Electric Utility Generation and Substation Battery Discharge Testing

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INTRODUCTION

Battery discharge testing seems to be a controversial subject among battery users. It is admittedly the most expensive part of a battery maintenance program both in terms of labor and equipment costs. Yet it remains a fixture in the Institute of Electrical and Electronics Engineers Inc. (IEEE[1]) battery maintenance standards. The recent article "A Utility Perspective of Substation Battery Maintenance and NERC PRC-005" (B1) by Paul L. Gogan, Manager of Electric Distribution Reliability and Planning at We Energies published on the Power Quality Advisor website recommended replacing discharge testing with the use of internal ohmic measurements for transmission substation batteries.

This paper will examine the subject of discharge testing in light of what is occurring in the utility industry with a specific look at transmission and distribution system batteries. In so doing, we will rely on Mr. Gogan's paper along with the responses to the paper by Mr. J. Marrero (B2) and L. Meisner (B3). Two excellent papers have been published on the North American Electric Reliability Corporation (NERC) standards at the last two Battcons by Mr. T. Chapman (B9) and (B10).

While utilities employ batteries in traditional telecommunications and uninterruptible power supply applications, the focus of this paper is on generation stations and transmission and distribution substation battery discharge testing.

A Brief History

Discharge testing as a means of determining a battery's ability to perform its design function is part of the original IEEE 450[2] standard. The recommendation for testing every 5 years was subsequently copied into the newer battery maintenance standards. Recently the IEEE maintenance working groups have re-examined the 5 year recommendation in light of experience high rate vented lead-acid battery designs. As a result, the 5 years was changed to 5 years or 25% of the expected battery service life in IEEE 450-2010.

Due to the shorter service life observed with VRLA batteries, IEEE 1188[3]-2005, "IEEE Recommended Practice for Maintenance, Testing, and Replacement of Valve-Regulated Lead-Acid Batteries for Stationary Applications," was changed to 2 years or 25% of the expected battery service life.

Most electric generating stations whether they be nuclear, coal, natural gas, hydro, etc. perform periodic discharge tests of their batteries. The majority of these batteries were/are tested because the financial risk due to plant down time or serious equipment damage should a battery fail when called on, and are often too large to trust to alternate methods. While the regulatory requirements and financial risk were and are motivating factors, the world has changed. Now we are seeing the insurance companies that provide insurance for generating assets requiring testing as part of the maintenance program. The advantage such installations have is that they often have dedicated resources and test equipment to perform the testing.

Substation applications are very different. The primary purpose of the battery is the transfer trip to clear the substation in a fault. After the fault is cleared, there is almost no load on the battery until the dispatcher/grid operator needs to close breakers at the substation. In this instance, the battery only needs sufficient power to close the incoming line breaker which brings the battery charger on line. After that, the remaining breaker operation(s) can be carried by the charger. The disadvantage of substations is that they are spread all across the country and travel time to a single substation for maintenance can be a significant resource challenge.

[1] IEEE is a registered trademark of the Institute of Electrical and Electronics Engineers Inc.
[2] IEEE 450 is a registered trademark of the Institute of Electrical and Electronics Engineers Inc.
[3] IEEE 1188 is a registered trademark of the Institute of Electrical and Electronics Engineers Inc.

To Test or Not to Test

Nearly every user can come up with a reason for not performing discharge tests. Some of the more common ones, including those cited in Mr. Gogan's paper include the following:

1. Discharge testing harms the battery or shortens battery life.

   Response: Discharging and recharging a battery is part of the normal battery formation process. Even an inexpensive vented lead-calcium battery (typically the battery type which is most affected by discharge cycles) is easily capable of 40 or more discharge cycles. Performing discharge testing at the frequency recommended by IEEE standards will result in a maximum of 6 discharges over battery life. This is not significant compared to the battery capabilities and the number of cycles expected in the normal life of a battery in standby service.

2. This is a critical installation and we don't have a backup battery.

   Response: This is true for most battery installations. While there are a few nuclear plants with swing batteries as stated by Mr. Gogan, they are the rare exception rather than the rule. Options such as bringing in a temporary battery or using split strings are employed by many companies to allow for testing. When considering a transmission and distribution (T&D) substation battery which is commonly in the 100 to 200Ah size, a temporary battery mounted on a trailer with the test equipment has been deployed by some utilities and is a relatively inexpensive solution. For truly critical applications, future substation designs and if possible, back fits to existing to add a redundant battery may be an economic solution to ensuring reliability.

3. Battery recharge time places the installation at risk.

   Response: Again this is true for most battery installations. However for a transmission substation battery with limited size, the recharge times is normally very short in the 2-6 hour range. Since no utility performs testing at times of risk to the transmission system, the actual risk (probability x consequences) during testing and recharge for a single T&D substation battery is very small.

4. We don't have the space

   Response: Discharge test equipment is normally in a location remote from the battery itself. Typical battery access is only to the field terminations. Mounting the test equipment on a trailer as described in item 2 is a space saving alternative for providing space within a building for the test equipment.

5. Testing is too expensive

   Response: This is all too true for small batteries such as emergency lights, telephone relays etc. Most small batteries are replaced on a periodic basis rather than tested. The author does not believe it is true for most T&D substation batteries. The real issue is the sheer number of such batteries (I'll guess the number is around 50,000) in the T&D system and the fact that substations are scattered over the entire utility service area. Testing these batteries poses a major financial burden on the T&D companies. In my opinion, this issue is what drives users to look for alternatives to conventional discharge testing. Internal Ohmic Value Testing is one such alternative and was being employed by T&D companies prior to the NERC rules being promulgated. Because of the duty cycle of a typical substation battery, the use of modified performance test in lieu of a conventional performance test is recommended. This demonstrates the high rate capability of the battery for the fault clearing duration and the ability to restore power after an outage period.

   While there are T&D companies that perform discharge testing, there are more that do not. From personal correspondence, prior to the NERC rules, there were some utilities that did minimal maintenance on small substation batteries and simply replaced the batteries when they failed. This was seen as the most cost effective solution. Grid disruptions were minimal with the major impact being the time it took for a technician to drive to the substation and operate the breakers manually. Under the current new grid reliability standard (in particular PRC-005-2), this is no longer an acceptable practice.

Internal Ohmic Value Testing

One of the more recent changes in battery maintenance tools was the introduction of internal ohmic value test sets. These test sets use algorithms to calculate the internal ohmic value of a battery cell or module that is expressed in Ohms (resistance or impedance) or Siemens (conductance).

In order to evaluate the capabilities of these devices, the Electric Power Research Institute (EPRI[4]) conducted an extensive study of more than 40,000 battery cells, using all three major test sets available at the time between 1998 and 2002. The results showed that there is a correlation between the ohmic value and cell capacity (i.e. as the internal resistance of the cell increases, cell capacity decreases). The disappointing conclusion of the study was that there was no way to directly correlate a cell's internal ohmic value to its actual (tested) capacity.

The results of the EPRI study were published in "Stationary Battery Monitoring by Internal Ohmic Measurements," EPRI Report 1002925 (B4), dated December 2002. A presentation of the results, "Internal Ohmic Measurements and Their Relationship to Battery Capacity – EPRI's Ongoing Technology Evaluation," (B7) Eddie Davis, Edan Engineering Corporation, Dan Funk, Edan Engineering Corporation, Wayne Johnson, Electric Power Research Institute, was presented at Battcon 2002.

Some key points of the study presented in the 2002 Battcon paper are summarized below:

- The test equipment is able to detect a change in internal ohmic value, but it cannot determine the cause of the change.
- The test equipment does not know the application. High rate applications are impacted more than low rate applications for a given change in internal ohmic value.
- Internal ohmic measurements do not correlate to battery capacity.
- A single low cell may have minimal impact on overall battery performance. In this instance it is important to stress the word MAY. There are instances where a single cell can and has rendered a battery incapable of performing its design function. While this is more common with VRLA batteries, it can and does occur in vented lead-acid batteries and can be found using internal ohmic measurements.

FERC and NERC

As a result of the attacks of September 11, 2011, the federal government initiated actions to review the reliability of the United States critical infrastructure. One of the items studied was the electric power grid. Reliability of the U.S. power grid is the responsibility of the Federal Energy Regulatory Commission (FERC). After the review, FERC decided that new standards needed to be developed and enforced. Rather than create a new branch of FERC or a new agency, FERC directed that these activities be assumed by NERC.

As a result, NERC formed committees to draft new standards for grid reliability and reliability of the equipment necessary to ensure grid reliability. The standards of interest to us fall under "Protection and Control" (PRC). The first of those of interest is PRC-005-1, "Transmission and Generation Protection System Maintenance and Testing," (B5). This standard has been issued and currently at revision 1. The standard which directly discusses batteries and DC systems is PRC-005-2, "Protection System Maintenance," (B6) Draft 2 dated February 22, 2012. Battery and DC system maintenance is addressed in Tables 1-4(a) through 1-4(f) of the standard.

[4] EPRI is a registered trademark of the Electric Power Research Institute

DISCUSSION

Where we are:

The responses to Mr. Gogan's paper by Mr. Marrero and Mr. Meisner identify areas where the author's disagree with Mr. Gogan. Among these disagreements are:

- IEEE-450 was written for nuclear plants. For the 1972 version this was true. However, it has not been true for over 20 years. The current 2010 edition reflects participation from users across multiple industries, battery manufacturers, service companies and test equipment companies. During the revision, the working group reviewed the recommended practices to ensure they provide guidance for the commercially available vented lead-acid battery chemistries. As such it is a consensus document with application to any commercial vented lead-acid battery.

- Nuclear power plants have spare batteries. This is true for a very limited number (less than 10) of the existing 104 nuclear plants operating in the U.S. However, it will be true for the next generation of plants that are just entering the construction phase.

- Testing harms the battery. As previously discussed this is not true for any lead-acid battery.

- Conductance testing can be used to determine <u>battery</u> capacity. Again, this is not true. There is a correlation between internal ohmic value and <u>cell</u> capacity, but not to the extent that cell capacity can established based on the internal ohmic value. Determining the impact of individual cell capacity on battery capacity requires a discharge test.

- Specific gravity measurement is a low value added activity. While this has been shown to be true for lead-calcium batteries, it is specifically not true for lead-antimony (antimony content >6%) batteries.

While the author agrees with the responses, there is also reason to agree with Mr. Gogan's position on the use of internal ohmic value testing for some batteries.

NERC PRC-005-2

One of the key elements of NERC PRC-005-2 is that the use of internal ohmic measurements is coupled with conduction path maintenance. The entire conduction path, inter-cell, inter-tier, inter-rack and battery terminals must be properly maintained as recommended in the applicable IEEE standards.

One of the weaknesses of the current version of the NERC standard is that it treats all substation batteries equally. While there is no such thing as an unimportant battery, not all installations are the same (i.e. some are more critical than others). Using a nuclear power plant as an example, I will attempt to show how this applies to T&D batteries and in general to utility batteries. A nuclear power plant has four basic battery functions:

1. Safety-related: Protect the health and safety of the public

2. Emergency response: Start diesel generators, maintain communications, fire protection, emergency lighting, security systems etc.

3. Equipment protection: Prevent damage to major equipment (turbines, generators etc.)

4. Power restoration: Switchgear control power

The following table provides the author's opinions on how these basic functions relate to T&D substation batteries:

Function	Application Examples	Recommended Battery Testing
Protect public health and safety	1. Emergency Management Centers 2. Police and Fire dispatch Centers 3. Fire and Police Houses/Centers 4. Hospitals 5. Jails/Prisons 6. Communication systems/installations required for emergency management	Discharge Testing (For substations, use a Type I Modified Performance Test to verify battery high rate performance.)
Protect grid reliability	1. Transmission line controls (>138kV) 2. Black start power generating station controls 3. Power generating station switchyard controls	Discharge Testing (For substations, use a Type I Modified Performance Test to verify battery high rate performance.)
Power restoration 1	1. Traffic controls 2. Communication systems 3. Industrial users	Internal Ohmic Value or Discharge Testing
Power Restoration 2	1. Commercial businesses (shopping centers, retail outlets, etc.) 2. Residential neighborhoods 3. Industrial users with interruption agreements	Internal Ohmic Value or Discharge Testing

CONCLUSIONS

1. There is a correlation between cell capacity and internal ohmic values. The real issue is risk. Internal ohmic value measurements coupled with conduction path maintenance provides a probability that the battery is capable of performing its design function.

2. The author does not believe that there will be a consensus among T&D utility companies to perform discharge testing on small substation batteries unless NERC makes it a requirement. The current draft of NERC PRC-005-2 (B6) provides alternatives to discharge testing and many utilities will make use of those alternatives.

3. Battery manufacturers will ultimately determine the cutoff of where internal ohmic value testing can be used as an alternative to discharge testing. The author is aware of this for small substation batteries less than or equal to 200Ah at C_8, but is not aware of its use in other applications.

RECOMMENDATIONS

1. For large batteries, which the author will define as greater than 500Ah at C_8, discharge testing should be performed. It should be noted the definition of a "large battery" i.e. one that requires discharge testing in lieu of internal ohmic value testing will ultimately be determined by the battery manufacturer. That said, there are manufacturers that do not accept the use of ohmic value testing as a valid method for determining cell or battery performance.

2. For batteries in applications that ensure grid reliability and/or protect the health and safety of the public, discharge testing should be performed. These applications are too important to trust to any other method for ensuring the battery can perform its design function.

3. When personnel and equipment are available, T&D substation batteries should be discharge tested in accordance with the appropriate IEEE Standard.

4. T&D substation batteries should be tested using a Type I Modified Performance Test as defined IEEE 450-2010, Normative Annex I.

5. In the author's opinion, battery monitors are no substitute for periodic discharge testing or visual inspections. Monitors are good diagnostic tools and reduce the labor burden associated with battery maintenance. While allowed by PRC-005-2, Table 1-4(f), battery monitors should not be used as a maintenance substitute for critical infrastructure applications as defined in item 2 above.

6. Unlike the Example of Excellence (B8) issued by NERC, it is not necessary to disassemble and clean the connections on a routine basis and considering the small terminal posts on most T&D substation batteries it is not recommended. Rather, connection resistance should be taken, the connections inspected for corrosion and corrective action taken based on the results.

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