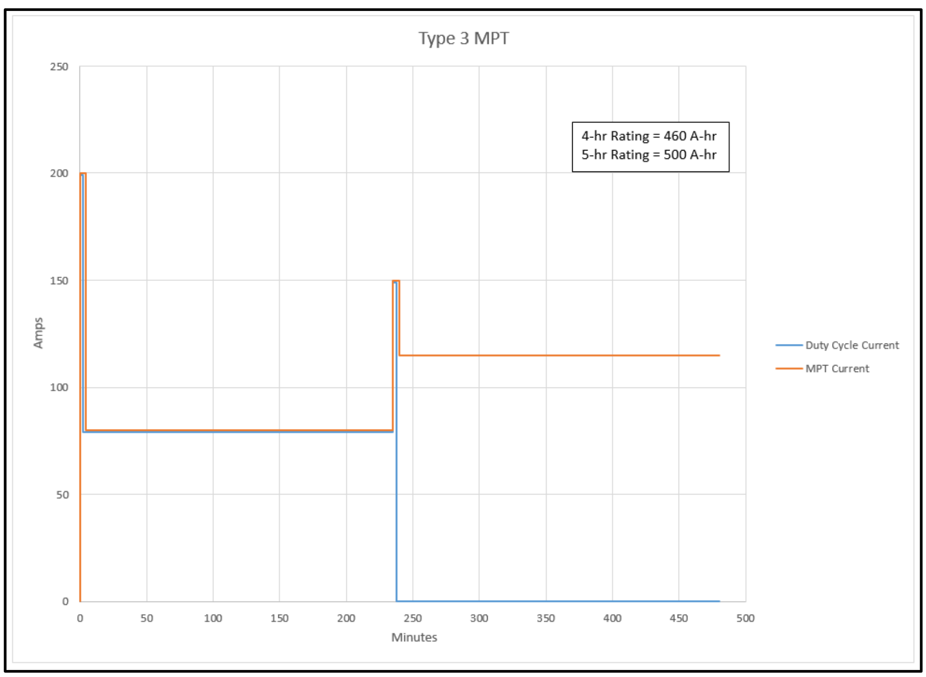

Figure 8: Type 3 Modified Performance Test

Selection of Test Rate

The discharge test rate will depend upon the type of test being performed and the application of the battery. The Service test discharge rate should correspond to the current(s) of the battery duty cycle. The Acceptance and Performance tests' discharge rate should be constant current or constant power and based upon the manufacturer's rating for the test duration selected and end voltage. It is typical that the test duration is the same duration of the duty cycle used to size the battery. For example, a telecommunications battery test might be performed at the 4 hour rate, a switchgear and control battery test might be anywhere between the 1 and 8 hour rate, and a UPS battery test might be at the 10 minute rate, assuming the battery was selected and sized for the application.

Methods for Calculating Capacity

There are two methods for battery capacity testing - time adjusted and rate adjusted. Time adjusted is recommended for test durations greater than or equal to one hour. Rate adjusted is recommended for test durations less than one hour. All tests on a battery should use the same method.

- **Time Adjusted**
  This is the simplest method to perform. Simply discharge the battery at the rate determined from the manufacturer's information and then correct the capacity calculation based on the initial battery temperature per the directions in the standard. Modified Performance Tests must use this method. This method is recommended for test durations of 1 hour or greater.

- **Rate Adjusted**
  This method is a little trickier in that there are two variants - one that uses the manufacturer's full published rate and one that adjusts the manufacturer's published rate for end-of-life conditions. Either can be used and will provide valid results. Using the full published rate variant is simpler and is the most common. To perform either of these variants, the discharge rate is not corrected for the initial battery temperature (assuming the temperature is between 15˚C to 35˚C) per the directions in the standard. The initial battery temperature correction factor is applied during the capacity calculation. This method is required for tests of less than one hour but is acceptable for all test durations.

Why Test

The only means available to determine the capacity of a battery is through a controlled discharge test using the guidelines described in IEEE Std. 450, 1188 and 1106. If the results of a capacity test are below 80% of the manufacturer's rating, the battery should be replaced if it is lead acid. Replacement for nickel cadmium cells depends upon the sizing criteria and capacity margin compared to the load, but often nickel cadmium are sized using the 80% capacity end of life criteria. Timely replacement of the battery is critical in order to maintain the reliability of the connected dc system and loads.

Why two Performance Tests (i.e. why have a Modified Performance Test)

Modified Performance Test Type 1 was added to IEEE Std. 450 in 1995. Types 2 and 3 were added in 2002. They were added to cover industries that require both Service Tests and Performance Tests be performed at the same time. This is the case in the commercial nuclear power industry where the Nuclear Regulatory Commission (NRC) requires that safety related batteries undergo a Service Test every 18 or 24 months (typically based on refueling outage frequency) to ensure that they can cover their duty cycle. They generally also require that these batteries undergo Performance Tests at least every five years to make sure the batteries have at least 80% capacity and haven't experienced any degradation that would require increasing the frequency of the tests. Many plants can only do this testing while in an outage so when these two frequencies line up, it requires the plant to perform both tests. Some plants struggled due to the time required to perform both these tests during short outages. Creating the Modified Performance tests that covered both requirements in one test, eliminated this issue.

When to Test

IEEE Std. 450 recommends an Acceptance test initially, then a Performance test after about two years in service and then on a timeframe equating to 25% of expected life (typically 5 years based on a 20 year life). IEEE Std 1188 recommends an Acceptance Test initially, then a Performance test interval not to exceed two years or 25% of expected service life, whichever is less. For example, for 2 volt VRLA units with an expected service life of 12 years in UPS service, the Performance test interval would be every 2 years. The recommended frequency drops to annually once the battery reaches 85% of expected service life or degradation is identified. After 85% of expected service life, frequency can be every two years as long as the capacity remains above 100% and the battery shows no sign of degradation. Degradation is defined as the battery's capacity dropping more than 10% from that of its previous test or when the battery is below 90% of its rated capacity. This includes a 10% capacity drop even when the battery capacity is above 100%. For example, a battery with a capacity of 118% that drops to 105% at the next Performance test is considered degraded. Note for batteries sized for short run times (significantly less than 1 hour), degradation can be indicated by less than a 10% drop from the last test due to a reduction in battery efficiency as the discharge time decreases.

IEEE Std. 1106 recommends an Acceptance test, then a Performance test after about two years in service, and then every 5 years until excessive capacity loss is observed where the recommended frequency drops to annually. Excessive capacity loss is when the capacity drops by more than 1.5% per year.

The basis for these test frequency recommendations is as follows:

- The Acceptance test ensures there were no problems during the battery's manufacturing process and the battery can perform as expected. If done after installation, it will also ensure no damage was done during shipping, storage, and installation and can confirm the installation was performed correctly.
- The two year Performance test ensures there are no "infant mortality" issues.
- The next Performance tests are used to track the battery along the Life-Capacity Curve (see Figures 2, 3 & 4) to make sure its SOH is moving along as expected. The 25% of life (for Lead-Acid VLA and/or 2 years for VRLA) and 5-year (for Ni-Cd) intervals were deemed acceptable durations for ensuring the battery will be okay until the next test, assuming no degradation or excessive capacity loss is identified.
- For Lead-Acid at 85% of life, the battery would not necessarily be expected to make it another 25% of life which is why the frequency drops to annually. The caveat is a battery that is over 100% is expected to be okay for at least two years. If the capacity has dropped by more than 10% since the last test, the battery is declining faster than expected and more frequent testing is warranted. After the battery reaches 90%, a significant capacity drop could cause the battery to not be able to perform its function for the next 25% of life timeframe, thus requiring a more frequent test schedule.
- For Ni-Cd, a capacity loss greater than 1.5% per year indicates the battery is declining faster than expected and more frequent testing is warranted.

Do Discharge Tests harm the battery?

Discharge tests performed at the manufacturer's published rate down to the cell's minimum voltage (e.g. 1.75 volts/cell) do not damage the cell (as a general rule of thumb). Most VLA cells are designed for at least 30 such discharges and a typical VLA battery in a switchgear and control application will only experience about seven such planned discharges (i.e. at 0, 2, 7, 12, 17, 18, and 19 years of life) during their expected life. Discharges due to the battery being called upon due to a loss of normal power must be included in this number. As such, it is good policy to record the number of deep discharges a battery experiences. A note of caution on the test rate and duration: in cases where battery systems are selected for extremely long duration (e.g. 100 hours), it is important the user discusses with the manufacturer the appropriate test end voltage. Conversely, a battery system selected for a very short duration (e.g. 5 minutes) application, should not be tested at long durations (e.g. 3 hours) without discussion with the manufacturer and adjustment to the test end voltage.

Conclusion

While there are other testing technologies that propose to provide a battery's capacity and SOH that are simpler, faster, and cheaper than discharge testing, all have shown to have issues. As such, trending capacity test results remains the only true method to determine a battery's capacity, SOH and its expected future life. Though costly and time consuming, capacity testing provides the owner the peace of mind that the battery will function as expected when needed.

References:

1. IEEE Std. 450-2020, "Recommended Practice for Maintenance, Testing, and Replacement of Vented Lead-Acid Batteries for Stationary Applications", http://standards.ieee.org.
2. IEEE Std. 1188 -2005,"Recommended Practice for Maintenance, Testing, and Replacement of Valve-Regulated Lead-Acid Batteries for Stationary Applications", http://standards.ieee.org.
3. IEEE Std. 1106- 2015, "Recommended Practice for Installation, Maintenance, Testing, and Replacement of Vented Nickel-Cadmium Batteries for Stationary Applications", http://standards.ieee.org.
4. IEEE Std. 485-2020, "Recommended Practice for Sizing Lead-Acid Batteries for Stationary Applications", http://standards.ieee.org.