# MISLEADING RESULTS USING IEEE BATTERY TESTING PROCEDURES

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## ABSTRACT

There is a fundamental conflict between the IEEE sizing method and IEEE testing recommendations. For an application in which the end of useful battery life is set at 80% of rated capacity, the sizing method defines this point using 80% of published current for 100% of the time, while the testing procedure defines it using 100% of the current for 80% of the time. The testing calculation method is flawed, in that it ignores changes in battery efficiency at different discharge times. While tests of long duration are relatively unaffected, this inconsistency can have pronounced effects on high-rate testing. Batteries can appear to fail prematurely, often after just a few years in service. This paper analyzes the problem and outlines what the IEEE battery standards committee is doing to address the issue.

## HISTORY

When IEEE 450[1] was first written, about the only users following its testing recommendations were those in nuclear power generation. Indeed, the scope of the early versions of this document was limited to 'large' vented lead-acid batteries in generating stations and substations. Safety-related batteries in nuclear generation were designed for 4- or 8-hour discharges, and were tested accordingly. As reliable battery performance has become more critical in other areas, more and more users have taken to performing discharge capacity tests on their batteries—and not just in utility applications. This was formally recognized in 1995, when the scope of IEEE 450 was broadened to include all stationary applications.

Other IEEE battery maintenance and testing standards cover nickel-cadmium (Ni-Cd) batteries (IEEE 1106[2]) and valve-regulated lead-acid (VRLA) batteries (IEEE 1188[3]).

While few problems were encountered with discharge tests of several hours' duration on vented lead-acid batteries, it was soon found that tests of shorter duration (typically one hour or less) seemed to result in many more premature battery 'failures.' The same effect was seen with VRLA batteries, while for Ni-Cd there have been many more 'failures,' even for quite long discharge tests.

## THE PROBLEM

It is generally known that all batteries degrade with age, and this degradation has to be taken into account in the sizing calculation. This can be done either with a formal aging factor, as detailed in IEEE 485[4] for lead-acid or IEEE 1115[5] for Ni-Cd, or less formally, as in, 'think of a load, then double it.'

The problem comes in trying to monitor capacity degradation with age, so that the battery does not fall below the minimum requirements used for the sizing calculation. The sizing method calculates the base capacity required to support a duty cycle, then adjusts it with an aging factor. For example, if the end of life point is defined as 80% of rated capacity, the base capacity is multiplied by 1.25, so that the full duty cycle can still be performed when the battery is at 80%.

Now it is necessary to define 80% of rated capacity. The assumption that is implicit in the sizing is that this is 80% of the published current for 100% of the time, since rated capacity is proportional to published performance for a particular plate type. However, the IEEE testing recommendation calls for the battery to be tested at the full published current and defines an 80% battery as one for which the voltage reaches the minimum value at 80% of the time for that current. We now have to relate one measure – 80% current/100% time – with another – 100% current/80% time. These are definitely not the same, because the efficiency of a battery varies with time and it cannot deliver as much capacity in the shorter time as in the longer.

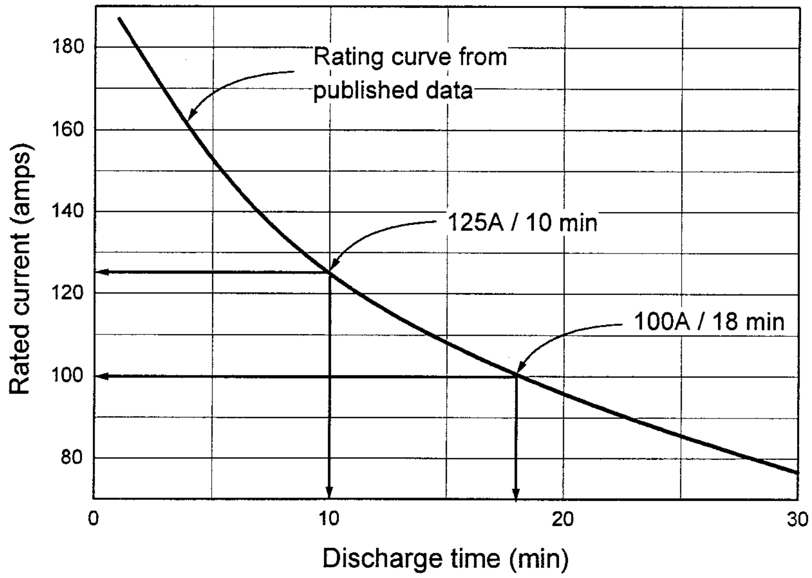


**Figure 1 - Lead-acid general purpose cell performance**

## EXAMPLE

Let us look at a specific example, using a load of 100A for 10 minutes. If we calculate the base capacity for this load, then apply an aging factor of 1.25, we would install a battery that can supply 125A for 10 minutes. This is because a battery that is 25% larger (in ampere hours) can supply a current that is also 25% larger (assuming the plate size stays the same).

If we look at the published data for a typical general purpose vented lead-acid battery, shown in Figure 1, we see that a new battery that can supply 125A for 10 minutes will support our actual load of 100A for 18 minutes. Note that, while the 18-minute current is lower, the capacity removed is much higher—1800 ampere minutes at the 18-minute rate, against only 1250 ampere minutes at the 10-minute rate. This is because the battery becomes more efficient as the discharge time increases.

Now, when it comes to testing this battery, let us assume that the 100A equipment load will be used. The test engineer looks up 100A in the published data and determines that this is the 18-minute rate. Following IEEE 450, he then defines the end-of-life point as 80% of 18 minutes, or 14.4 minutes. He performs the test, finds that the battery reaches the end voltage at, say, 13 minutes, and states that the battery has reached the end of life and must be replaced.

Although the test engineer is correct in his interpretation of IEEE 450, the conclusion is nonsense. The battery was sized for 100A for 10 minutes, and to say that it should be replaced when it can 'only' give 13 minutes at this current is clearly incorrect.

The basic problem here is that the IEEE testing method ignores the changing efficiency of the battery at different discharge times. A new battery can deliver 80% of its 10-minute rating not just for 125% of the time, but for 180% (100A for 18 min, vs. 125A for 10 min).

## THE SOLUTION

An explanation of this problem has been difficult to promote on a test-by-test basis. It involves convincing a test engineer, or the final user, that an internationally accepted standard is flawed. The IEEE battery committee has recognized this problem, and has reached a tentative agreement regarding IEEE 450. At their fall 1998 meeting, the committee agreed to restrict the validity of the existing test method to acceptance tests and to performance tests with durations of greater than one hour. A new method will be adopted, valid for all performance tests, using a derated

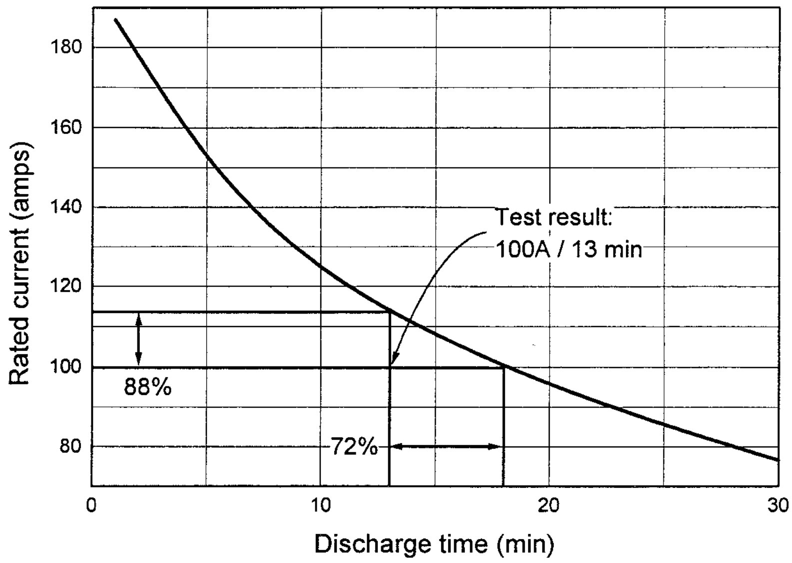


**Figure 2 - Capacity calculation**

test current. Note that this agreement will not become official until the new document has been balloted and adopted by the IEEE-SA Standards Board.

The new method for performance testing throughout life calls for the test current to be derated for the end of life capacity. If the aging factor used in the sizing calculation is known, then it is simple enough to use this to calculate the test current.

Using the example above, for a 10-minute test, the published 10-minute current of 125A would be divided by the 1.25 aging factor to give a test current of 100A, which is the same as our original equipment load. To allow trending of the test results, the test must always be continued to the final voltage, even though the test duration may be considerably longer than the intended duty time. In the case of a new battery at 100% capacity, the test duration would be 18 minutes. This would reduce to 10 minutes at the end of life. 100A for 10 minutes is the same as the original duty, so the sizing method and the test procedure are now compatible.

If the original aging factor is not known, the assumed end of life would be used. For example, for a substation battery where the original calculations are unavailable, a user would probably decide to use an 80% pass/fail criterion, so he would use 80% of the published rating for the test current.

## CALCULATING PERCENTAGE CAPACITY

Whatever test method has been used, whether or not the test current has been derated, it is possible to calculate a meaningful percentage capacity figure. In this case, it is necessary to perform the calculation based on current, rather than time. The formula is as follows:

$$\% \text{ capacity} = [I_a / I_t] \times 100$$

where

$I_a$ = actual rate used for the test
$I_t$ = published rating for time t
t = time of test to specified terminal voltage

Figure 2 shows a graph of the performance of our general purpose lead-acid battery. In the previous example, using a test current of 100A (the 18-minute rate for a new battery), a test time of 13 minutes was attained. From the graph, it is possible to read off the published current for 13 minutes, at 114A. The correct calculation of capacity is then to express the test current for that time as a percentage of the rated current. In this case, the correct calculation is 100/114 x 100 = 88%.

By comparison, the capacity that would be calculated using IEEE 450 is 13/18 x 100 = 72%.

The figure of 88% capacity reflects the fact that some degradation has taken place, but correctly shows that the remaining capacity is still above the minimum requirement.

## TYPICAL USER QUESTIONS

**Q. What happens if I didn't use an aging factor in the sizing calculation?**

A. The new method can still be used. In this case, the aging factor is 1.0, and the 'derated' test current is the same as the published current. Of course, the battery will 'fail' much sooner, but it is up to the user to determine when the battery can no longer be used.

**Q. If I can perform the new calculation for a test at the full published rate, why should I bother to derate the test current?**

A. The most accurate indication of the end of a battery's life is when the test duration is the same as the duty cycle duration. In our example, a test at the exact end-of-life point would last for 10 minutes—the same as the specified duty cycle. If the full 125A rating were used as the test current, the end of life (80% of rated current) would occur at a test duration of 4.5 minutes. This is not truly representative of the 10-minute capability of the battery and would result in a premature end-of-life indication (but less premature than with the existing method).

**Q. How do I account for temperature effects?**

A. The discussion in this paper has ignored temperature effects, in an effort to make this complex issue as understandable as possible. There is an ongoing debate in the IEEE 450 Working Group as to whether temperature adjustments should be made before or after a test, either by discharge rate adjustment or simply by calculation. In the author's opinion, it is always best to adjust the test rate, for the same reason, as outlined in the previous answer, that the test rate should be derated for the end-of-life capacity.

**Q. Does the new method work for battery capacities above 100%?**

A. Yes. Taking our example, let us assume that a test is carried out at 100A and the final voltage is reached at 20 minutes. From Figure 2, the rated current for 20 minutes is 96A, and the capacity calculation is 100/96 x 100 = 104%.

**Q. Which method should I use for a 2-hour test on a VRLA battery?**

A. The changes in IEEE 1188 are likely to reflect those of IEEE 450, at least as far as the test discharge rate and capacity calculation method are concerned. The preliminary agreement to limit the applicability of the existing method to test durations of greater than 1 hour means that either method could be used for a 2-hour test. Bear in mind, however, that there is an error involved with the use of the existing method for ***all*** test durations. This error is insignificant for long discharges, but becomes progressively more severe as the test duration is decreased. By the time the duration is down to 1 hour, the error is unacceptably large. For a 2-hour test on a battery approaching the end of life, the existing method might indicate a capacity that is around 5% lower than by using the derated current method.

**Q. Can I use the existing method for a 3-hour test on a Ni-Cd battery?**

A. The difference between the two test methods is actually much larger for Ni-Cd than for lead-acid. It is likely that the next issue of IEEE 1106 will restrict the validity of the existing method to acceptance testing only, with the derated current method being used for all test durations for a battery in service.

**Q. Why is Ni-Cd more severely affected by this issue than lead-acid?**

A. This issue has a pronounced effect for discharges where a battery's capability has dropped below 100%, and where the average battery voltage is lower (such as high rate discharges for lead-acid). There is a fundamental difference between the characteristics of Ni-Cd and lead-acid batteries, which makes Ni-Cd more susceptible to this problem. The aging of Ni-Cd batteries is essentially a linear decline in capacity, whereas lead-acid batteries show increased capacity through the first two thirds or so of their lives, followed by a rapid deterioration towards the end of life. A Ni-Cd battery halfway through its life will be at about 90% of rated capacity, whereas a vented lead-acid battery would be at about 108% at its halfway mark. On discharge, the flatter part of the voltage curve for Ni-Cd is somewhat lower than for lead-acid. Since one of the effects of aging is to lower the average voltage on discharge, there can be a large effect on discharge time as the battery capacity declines. The combination of these two factors results in the greater impact of this issue on Ni-Cd tests.

**Q. How long is it going to take before all three IEEE testing standards are changed?**

A. Unfortunately, the IEEE battery standards process is not a speedy one. There are a number of other issues to be addressed with IEEE 450, but it is expected that the final draft will be ready for the balloting process before the end of 1999. Due to the contentious nature of this particular change, it can be expected that it will take some time before all comments are resolved. Overall, the process is likely to take about two years. IEEE 1188 and IEEE 1106 are just entering the review process, but their passage should be easier, since most objections will have been resolved in the process with IEEE 450. The IEEE 1106 review will probably be completed in about two years; while the process may last up to a year longer for IEEE 1188.

## REFERENCES


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

[2] IEEE Std. 1106-1995, *"IEEE Recommended Practice for Installation, Maintenance, Testing and Replacement of Vented Nickel-Cadmium Batteries for Stationary Applications"*

[3] IEEE Std. 1188-1996, *"IEEE Recommended Practice for Maintenance, Testing, and Replacement of Valve-Regulated Lead-Acid (VRLA) Batteries for Stationary Applications"*

[4] IEEE Std. 485-1997, *"IEEE Recommended Practice for Sizing Lead-Acid Batteries for Stationary Applications"*

[5] IEEE Std. 1115-1992, *"IEEE Recommended Practice for Sizing Nickel-Cadmium Batteries for Stationary Applications"*