

“FIRE IN THE HOLE 101!” AN ENTRY-LEVEL GUIDE TO DISCHARGE TESTING LEAD-ACID STATIONARY BATTERIES

**Rick Tressler
Manager, Training and Education
Alber
Boca Raton, FL**

ABSTRACT

Stationary batteries require care in two distinct areas. The first involves the need to conduct routine inspections of the system which includes collection of operational data while the battery is in normal operational service. This activity, also known by some as “manual monitoring”, is recommended by both the battery manufacturer as well as the IEEE in its published standards. The collected data needs to be analyzed, compared and trended over time to keep track of general battery condition as it ages. The other required area of attention involves the utilization of industry recommended practices that focus on periodic discharge testing. These are dynamic tests of a battery and, when properly conducted, truly provide results that indicate a battery’s ability to perform as well as its condition. The problem here is that users are not testing their batteries. Frequently, the user does not understand the importance and fundamentals of such testing. Admittedly, the costs associated with performing discharge testing can be fairly high. The previous notwithstanding, it still needs to be done. The purpose of this paper is to introduce the reader to the basics of discharge testing. It discusses how battery capacity is determined by the battery manufacturers and explains published performance charts and tables. The IEEE recommended practices are noted and several common traps to avoid are also explored.

INTRODUCTION

As more Battcon conferences pass, I have noticed a significant increase in the hands that go up in response to the question, “How many of you here are attending Battcon for the first time?” Keeping that thought in mind I decided to author this paper. As the title infers, it is written for the beginner or novice battery user and will provide a good foundation relating to dynamic testing of a lead-acid stationary battery. It can also be used as a review for the more experienced users that may have been away from the subject for some time. As with things having a technical nature, if you don’t use the information routinely, it is easy to forget how and why things are done. I sincerely hope you find the paper interesting and can put the information to use in your application.

WHY TEST IN THE FIRST PLACE?

While routine preventive maintenance inspections or manual monitoring of a battery are a good practice, the data does not provide an indication of the battery’s remaining service life or capacity. General condition is indicated from data analysis and can point the user in the direction that will indicate the need for a more substantial, quantitative test of the system on a dynamic level. We would all like to have a test instrument that would make a measurement and display the remaining service life and capacity of a battery or cell. We’re just not there yet and I predict it will be a while longer before we see such instrumentation, if ever.

A battery should be tested periodically as recommended by the battery manufacturer and industry recommended standard practices, such as those published by IEEE (Institute of Electrical and Electronics Engineers). A battery should be tested periodically because;

- A test will determine where the battery is located on its predicted life curve
- It will tell the user when to replace the battery
- Testing will identify faulty intercell connectors
- A test will locate weak and failing cells that static testing may not
- If it is *not* tested, it will fail at a most inappropriate time
- You bought the battery to ensure supported equipment does not fail

BATTERY PERFORMANCE SPECIFICATIONS

Okay, so you've accepted the fact you need to test your battery and why. Now, a common question that's asked is how do I know what the battery is capable of doing? This question usually leads into other questions such as, what is its capacity, how long will it run, what cell end-voltage should be used and what's 77 degrees got to do with anything?

Enter the battery data sheet. All batteries made have one and the information which it contains is established by the manufacturer. The data sheets contain a wide variety of information about the battery. For the purposes of this paper however, we're interested in the part that tells us what a battery can do electrically. Such information contained in the data sheet that leads us to that includes;

- The model of the cell
- Its specific gravity rating
- Discharge cell end voltage(s)
- Ampere-hour rating for a range of discharge times in minutes, hours, or both *AND/OR*
- Watts per cell rating for a range of discharge times in minutes or hours
- Footnotes

AVERAGE CELL PERFORMANCE DATA * (Discharge Rates in Amperes **)																	
TYPE	Nom. Ah Cap	8 HR	7 HR	6 HR	5 HR	4 HR	3.5 HR	3 HR	2.5 HR	2 HR	1.5 HR	60 MIN	30 MIN	15 MIN	5 MIN	1 MIN ¹	1.50 VPC ¹
1.250 SPECIFIC GRAVITY TO 1.75 END VOLTS PER CELL																	
DX-5B	280	35	40	43	49	58	64	69	82	98	117	156	250	345	479	562	741
DX-7B	400	50	55	62	71	84	93	99	119	140	172	230	372	512	713	838	1100
DX-9B	528	66	72	81	92	109	116	126	154	180	223	301	492	675	941	1112	1451
DX-11B	712	89	102	112	128	152	167	189	213	252	310	407	606	839	1043	1251	2124
DX-13B	832	104	116	128	148	178	195	221	250	299	369	481	722	995	1251	1498	2543
DX-15B	928	116	129	143	166	200	220	251	285	344	426	552	842	1148	1480	1738	2960
DX-17B	1024	128	140	155	183	221	245	279	318	388	481	621	954	1296	1688	1979	3376
DX-19B	1048	131	146	166	192	227	249	283	323	394	489	655	1030	1379	1833	2183	3579
DX-21B	1168	146	163	184	213	252	277	314	369	437	543	800	1185	1600	2146	2446	4140
DX-23B	1280	160	179	203	235	277	305	346	395	481	598	865	1292	1741	2330	2677	4510
DX-25B	1400	175	195	221	256	303	333	377	431	525	652	926	1306	1881	2516	2903	4871
DX-27B	1744	218	243	275	316	378	413	460	531	627	778	1018	1546	2078	2778	3127	5385
DX-29B	1816	227	252	286	330	394	431	486	564	666	819	1077	1649	2215	2957	3453	5741
DX-31B	1872	234	262	297	343	407	445	477	576	681	856	1132	1750	2348	3129	3678	6091
DX-33B	1944	243	270	306	354	419	460	487	595	704	890	1185	1849	2478	3299	3901	6428
DX-35B	1976	247	277	313	363	429	469	485	610	726	923	1237	1946	2605	3463	4123	6761

Figure 1
Excerpt of Cell Performance Data Sheet

<p>*Ampere values listed represent 100% of the initial capacity. **At 77°F (25°C) includes intercell connector drop. ¹One minute rates to 1.50 VPC and 1.75 VPC should only be used for short circuit calculations and not as performance data. ²Nominal Amp-Hour capacity at the 8 hour rate. All data subject to change without notice.</p>

Figure 2
Data Sheet Footnotes

Figure 1 represents the information typically found on a data sheet. This particular one lists performance rates in amperes. It covers cell sizes ranging from the 5 plate cell up through and including the 35 plate model. The plate count refers to the total number of plates, both positive and negative, that are used in a given cell size. The DX-35B, for example has a total of 35 plates, 17 positive plates and 18 negative.

Lead-acid manufacturers always use one more negative plate than the positive count. That way, every positive plate has a negative on both of its sides allowing full utilization of the positive plates.

This particular cell denotes its rated specific gravity in the suffix code. The “B”, means the nominal rated gravity for the cell is 1.250. An allowable operating range for this manufacturer is 1.240-1.260. Cells using standard gravity of 1.215 have no suffix code with a normal range of 1.205 to 1.220 typically. When referring to a cell’s performance rating, use caution when checking the numbers, as there are figures on many sheets for both standard as well as high gravity ratings. Changing a cell’s gravity from standard to high increases cell performance by about 13%.

Across the top of the discharge amperes ratings is what I refer to as the *discharge rate header*. This assigns a specific time period to a discharge current for a given cell size for a specific time. In this case, the DX series cells are rated from 5 minutes up through and including 8 hours. That is not to say that the cell cannot be discharged at some other rate, such as the 5.5 or 6.2 hour rate, or even a rate for a time in excess of 8 hours. In such cases, the battery manufacturer should be consulted for non-standard rates. The header is used in conjunction with the ampere ratings which make up the matrix in the body of the table below the discharge rate header. These numbers are expressed in amperes. This data is frequently mistaken for ampere-hours. In this sheet, the only numbers that indicate ampere-hours are those under the *Nom Ah Cap* column. Further, this column is the capacity of the cell when discharged at the 8 hour rate to 1.75 volts per cell average.

Using the DX7-B as an example, you will note that the cell is rated at 400 ampere-hours when discharged at the 8 hour rate. This means that it can be discharged at the rate of 50 amperes for 8 hours. Ampere-hours are nothing more than amps x hours at a given discharge rate, to a specified cell end voltage and referenced to 77 degrees, F. In this case, the cell end voltage is 1.75 volts. If any of the discharge conditions are changed, the calculated capacity of the cell will change. Another misconception about battery performance is that if a battery is rated for 50 amperes at the 8 hour rate, it can be discharged at 100 amperes at the 4 hour rate. Simply doubling the discharge current at half the time won’t work. The relationship between discharge current and the rate is not a linear one, as can be seen in Figure 1. Rather, it is exponential, with the discharged ampere-hours approaching zero as the time approaches zero. At the 4 hour rate, the current that the cell can deliver is 84 amperes; only 40% higher than the 8 hour rate. A cursory check of the cells within this table shows this is generally true for other size cells and rate comparisons within the data sheet. The reason for this is when the cell discharged at a higher current, there is less time for the electrolyte to penetrate the active material in the positive plate. This is the fundamental behind why telecom batteries make poor UPS batteries. The telecom plate design is much thicker than its UPS brethren and works well given sufficient time for the electrolyte to access the paste.

FOOTNOTES

The Footnotes section of the data sheet is shown in Figure 2. Always consult the footnotes, as they provide additional information that may need to be considered when sizing a new battery or determining test parameters. Note the single and double asterisks as well as footnotes 1 and 2. The battery manufacturer indicates in the first note (*) that the cell will deliver 100% of its rated capacity, assuming it has been properly installed and commissioned. Not all types of cells are rated with 100% capacity on delivery. Some may deliver only 90% of their rated capacity on delivery. If 100% capacity on delivery is required from a battery not rated for this, the buyer must specify that requirement in the order. The second note (**) indicates the battery is assumed to be operated at standard temperature to achieve the times. If it is not, adjustments to the discharge test rate or time, per IEEE recommended practices are in order. Temperature is frequently overlooked when a battery is tested. Capacity is not the only parameter affected by temperature. A battery operated at lower than standard temperature will experience reduced charge acceptance after a discharge, increasing recharge time. Conversely, higher than recommended operating temperatures shorten life and result in excess charge (float) current. Flooded cells use more water and VRLA types dry out. The battery manufacturer also assumes that the cells will be installed per their instructions, including proper interconnection preparation, with bolt torque and connection resistance verified. Note 1 advises that the highest rates published at 1 minute to 1.75 and 1.5 volts per cell *cannot be used* as sizing data. These values are used to determine short circuit ratings and calculation of internal resistance. Lastly, Note 3 simply states that the ampere-hour rating at the far left of the data sheet is for the 8 hour rate to 1.75 volts.

TESTING A BATTERY

Now it’s time to look at the processes that relate to testing a system. How often a lead-acid battery should be tested is a function of its type. If the battery is a flooded type, it should be tested upon completion of installation, then again at approximately 2 years service, then at intervals not to exceed 25% of the battery’s design life.

For a battery with a design life of 20 years, that's once every 5 years. When its capacity drops below 90%, of rated or falls more than 10% from the previous test (degradation), it should be tested at 1 year intervals until reaching 80% capacity.

If the battery is a VRLA (valve regulated lead-acid), it should also be tested as above, however, the intervals are yearly for subsequent tests and at 6 month intervals once degradation occurs. Once the battery reaches 80% capacity, the battery is then considered to be at end of life. The need to test VRLA batteries is considered by many to be even more important than testing flooded batteries because the VRLA battery is less predictable and shorter-lived overall and fails for different reasons than the flooded battery.

Over the years, I have spoken to people who do not test their batteries because they have been told, or for other reasons believe that testing it will cause it terrible harm. That could not be further from the truth. Consider the typical lead calcium flooded battery, for example.

It is designed to undergo 50 discharge cycles to 80% depth of discharge. That is considered to be *a lot* of discharge activity. Depending on the specific application for a system, the battery may *never* be discharged below 20%. Such would be the case for a battery utilized in UPS service. Momentary discharges of less than one minute result in even lower depth of discharge. In the U.S., utility power outages are generally infrequent and short-lived when they *do* occur. Even if tested in accordance with IEEE recommendations, and the battery were to last 20 years with 80% capacity remaining, the battery would have been tested 5 times minimum, leaving 45 full discharges remaining, most of which will likely never be realized. So, testing a battery in accordance with industry recommendations is not damaging to a battery. Conversely, consider the career damage one might endure if a battery is *never* tested. Many are not tested and the users are not aware of potential problems.

The data sheet shows a number of rates at which the battery may be discharged. The rate actually selected becomes a matter of several considerations. Generally, the battery should be best tested at a rate and cell end voltage that equates to that of the actual application, or nearly so. Testing a UPS battery, for example at the 5 hour rate to 1.88 volts per cell would not really serve the purpose very well because a UPS battery is generally sized for an end of discharge voltage to 1.67 volts per cell or lower and at a discharge rate of 30 minutes or less. The former test specification would not really demonstrate the battery's short duration, high rate capability. Likewise, testing a battery designed for long duration, low rate discharges, such as telecommunications, at the 15 minute rate won't tell you very much either, except as to how well the battery performs at the high rate, short duration figures.

EQUIPMENT REQUIREMENTS

Many industrial stationary batteries can be tested with load banks that connect directly to the battery. The load is controlled automatically or manually with overall current and voltage monitored throughout the test. Individual cell voltages are monitored so that weak or faulty cells/monoblocks can be identified. Additional equipment that connects to the load bank handles control and data logging tasks. Test data is stored on a computer for recall at a later time. UPS battery systems in excess of 250 volts may have to be tested through the system inverter with and AC type bank.

Another consideration is the DC load bank equipment voltage and current limitations. Such equipment has a specific limit on these parameters and as such, must be considered before committing them to the task. Commercially available DC load bank equipment ranges from 24 volts up through and including 250 volts nominal from under 100 amperes up through nearly 2000 amperes per unit. Should a battery have an operating voltage above these parameters of the largest single load bank, a series-parallel arrangement is then required. This can become a very expensive venture for system owners who wish to purchase their own capacity test systems.

HOW DOES DISCHARGING THE BATTERY AFFECT MY LOAD?

Testing the battery will always have some level of impact on the critical load. The extent of which has a lot to do with the application of the battery. In many cases, the battery will need to be isolated from the charging system while the test is conducted. This is common for large UPS batteries. If the site is equipped with a generator, the end user may transfer the load to generator, then, disconnect the battery from the UPS, allowing the system to run on the emergency source. Once testing is complete, the battery is reconnected to the UPS and allowed to charge for a period of time before the system is retransferred to the normal utility. Another possibility is to have a "temporary" battery brought into the site, paralleled to the DC bus and used in the interim, while the primary battery system is tested. This method has its limitations, however regarding the size of the temporary battery and its required backup time.

Some systems can be tested where the battery remains connected to the load. This is called “on-line” testing and is somewhat of a compromise. This kind of testing is performed in the utility industry with substation batteries. With on-line testing, the battery remains connected to the charging system and load. A test specification that uses a higher than normal cell end voltage and lower load current is used to measure capacity. The idea behind this kind of testing is to limit the exposure of the system, leaving *some* remaining capacity in the battery post-test, in the event a discharge should occur. At the same time, should the battery be needed, it remains available to support the load during the test.

WHAT ABOUT TEMPERATURE?

Recall from the data sheets footnotes that published performance is based on an electrolyte (battery) temperature of 77 degrees, F. (25C.). A brief recall of batteries 101 is in order. Battery temperatures above 77 degrees result in performance above published figures in most cases. Conversely, when the temperature is below 77 degrees, performance can become considerably degraded (less run time), especially in the high rate short duration category.

When a battery is tested at a temperature *other* than this, allowances must be made or the test results will be erroneous. This is especially true for UPS batteries, as they are frequently rated for run times at one hour or less. Allowances for temperature come in the form of discharge rate or time adjustments to the published values and depending upon the actual case, may be made pre-test or post-test. Excellent sources of technical material that address this and other related subjects include the IEEE recommended practices. They include 450-2002, 1188-1996, 485-1997, 484-2002, and 1184-1994. Check the bibliography for the detailed titles of these documents.

TESTING TRAPS

Testing can be problematic, or the results are nowhere near what the user expects. Successful testing is all about planning. Understanding what is really required to pull off a successful test will go a very long way to ensuring that it does. The following should provide you with some insight into ways you can use this information to avoid some of the common problems.

Test Specification

One of the biggest problems on test day is that no one has the test specification at hand. A battery cannot be tested without one. The specification comes from one of two sources; the battery manufacturer’s published data or the system design specification. Without one or the other, the load cannot be determined, nor can the cell end voltage, also known as the EOD voltage (end of discharge voltage). What’s worse than having not having a test specification, is using one that’s incorrect. Nothing good will come of this, so get the right test requirements up front.

Temperature

Battery systems rarely operate at standard temperature (77, F.). Allowances should be made for nonstandard conditions, especially when the battery is in UPS service and its temperature is hovering in the low to mid 60’s. While operating the battery at a slightly lower temperature than standard is fine, a UPS battery that is operating at 62 degrees, F. will not perform as designed unless temperature was factored into the sizing equation up front. Batteries rarely are, so consult the appropriate IEEE standard for advice. A common correction that some attempt to make for this is to warm up the battery room the night before the test. This won’t work because sufficient time is not allowed for the thermal mass of the battery to catch up with the ambient. This can require 36 hours or longer for very large systems.

AC load bank settings

UPS systems are rated in KVA as well as KW. Power factor is generally at .8 or .9 (80%-90% of the KVA rating). So a system that rated at 500 KVA at .8 pf is really rated for a maximum AC load of 400 KW. Time and again, the operator sets the load at 500 KW and can’t figure out why the UPS quits on an overload condition. KVA and KW are never equal in the real world because loads are never perfectly resistive in their makeup. Built-in instrumentation on rented AC load banks can be notoriously out of calibration. When such load banks are used, verify their accuracy with actual voltage and current measurements with calibrated volt meters and AC current clamps.

Pre-test battery condition

If the battery has not been maintained in accordance with the battery manufacturer’s recommendations, it should not be tested until its condition and fitness for a test can be determined. This is where the “Fire in the Hole” part of this paper comes in. Over time, connections can become loose, corroded, etc.

Other problems can exist that are not readily apparent to the user including dead cells or an undercharged system. On test day, the battery goes under load and an inter-cell connection could fail, or, worse yet one or more cells fail catastrophically. This is just of numerous reasons for properly maintaining the battery in good condition.

Expectations of individual cell end voltage

When a battery system is tested, assumptions as to what the behavior of the cell voltages will be at the end of the test have been made. This assumption (an erroneous one) is that all the cells will be at exactly the same voltage at EOD. This is not true and will never happen in real life, due to the internal resistance differences among the cells in the string. The values of the cells are an *average* for the battery on the whole. As an example, if a 60 cell substation battery is discharged to an EOD voltage of 105 volts, the *average is* 1.75 volts per cell. Some cells will be above, some below and some will actually be 1.75 volts. Sometimes the technician sets up the test so that it will be terminated when the first cell reaches 1.75V. This will almost certainly result in premature termination of the test and will not allow a proper assessment of the condition of the rest of the battery. If a specification is written that states *no individual cell* will be allowed to fall below a certain voltage, be prepared to buy a much larger and more expensive battery than what is actually required. The battery is really being graded on its overall performance. That is what the battery manufacturer is looking at when battery capacity is being measured. That said, however, individual cell voltages are monitored during the test so that weak or defective ones can be detected and replaced. Cells that appear to be significantly lower than the expected average value should be noted. The battery manufacturer should be contacted for guidance as some may need to be replaced.

Load bank placement

Load banks can generate a lot of heat. Be very cautious when determining where they will be placed, especially when the test duration is several hours. Most of these heat dissipating units cannot be operated outdoors, unless they are protected from precipitation. Parking garages are frequently a good choice, providing heat, smoke or fire detection systems can be disabled or better yet, do not exist in the first place. Getting them turned off or “zoned out” may not be possible. That applies to *any* location that’s being considered. The trap here is that it’s usually not considered until the fire suppression system is discharging as a result of a sensor picking up the heat from the load bank. Then it’s too late.

Load cabling requirements

Along with load bank placement, the size of the power cabling and its required should be of concern and planning is essential. Voltage drop should be another consideration, and generally should be limited to no more than 3 volts between the battery and the load bank. To provide a point of perspective, consider a battery that is to be tested at a load current of 1200 amperes. The load bank is going to be a short 50 feet away from the battery. The allowed drop is 3 volts. To satisfy the cabling requirements, 2 pieces of 500 MCM able are required; one positive, one negative. The cable will dissipate 3.6 KW. To lower the drop to 2 volts, you would need a quantity of 2, 350 MCM cables per polarity. Measure carefully. It’s rare that a straight-line distance from the battery to the load bank is going to be the case.

Cell failure during a test

The IEEE recommended practices provide guidance on how to handle a cell failure during a load test. Generally, you get one shot at bypassing a cell that is headed towards failure. Leaving it in the circuit will lead to complete reversal if permitted and that should be avoided, unless the battery is at the 95% point on the test. The time allowed for the bypassing task if performed, is limited to 10% of the total test duration or 6 minutes, whichever is shorter. The way to avoid the trap here is to have plan “B” ready. Making one up on the fly won’t work. If this is a 15 minute UPS battery test, forget it. You can’t stop the test to bypass the cell because the time it’s going to take to complete the task will be nearly 50% of the total test time and the battery will begin to recover making the whole test invalid. The test will have to be halted, the offending cell(s) replaced and the battery retested at a later date.

SUMMARY

Briefly, the bullet list below recaps the discussion points presented in this paper.

- A stationary battery should be discharge tested to determine its point on the service life curve
- Understand the information presented in battery data sheets
- Read the footnotes contained in the data sheet
- Testing your battery properly will not damage it
- Read the IEEE standards for guidance on testing recommendations
- Understand the test equipment to be used, its operational limitations and how to use it
- Make the required allowances for non-standard temperature when testing a battery
- Avoid the testing traps that can cause a good test to go bad

Bibliography

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