NEW CONCEPTS IN BATTERY MONITORING AND MAINTENANCE AT NUCLEAR PLANTS

Kyle Floyd
Founder
Covenant Service Company, LLC
Columbiana, AL 35051

INTRODUCTION

Current practice for battery monitoring and maintenance within the nuclear power industry in the United States originated in the 1970's. In 1980 the IEEE Battery Working Group (predecessor to the current IEEE Stationary Battery Committee) proposed some changes to the standardized technical specifications for dc systems which were adopted in the 1980's. Significant changes were proposed beginning in 1995 with an interim release in 2000. The latest series of changes called TSTF-500 are now in the process of final review and approval by the Nuclear Regulatory Commission (NRC).

In anticipation of the approval and issuance of TSTF-500, this paper presents some of the changes in conceptual form. One concept presented will be differentiating between verifying the capability of the battery to satisfy its critical design functions and maintaining the battery in optimum condition. The second concept is building and maintaining a sound technical basis for the limits associated with each battery parameter. The third concept is effective presentation of information for normal and abnormal conditions to assist all those involved with the battery systems.

This paper is being presented for several reasons. First, there are some of you directly involved in nuclear plant operations that may not be familiar with these changes. Hopefully there are many more that have some interest in the nuclear industry in general. Second, I believe this conference is an effective venue for discussions for all applications. Hopefully you will join in the discussion so that we can all learn from one another.

BACKGROUND

This discussion will begin with suggested modifications to the standard technical specifications covering batteries in effect in 1980 for the nuclear plants within the United States of America. The standard technical specifications are the boiler plate documents governing operation of each nuclear unit. The suggested changes were made by the IEEE Working Group on Batteries serving in a technical advisory role. An NRC representative served as an individual contributor on the group at that time. Fortunately at least one NRC representative has served on the committee since that time. Since that initial change there have been a number of other changes over the years, however the latest change designated as TSTF-500 is actually a revision to an earlier change, TSTF-360 which was approved in 2000. Due to some issues with TSTF-360 it was held in abeyance in 2006 while TSTF-500 was fully reviewed and approved. This paper will discuss changes designated as TSTF-360 and TSTF-500 as though they were one overall change.

The actual documents regulating nuclear plant operations are approved by the NRC under their procedures with input from the public and various industry groups. The process of making changes is systematic and thorough and requires a concerted effort by many parties before a completed revision is approved. This paper will be addressing concepts in general with some of the details where required. The total number of pages in the TSTF-500 package is over 400.

The terminology used is comparable to that used in IEEE 450 with 'maintenance' including visual and instrumented inspections, corrective actions, performance discharge testing and monitoring. The term 'capability' as used here means the battery has adequate voltage and discharge capacity to fully perform its critical design functions. The service test described in IEEE 450 is a test of this capability for the nuclear plants. This test uses the bounding duty cycle defining all required loads and durations. Measurements of terminal voltage, specific gravity and/or float charging current and electrolyte temperature provide indications of this capability between service tests. In this context monitoring consists of recording, tracking and trending all inspection and testing data taken over the life of the battery. This can be accomplished by individual instruments and records or by automated monitoring systems.

DISTINGUISHING CAPABILITY FROM MAINTENANCE

The overall concept of separating the items related to capability from the items more concerned with maintenance is illustrated in Figure 1 below. The items moved to the administrative program will continue to be maintained and controlled to ensure the optimum performance and service life of the batteries. The items in the new technical specifications will be focused on verifying battery capability.

Note: The bracketed [ ] values used in the figures and tables are only typical values that will be replaced by site specific values for each nuclear generating unit.

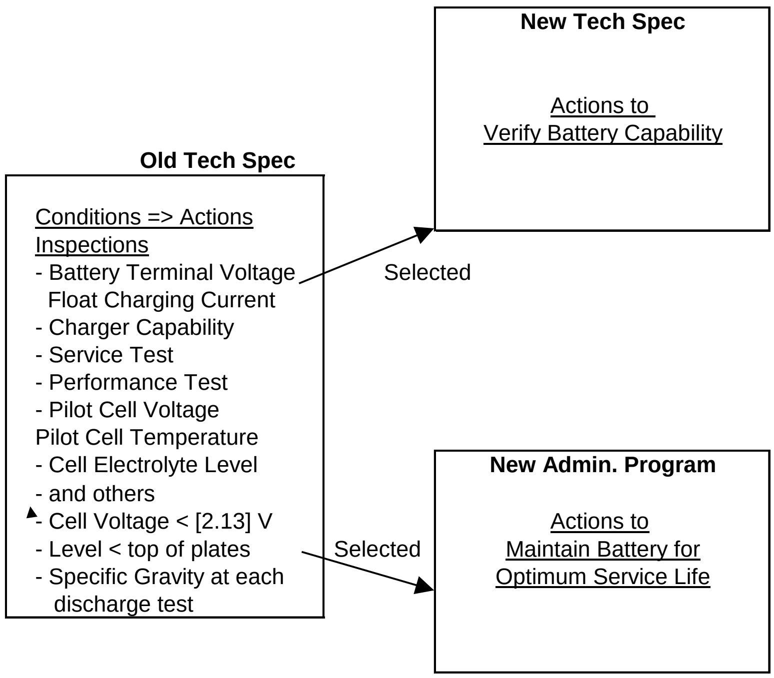

Figure 1 – Separating Capability and Maintenance

In the normal sequence there are scheduled Inspections (surveillances) that result in certain Conditions when the limits are not met which initiate the Corrective Actions to restore the limits. The Inspections either verify the Conditions are satisfied or the associated Actions are taken to restore them within the Completion Times. This process is described in more detail below to illustrate contents of the respective Capability and Maintenance sections indicated in Figure 1.

Capability

As part of this change more emphasis is placed on restoring a fully functioning charger and verifying the state of charge of the battery in an expeditious manner. This takes the form of a three-tier approach indicated by Condition 4.A in Table 1 and described below.

The three-tier, focused approach is intended to quickly stop any discharge, assess the battery state of charge and restore a fully functioning charger. If the limits for each of these steps are not met, then the path to shutdown is started. If the battery is partially discharged then restoring the battery terminal voltage via another charger or adjustments to the connected charger stabilizes the system so that voltage and current measurements can be taken. If the battery terminal voltage is greater than or equal to the Minimum Established Float Voltage (MEFV) as in Action A.1, then there is an indication that the charge current is on the exponential portion of the charge cycle. If Action A.1 is not met within 2 hours, then the system cannot be assessed as fully capable and steps would be taken toward an orderly unit shutdown. If Action A.1 is met within 2 hours, then Action A.2 is taken to verify the float charging current of the battery. If the current flowing into the battery is less than the return to service limit of [2] amps within [12] hours then the battery is assessed as fully capable based on the documented basis for the selection of this limit. With Action A.2 completed as required each [12] hours, then Action A.3 restores the charger to full capability within [72] hours.

Table 1 – Conditions and Corrective Actions

Condition	Required Action	**Completion Time**
4.A One or more chargers incapable	A.1 Restore battery terminal voltage to ≥ MEFV AND A.2 Verify battery float current ≤ [2] amps AND A.3 Restore charger(s) to fully capable condition	2 hours Every [12] hours [72] hours
4.B One or more batteries incapable	B.1 Restore batter(ies) to fully capable condition	[2] hours
4.C One subsystem incapable	C.1 Restore subsystem to fully capable condition	[2] hours
4.D Required Action and Associated Completion Time above not met.	D.1 Be in MODE 3, AND D.2 Be in MODE 5	6 hours 36 hours
6.A One or more batter(ies) on one subsystem with 1 or more cell float voltage < [2.07] V	A.1 Verify battery terminal voltage ≥ MEFV AND A.2 Verify battery float current ≤ [2] amps AND A.3 Restore affected cell voltage ≥ [2.07] V	2 hours 2 hours 24 hours
6.B One or more batter(ies) on one subsystem with float current > [2] amps	B.1 Verify battery terminal voltage ≥ MEFV AND B.2 Verify battery float current ≤ [2] amps	2 hours [12] hours
6.C One or more batter(ies) on one subsystem with one or more cells electrolyte level < Minimum Established Design Limits (MEDL)	C.1 Restore level above top of plates AND C.2 Verify no evidence of leakage AND C.3 Restore level to ≥ MEDL	8 hours 12 hours 31 days
6.D One or more batter(ies) on one subsystem with pilot cell temperature < MEDL	D.1 Restore pilot cell temperature to ≥ MEDL	12 hours
6.E One or more redundant subsystems with battery parameters not within limits	E.1 Restore battery parameters for one batteries in one subsystem to within limits	2 hours
6.F Required Action or Associated Completion Time of Condition A, B, C, D or E not met, OR One or more batter(ies) on one subsystem with one or more battery cells float voltage < [2.07] V and float current > [2] amps	F.1 Declare associated battery incapable	Immediately

Notes: Operating Conditions are prefixed by “4” and Battery Parameter Conditions are prefixed by “6.” Shutdown Conditions are very similar to those for Operating and are omitted from the table.

These Conditions, Actions and Completion Times are comparable to those of IEEE 450 (Ref. 1).

As shown in Figure 1 above there are scheduled inspections (surveillances) that initiate the corrective actions when the limits are not satisfied. These inspections either verify the above conditions are satisfied or the associated corrective actions are taken to bring them back into compliance with the limits within the completion times indicated. These inspections are summarized in Table 2 below and described in more detail.

The inspections discussed below are still a part of the process related to verifying battery capability. There are other inspections associated with battery monitoring and maintenance that have been moved to the administrative program. These inspections will be discussed in the maintenance section.

Table 2 below shows the type and frequency of inspections for the Operating and Battery Parameter sections. The Shutdown section is similar to the operating section and is not shown.

Table 2 – Inspections associated with Battery Capability

Inspection	Frequency
4.1 Verify battery terminal voltage ≥ Minimum Established Float Voltage	7 days
4.2 Verify battery charger output voltage, current and capability	[18] months
4.3 Verify battery capability to meet design duty cycle using service test or a modified performance test	[18] months
6.1 Verify battery float current is ≤ [2] amps	7 days
6.2 Verify pilot cell float voltage is ≥ [2.07] volts	31 days
6.3 Verify electrolyte level of each cell is ≥ minimum established limits	31 days
6.4 Verify pilot cell temperature is ≥ minimum established design limits	31 days
6.5 Verify float voltage of each cell is ≥ [2.07] volts	92 days
6.6 Verify battery capacity is ≥ [80] % of mfrs. Rating using performance test or modified performance test	[60] month or more often if degraded

Note: Numbers are preceded by 3.8 in TSTF-500

These inspections are similar to the monthly and quarterly inspections and discharge tests described in Reference 1. The battery terminal voltage and float current are done more frequently due to their critical nature. Remember the bracketed [ ] values are placeholders for the actual specific limits established for each battery in a given generating unit. The bracketed times depend upon the type of nuclear system and other site specific parameters.

<u>Maintenance</u>

The corrective actions related to long-term maintenance will now be located in the separate Battery Monitoring and Maintenance Program and include the following:

- Restore battery cells with float voltage less than [2.13] volts, and verify remaining cells are greater than [2.07] volts.
- Equalize and test battery cells when electrolyte level drops below the top of plates.
- Limits on average electrolyte temperature, battery connection resistances, and battery terminal voltage.
- Obtain specific gravity readings of all cells at each discharge test, consistent with manufacturer recommendations.

This administrative program will have detailed processes and procedures to address each of the conditions above. There will be inspections and corrective actions associated with this program in accordance with Reference 1 and regulatory guidance. This program is intended to restore and maintain the battery in optimum condition such that full performance and service life are achieved.

In summary, the essential parameters to determine battery capability with appropriate corrective actions are retained in the technical specifications. Other items related to long-term maintenance will be moved to a separate program. The urgency of these corrective actions determined where they would be placed. This overall process is designed to maintain the batteries in optimum condition so they are fully capable of supporting the connected loads when required. IEEE 450 is the base standards document for both sections of the overall program.

As with any program or process each part is important and contributes to the success of the whole. Each level of inspections and corrective actions is intended to focus the proper attention to returning the battery system to full capability as soon as practical. Many of the annexes in Reference 1 address this process in much more detail.

DOCUMENTING THE TECHNICAL BASIS

The technical basis documentation requirements are obviously not a new concept. However, TSTF-500 identifies the items requiring formal verification and specifies the regulatory commitments required to support its adoption. For example, letters are required from the battery manufacturers verifying the acceptability of using float charging current monitoring instead of specific gravity monitoring to determine battery state-of-charge and also verifying that this will hold true over the life of the battery. The equipment used to measure the float charging current must also be verified to have the necessary accuracy and capability for the expected current range, usually from the maximum current limit of the charger down to the float current for the battery.

A portion of the design margin used in battery sizing must be dedicated for use with the selected float charging current limit, also called the return to service limit. This margin compensates for less than 100% state-of-charge associated with the selected limit. The battery will not be fully charged at this point on the exponential curve and this dedicated design margin compensates for this situation. The selection of this limit will need to be fully documented and made available for review by the NRC.

There are many other parameters such as the minimum established float voltage, minimum design temperature limit for the battery electrolyte temperatures and connection resistance limits that must also be documented for each battery at each nuclear plant. A model application has been prepared to identify all of these documentation requirements so the submittal process should be easier.

In my opinion the documentation submitted for TSTF-500 should be based on one or more design basis calculations with complete references to the sources for all inputs and assumptions. If the source is not a nationally recognized code or standard then it should be attached to the calculation and/or filed in a Quality Assurance record for ready retrieval (long after it was initially prepared). Poor documentation has been a weakness for some limits in the past.

EFFECTIVE PRESENTATION OF INFORMATION

TSTF-500 and other proposed change documents do not specify how the various battery parameters should be displayed. There are so many variations in plants and system configurations that this would be impossible. However, the following discussion will present some ideas regarding how some of the normal and abnormal charge and discharge conditions can be presented. This discussion will focus on the assisting the users in gaining the most from the information being presented.

The simplified figures below illustrate the expected voltages and currents for operating modes of float, discharge and charge. Obviously there are battery monitoring systems with much better graphics. The intent here is to capture the concepts and allow others to create the actual graphics.

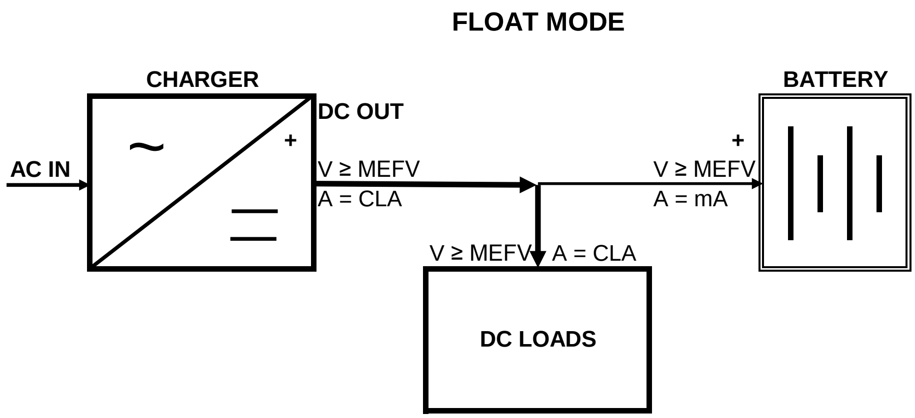

Figure 2 – Battery System in Float Mode
MEFV = Minimum Established Float Voltage
CLA = Continuous Load Amps (House Service loads)

Figure 2 illustrates the most prevalent operating mode for battery systems in float service. The charger supplies the continuous house service loads (normally in Amps) and the small float current (normally in milliamps) needed to maintain the battery in the fully-charged condition. The equalize mode of operation would be similar but the voltages will be at the higher equalize level with a higher float current flowing into the battery due to the higher applied voltage. With the indications embedded in the graphic, this would be a helpful display for normal operations.

In the event of a faulty/defective charger or during a planned discharge test during an outage, the battery system would be in the discharge mode shown in Figure 3 below.

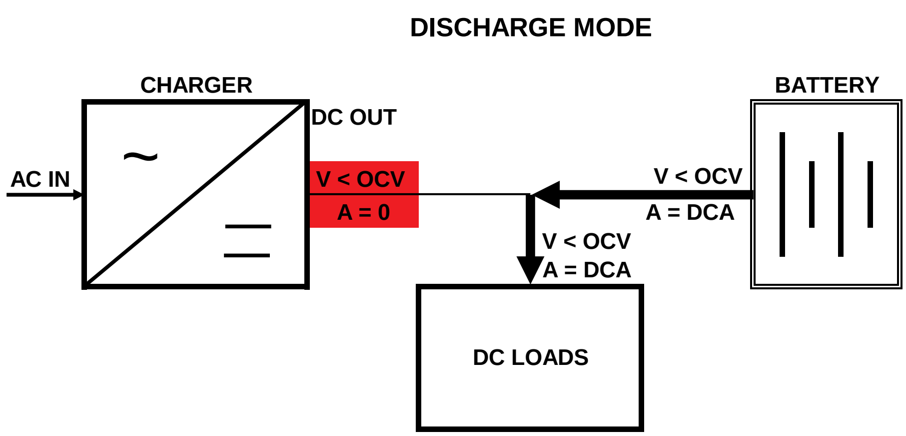

Figure 3 – Battery System in Discharge Mode

OCV = Open Circuit Voltage of the battery (~2.07 volts per cell)
DCA = DC Amps which may include momentary and continuous loads

Figure 3 illustrates the operating mode during discharge tests or in the event of a loss of the charger when the battery will be carrying all the dc loads. The charger dc output voltage would be less than the minimum established float voltage (MEFV), but not zero since the dc voltmeter is normally connected on the battery side of the charger output breaker. The dc bus voltage will be less than open circuit voltage since the battery is now carrying the dc loads. This would be a good graphic to use with color coding to call attention to a charger failure resulting in a battery discharge.

Once a discharge has occurred it is important to get the battery charged. Figure 4 below shows the diagram for the charge mode. The three-tier approach to corrective action described earlier can be used for this mode. Remember to Stop the discharge, Check the state-of-charge and Restore the charger! A good place to practice this sequence is during the battery discharge tests at each refueling outage.

CHARGE MODE

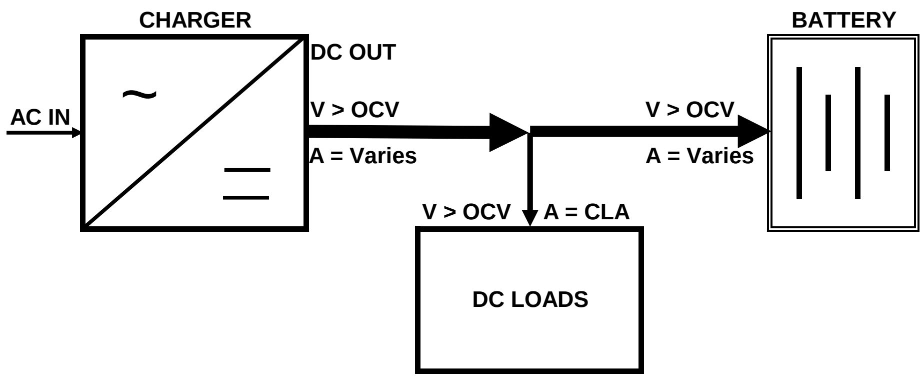

Figure 4 – Battery System in Charge Mode

Once the charger is restored it will carry the dc loads and also recharge the battery. The charger can be in current limit mode for some time before the battery voltage rises to the charger output voltage and the charging current begins the exponential decay. With knowledge of the battery system parameters and test results, the voltage and current profiles can be predicted as discussed below.

In addition to the figures shown above, there are situations when a simple spreadsheet with charts can be helpful in depicting the expected system responses to various operating conditions. Depending upon the type of graphics capabilities available, these features can sometimes be built into operating stations for system operators and the training simulator.

Regardless of the cause of battery discharges, it is helpful to know the expected discharge and charge profiles to be able to follow the system response and predict when the battery will be restored to float service. For example there will be service tests or modified performance tests done each refueling outage. Normal performance tests may be required at other times.

The battery used in the example is a 1.215 specific gravity, lead-calcium model with a nominal 8-hour rating of 1950 Ampere-hours (A-h) to 1.75 volts per cell average at 77 degrees Fahrenheit. The 4-hour duty cycle consists of 1 minute at 1472 Amps followed by 239 minutes at 330 Amps. This data along with other pertinent data will be entered into the spreadsheet or control system in use. There are usually certain simplifying assumptions made in this process.

In this example the first minute discharge is not shown on the figure but has been included in the calculations. The Net Charging Amps (NCA) is assumed to be 220 Amps. The charging efficiency is assumed to be 95% for the lead-calcium battery. The time constant in hours for the exponential decay curve is assumed to be 1 hour when recharge is done at equalizing voltage and 3 hours when recharged at low float. The actual values for the time constants for each battery system would need to be verified by testing.

Figure 5 illustrates a 4-hour duty cycle discharge immediately followed by charging at the equalize voltage for five time constants of the exponential decay curve where the battery is fully charged.

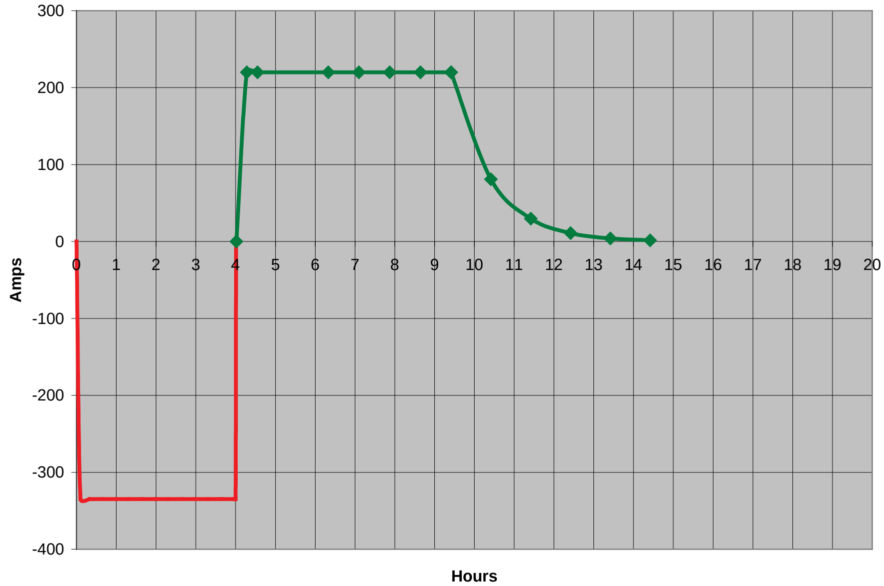

Figure 5 – 4-hr Duty Cycle Discharge, Charge at Equalize

This type of curve could be used in training or as one of the pull-up graphics on a battery monitoring system. Adding intelligence to the display could plot the actual data points during a discharge test and trend the data. Another use for this type of chart in a spreadsheet form would be to predict the normal service test discharge/charge cycles for outages and trend the data. This would also allow you to estimate the outage time required for each discharge test.

These are just some simple ideas that could be built upon to more effectively display the various normal and abnormal operating modes of each of your battery systems. TSTF-500 will be one of the more significant changes for battery systems in nuclear plants in quite some time. We need to make the best use of all the tools available to maximize the benefits to be gained from TSTF-500!

SUMMARY

In summary this paper was prepared to inform nuclear battery users as well as the general battery audience of a significant change coming in the monitoring and maintenance programs at nuclear plants. As with most changes in the nuclear industry it will take some effort at each plant to see it through to completion. However there are many benefits to be gained by making the change. The 3-tier approach to determining battery capability is very good to focus attention on taking the most important actions first. Moving the long-term maintenance items into a separate program should be helpful once the users become familiar with the changes. The complicated table for battery cell parameters will no longer be used. Thorough documentation for the technical basis for any change is well worth the effort.

The discussion on effective presentation will hopefully be of interest to some readers. You may be encouraged to discuss some of your ideas by doing a presentation in the future. Others may take the concepts presented here and improve upon them. Finally some of you may read ahead and come to the meeting prepared to provide constructive feedback so we can all benefit from your input and ideas.

REFERENCE

1. IEEE Standard 450-2002 *IEEE Recommended Practice for Maintenance, Testing, and Replacement of Vented Lead-Acid Batteries for Stationary Applications*