STATE-OF-CHARGE:
SPECIFIC GRAVITY VERSUS BATTERY CHARGING CURRENT

M. S. (Steve) Clark
Senior Engineer
Bechtel Power Corp.
Knoxville, TN

INTRODUCTION

One of the significant changes in IEEE 450-2002, Maintenance, Testing and Replacement of Vented Lead-Acid Batteries in Stationary Applications, was to endorse the use of battery current for monitoring the state-of-charge of lead-acid batteries. The position was recently accepted by the Nuclear Regulatory Commission (NRC) Office of Nuclear Reactor Regulation during review of Technical Specification Task Force Traveler 500. However, in talking to members of the battery community outside of the IEEE 450 working group, it appears that the basis for this change is not clearly understood. The purpose of this paper is to examine why the working group endorsed float current monitoring as the primary method to determine state-of-charge.

STATE-OF-CHARGE

For batteries operating in standby mode, the normal condition is for the battery to be fully charged. Traditionally, specific gravity (S.G.) measurements were used to determine if a battery was fully charged. However, newer battery types and the need to know the state-of-charge when the battery is not fully charged led the move away from S.G. to battery current. The need to know when sufficient energy has been returned to the battery for it to perform its design function is especially critical for nuclear power plants where batteries are the ultimate backup power source. Older nuclear plant designs rely on diesel generators and batteries, while in newest nuclear plant designs the batteries have replaced the diesels as the only source of standby power. Batteries in these applications can have up to 72 hour duty cycles.

SPECIFIC GRAVITY

A Brief History of Specific Gravity Measurements

When IEEE 450 was first written, the prevailing technology in use was the vented lead-antimony battery. This was the battery technology that the original authors were familiar with. As a result, this battery technology formed the basis for the original recommended maintenance practices specified in IEEE 450. As a result, it also formed the basis for the original Technical Specifications for nuclear power plants. During this time, measuring S.G. was the standard for determining if a battery was fully charged. Due to the relatively high float current of lead-antimony batteries, the gassing rates are sufficient to keep the electrolyte mixed between the top and bottom of the cell. This makes S.G. measurements an accurate way to know if the battery is fully charged. It was not until the widespread acceptance of other battery technologies that users began to question the use of S.G. as a means to determine if a battery was fully charged.

The first challenge was the flooded lead-calcium battery. Lead-calcium batteries have very low float currents and as a result have very low gas generation. The low gas generation result in electrolyte stratification (electrolyte concentration is lower at the top of the cell than the bottom). This limits the height of a lead-calcium battery unless techniques such as bubblers are used to maintain more uniform electrolyte concentrations.

With the rapid acceptance and use of lead-calcium batteries, the 1980 version of IEEE 450, Annex B included the use of a stabilized charging current for determining a battery was fully charged when S.G. stratification (or gradient) exists. Starting with the 1984 Nuclear Power Standardized Technical Specifications, float charging current was allowed as an alternate to S.G. readings for determining if a battery was fully charged.

Even with manufacturers aware of the limitations of S.G. measurement for lead-calcium batteries, many still include S.G. measurements as part of the recommended maintenance practices in their operating and maintenance manuals today.

As an example, when one major US manufacturer wants an accurate measurement of S.G., a 24 hour stand test is used. The stand test consists of a high level charge followed by period on float charge at the end of which the charger is disconnected and the battery is left off charge for a period of 24 hours. At the end of that time, the individual cell voltage is measured and the S.G. is calculated using the following equation:

Open Circuit Voltage (fully charged) = S.G. + 0.845

This rule provides an accurate representation of the overall S.G. of the cell. The 0.845 value varies slightly with battery S.G. but is accurate for most flooded lead-calcium battery designs with S.G. in the 1.210 to 1.250 range.

The introduction of Valve-Regulated Lead-Acid (VRLA) batteries (which have no means for measuring S.G.) should have flagged the IEEE Stationary Battery Committee that users needed a new method to determine state-of-charge.

As vented nickel-cadmium battery usage has become more widespread in the U.S., users were faced with a battery that has the same S.G. at full charge and fully discharged.

Even though the principal lead-acid battery technology in Europe is low-antimony (antimony content less than 3%) which results in higher float currents than lead-calcium batteries, some European manufacturers of flooded lead-acid batteries eliminated not only the recommendation to measure S.G. but also the sample tubes to take it.

In the author's experience battery engineers (particularly those in nuclear plants) tend to be slow to change and are more likely to apply the rule "If it's not broke, don't fix it." Since IEEE 450 is the principal document for nuclear plants and the working group has significant nuclear representation, IEEE 450 was slow to change. Couple this with a similar reluctance on the part of the NRC and you have a situation where there was strong resistance to change from the use of S.G. measurements as the primary method to determine state-of-charge.

In order to better understand the change, we must look at some of the facts surrounding it. First we will look at S.G..

S.G. measurements

As a preface, it is not the intent of the following discussion to discredit the use of S.G. as a tool to determine if a battery is fully charged. Rather, it is an attempt to provide background information for understanding the change in IEEE 450. The change in IEEE 450 was not sudden. It occurred over an extended period of time as data was accumulated and experience was gained in how to accurately measure float current.

Past trending of S.G. readings on multiple battery strings by the author resulted in the author forming the following opinions regarding S.G. measurements:

1. S.G. for individual cells or the battery average S.G. cannot be trended to predict the state of health or age of a particular lead-calcium cell or battery over time.
2. If a cell has a higher or lower S.G. than the other cells in the string, then it will normally have a higher or lower S.G. reading even if there is a wide variation in the average S.G. for the string between sets of readings.
3. S.G. changes much slower than individual cell voltage. Sudden changes in cell voltage readings are much more critical.
4. While there can be wide variation within individual sets of S.G. readings and between different sets of S.G. readings, the variations remain within acceptable bounds unless there is a problem with the test equipment or a cell failure.

The variables that enter into the accuracy of S.G. measurements are:

Electrolyte Manufacturing Tolerance

S.G. is a nominal value when it comes to making a battery. The normal tolerance for S.G. in a 1.215 S.G. battery is +/- .005. This means a fully charged cell can read anywhere between 1.210 and 1.220.

Stratification

In lead-calcium and some low-antimony designs (defined as antimony content <3%) the float current is too low to provide adequate mixing of the electrolyte on float charge. As a result, the heavy sulfuric acid tends to separate and settle to the bottom of the container. This condition, referred to as stratification, makes it difficult to obtain a representative S.G. sample from a single location within the cell. As a result, it may be necessary to measure the S.G. at 3 locations within the cell (top, middle and bottom) and average the results to obtain an accurate result.

Electrolyte level

On float charge the water in the electrolyte is slowly converted to hydrogen and oxygen by electrolysis. As this occurs, the S.G. of the electrolyte slowly increases.

Temperature

Most modern S.G. measuring tools incorporate automatic temperature compensation but the compensation (automatic or manual) is only as accurate as the temperature measuring system.

Recent recharges

Unless sufficient voltage is applied to a lead-calcium battery, recharges tend to result in significant stratification. It takes several days or weeks for gassing and diffusion to reduce the stratification. Even an equalizing charge may increase stratification if the equalize voltage is too low to produce sufficient gassing to mix the electrolyte.

Multiple S.G. readings

When using S.G. as a method to determine the state-of-charge following a recharge, the only accurate method is to measure and average the S.G. of each cell.

Common Factors affecting both S.G. and Float Current Measurements

There are two factors that affect the accuracy and repeatability of both S.G. and Float Current measurements. These are:

The human factor

Human beings do not always do the same task the same way every time. Due to stratification which is present to some degree in any vented lead-calcium battery on float charge, the depth that the S.G. sample probe is inserted into the battery cell impacts the result of the measurement. The greater the depth, the higher the S.G. reading that will be obtained. (This is normally only an issue in lead-antimony designs if readings are taken immediately following a recharge or if the variation in depth of insertion is extreme.)

As discussed later, float current is nearly always changing (float current fluctuations are often referred to as AC Ripple noise). As a result, the only way to obtain an accurate current measurement is to use a time averaging meter. The most commonly used method is to measure the voltage drop across the battery current meter shunt. Most batteries have float currents of less than 2 amps, and a typical current shunt has a value in the range of 1 amp = 1 millivolt. In human performance terms this means the technician is required to maintain a high quality connection at the two ends of the current shunt for a minimum of 30 seconds. To do the job correctly, often requires two technicians. While nuclear power plant electricians normally work this way, it is less common in other industries.

Meter accuracy

Typical S.G. meters have an accuracy is +/-.004. High accuracy devices are +/-.002. For a 1.215 S.G. this gives us an accuracy of +/- 0.32% for standard meters and 0.16% for high accuracy meters.

Digital multimeters or high accuracy voltmeters that are normally used for float current measurements have accuracies in the 0.025% to 0.01% range. This gives them the edge in accuracy over the S.G. meter. However, the reading is dependent on the shunt accuracy which is often the determining factor.

It is also possible to use averaging clamp on ammeters to measure float current. The difficulty is finding an ammeter capable of measuring small currents in large conductors. The author is not aware of any clamp-on ammeters capable of measuring current in large (350 to 1000MCM) cables that have sufficient resolution and accuracy in the normal float current range. While higher accuracy clamp-on ammeters exist, the jaw opening is too small for large conductors. If the cables are small enough, high accuracy clamp-on ammeters can be used on multiple cable inter-tier or inter-rack connections. Based on the author's experience, this requires the current in each conductor to be measured and summed. The reason is that there are variations in the connection resistance and at low current values these variations do influence the current flow in the parallel conductor paths.

Relationship of specific gravity to state-of-charge

Most users want to know if their batteries are fully charged, and, as previously discussed, S.G. was the industry accepted method to do it. As previously discussed there are several variables that influence the accuracy of S.G. measurements in a fully charged battery. This is of particular concern in the nuclear industry, where the state-of-charge is used to determine the "operability" of the battery, i.e., its ability to perform its safety design function, and whether or not corrective action must be taken to avoid a plant shutdown.

The use of S.G. to measure state-of-charge is based on the fact that in a fully charged battery there is no lead sulfate so all the acid is present in the electrolyte. Even with the inherent limitations associated with S.G. measurement, in this simplified case S.G. is an accurate indicator of the fully charged condition. The limitations with relying on S.G. as a state-of-charge indicator occur when the battery is less than fully charged

Acid to active material ratio

The first question in using S.G. as an indicator of state-of-charge in a partially discharged battery is: What is the ratio of active material to acid in the battery? An example is a typical cell design where the number of plates in a particular jar size can vary between 13 and 17. In a 13 plate cell there is significantly more acid than in a 17 plate cell. Therefore, the change in S.G. for a 20% discharged battery is higher in the 17 plate cell battery than in the 13 plate battery.

The example presented above shows why users cannot determine the S.G. change using their own resources. To determine the S.G. change, the battery manufacturer must be consulted. The manufacturer can then use the known quantity of acid and active materials to compute the S.G. for various states of charge.

This is relatively easy for a new battery with 100% capacity, but as capacity changes so will the change in S.G. As battery capacity declines toward the end of life, less of the active material is consumed during a discharge and hence acid is consumed during a discharge to the same end voltage. As a result, the reduction in S.G. at 100% depth of discharge (DOD) for a battery at 100% capacity is greater than for the same battery at 100% DOD at 80% capacity.

Mechanics of S.G. change during charge and discharge

To understand S.G. change during charge and discharge requires a look at the construction of the cell itself. In the cell, normal S.G. samples are obtained through sample tubes located in the corner of the cell. When doing a stratification test, samples are also obtained through the filler cap at the top of the cell and from the bottom of the cell below the sample tube.

However, S.G. changes occur in the space between the cell plates where there is no ability to obtain a direct sample. During discharge, acid is consumed and water is produced in this area. The lower S.G. electrolyte flows upward toward the top of the plates drawing higher density electrolyte into the bottom of the plates. The opposite occurs during recharge, high density electrolyte forms between the plates and drops to the bottom of the cell. As a result, low density electrolyte is drawn into the top of the plates.

Because the changes in electrolyte density are occurring between the plates, and samples are obtained in the dead space outside the plates or at the top of the plates, there is a significant time lag between the actual change in S.G. in the cell and the change at the sample location. Since the only mixing action occurring during recharge is between the plates, it can take several days for the gassing and diffusion to produce the maximum change at the sample location.

With the acid to active material ratio changing over battery life and the mechanics of S.G. change during charge and recharge, S.G. in and of itself is not an accurate indicator of state-of-charge for a partially charged battery. This limits the usefulness of S.G. measurements to anyone needing to know the state-of-charge of a partially discharged or recharged battery.

BATTERY CURRENT

Battery current monitoring is not a new concept. It is one of the parameters displayed at nearly every stationary battery installation and in the case of submarines some not so stationary battery installations. Its original use as a state-of-charge monitor was in calculating the ampere-hours removed from a battery and the ampere-hours returned to the battery. So long as the capacity of the battery is known, this provides a good method to calculate the state-of-charge. On recharge, if the ampere-hours returned is in the range of 105% (lead-calcium) to 110% (lead-antimony) of the ampere-hours removed, then the battery is fully charged. The additional 5 to 10% accounts for loses during the recharge such as heat, etc.

When a battery is on discharge, the calculation of ampere-hours removed, provides the only reliable method for calculating the state-of-charge.

Other than by calculating the ampere-hours returned to the battery during recharge and comparing that number to the ampere-hours removed during discharge how can we know the state-of-charge of a battery? This is one of the issues that has long plagued the nuclear industry and led to the adoption of a position by many that if a battery is not fully charged it is not capable of performing its safety design function. For most nuclear plants this means that if the battery is in any state other than fully charged, the plant has to shut down if the battery cannot be returned to a fully charged state within 2 hours.

When we speak of battery charging current we normally use two terms. In a fully charged battery we use the term float current. In a partially recharged battery we use the term charge current.

Float Current

Float current is the current flowing into a fully charged battery. While the capability exists in the battery current monitoring equipment to measure float current, float current was not seen as an important parameter for routine monitoring. One reason was that float current is so low that it is difficult to measure accurately using traditional current measuring techniques.

Recent advances in battery current monitoring and the need to determine the state-of-charge of batteries other than lead-antimony have renewed interest in using float current as an indication of the fully charged condition. With the widespread deployment of VRLA batteries the use of float current as an indicator for state-of-charge has become a key element of VRLA battery maintenance.

As with S.G., there are pros and cons with float current. To understand float current and its limitations, one of the key elements is to understand how it changes over the life of the battery.

Float Current Changes over Battery Life

<u>Vented Battery Designs</u>

<u>Pure lead acid</u>

Has a very low stable float current over the life of the battery.

<u>Lead-antimony</u>

Lead-antimony batteries have antimony content of 5% or greater. It has the highest initial float current which is normally 5 to 10 times that of lead-calcium or pure-lead designs. Float current increases slowly, and almost linearly, over the first 75% of battery life. At this point it is approximately double its initial value. It then increases more rapidly, rising to approximately 5 times the initial value at end of life.

This predictable change in float current over the life of the battery can be used to trend battery life over time.

Lead-calcium

Lead-calcium designs are generally described as having low stable float current over the life of the battery. While float current does rise slightly over the life of the battery the change is too small to be detected and can be disregarded.

Low-antimony

Low-antimony designs have antimony content of 3% or less. In low-antimony designs the float current starts out slightly higher than that of lead-calcium and rises slowly, normally in a nearly linear fashion to between 2 and 3 times its initial value. The degree of rise is a function of the antimony content with lower contents producing smaller increases over the life of the battery.

Like its lead-antimony predecessors, the predictable change in float current can be used to trend battery life.

Nickel-cadmium

Like pure-lead designs, nickel cadmium batteries have a low stable charging current over the life of the battery.

Valve-regulated Lead-acid (VRLA)

- VRLA batteries have higher float current than comparable vented batteries. The additional current is necessary to support the recombination reaction on the negative plate.
- Float current rises over the initial 2 to 6 months of operation until the battery becomes fully recombinant. VRLA batteries normally have excess water when first shipped. Until this excess water is vented the battery is only partially recombinant.
- The addition of catalysts lowers float current. The catalyst moves some of the recombination off the negative plate resulting in less current demand to support the recombination reaction.
- Operating conditions have a significant impact. VRLA designs are very sensitive to elevated temperatures and excessive charge voltage. Prolonged operation at elevated temperatures or excessive charge voltage can result in thermal runaway where the float current increases until the battery is physically damaged to the point it can no longer conduct.

Float Current Determination

The other question that arises is: How does a user know what the float current of a battery should be? The answer is to use the Tafel Curves (also called Tafel Lines) produced by the manufacturer that provide the relationships between float current/average cell voltage and expected plate polarization. If the user does not have a Tafel Curve for a battery, then the manufacturer can provide the information.

Float current measurements

Like S.G. there are limitations with float current measurements that must be taken into consideration when using it to determine if a battery is fully charged

- Float Current variation – There are a number of things in an operating plant that cause perturbations in battery current. During recharge, the perturbations are small enough relative to the magnitude of the overall current that they can be ignored. This is not the case when a battery is on float charge.

The source of the fluctuations is the battery capacitance. While this is a physical property of the battery, it accounts for the fluctuations in float current. The reason is simple to understand. The battery stores large amounts of charge on the plate surfaces. Because of this, the battery acts like a large capacitor and can respond much quicker than the charger to any fluctuations in voltage or current demand. Fluctuations are caused by variations in charger output voltage, starting and stopping of loads etc. These fluctuations are present in nearly every nuclear battery installation. In the green battery current line of Figure 2 these fluctuations are seen between the 0 and 4.5 minutes section of the graph.

This is the reason that it can appear that current is flowing into the battery or out of the battery at different times. In reality, there is no actual change in the battery state-of-charge. The variations in current are caused by the surface charge (capacitance charge) of the plates discharging and recharging due to fluctuations in the DC bus voltage.

- To compensate for the fluctuations in float current, the value of float current is determined by time averaging the readings. There are various trains of thought here on how long to time average. Some monitoring systems use up to a rolling 30 minute average. In discussions with knowledgeable users who employ this technique and from the author’s own experience 30 seconds is the minimum with most users in the 1 to 5 minute range.

  If a user only wants to verify the battery is fully charged, 30 seconds is normally sufficient to get in the 80 to 90% accuracy range for the reading. As is time increased, accuracy is improved, but unless the intent is trending the data for other purposes, the point of diminishing returns is rapidly reached. If is trending the data, then it is important thing to ensure the duration of the readings are the same. Mixing readings at 30 seconds and several minutes, makes it difficult to produce a usable trend.

- A number of high-quality commercial permanently installed remote battery monitoring systems capable of measuring float current are available. A major advantage of these systems is that the time averaging of float current measurement is done the same way every time.

Relationship of charge current to state-of-charge

Leaving behind the relatively simple case of a fully charged battery, we enter into the newest territory of how to relate battery charging current to the state-of-charge of a battery that is not fully charged. Reference 1 was developed to explore this relationship. The results are presented below:

Battery Recharge

Nearly every stationary battery system employs a constant voltage charger either as a standalone unit or as part of an uninterruptible power supply (UPS). These chargers and the batteries they serve follow very predictable recharge curves following a discharge. While the recharge curves may look different, the actual variations are caused by the depth of discharge and the amount of current available to recharge the battery after a discharge.

Figure 1 shows a normal recharge due to an operating event. Note that the time scale is a total of 10 minutes. This curve shows the characteristics of a classic constant voltage recharge curve.

1. The charger goes into current limit (red line) and stays there until the battery voltage reaches the charger voltage set point.
2. The battery charge current (green line) decays exponentially (on the bottom scale between the 5.5 minute and 4.5 minute period)
3. The charge decays until it reaches its steady state value for the voltage applied (on the bottom scale, starting at 4.5 minutes continuing to 0)

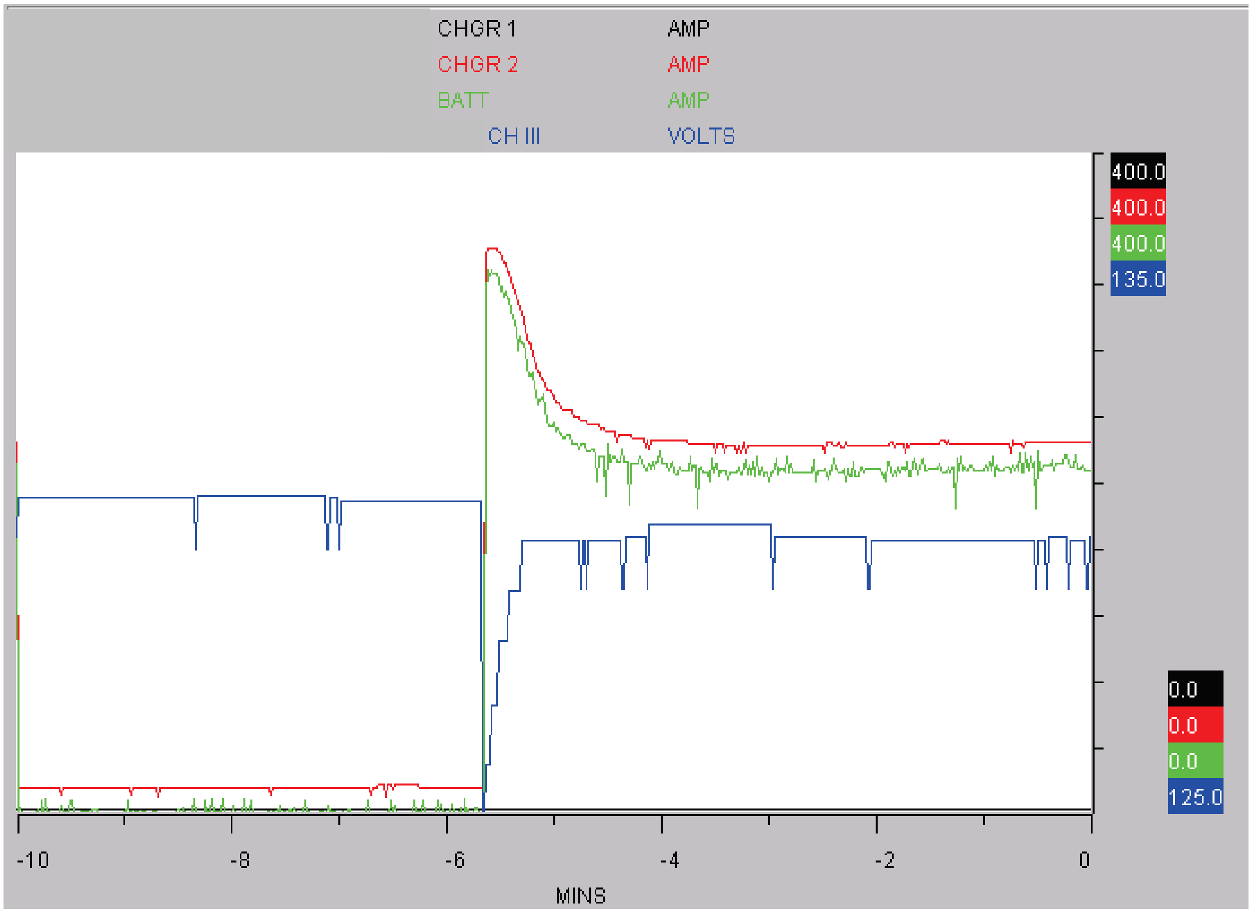

Figure 1 Recharge at float voltage following a short duration discharge

Since we know battery recharge curves are exponential decay curves, they can be defined by the equation:

$$A_{CL} \times e^{(-t/TC)}$$

where: A_{CL} = *Battery Charging Amps with charger at Current Limit*
TC = *time constant of exponential function*
t = *time in hours*

An important thing to note is that the battery charge current with the charger output current are not always the same. This is clearly seen in Figure 2 where the red line is the charger output current and the green line is the battery charge current. The difference between the two represents the buss loads the charger is supplying during the recharge.

Solving the exponential equation provides the results shown in the following table.

Multiples of Time Constants*	**Percent of Function's Value @ t = 0**	**Percent of Total Area under Curve @ t = 5TC**
0	100%	0%
1	36.8%	63.2%
2	13.5%	86.5%
3	5.0%	95.0%
4	1.8%	98.2%
5	0.007%	100.0%

The table defines the state-of-charge based on time constants by calculating the area under the recharge curve. As can be seen, at 5 time constants the battery is fully recharged. The method to determine when a battery is fully capable of performing its design function (or Operable in nuclear terms) is to look at the margins used in sizing the battery.

Method for determining when the battery is "Operable" ("Return to Service Limit", which defines when the battery is capable of performing its safety design function)

The term "return to service limit" will be used to simplify the text. In the nuclear industry, the purpose of the return to service limit is to provide an indicator that the state-of-charge of the battery is sufficient to perform its design function. To do this, the capacity margins used in sizing the battery are evaluated. As described in IEEE 485 there are three capacity margins that should be used in sizing every battery:

1. Aging – Batteries lose capacity as they age and unless the user plans to replace the battery at 100% capacity an aging margin should be included. In commercial UPS battery sizing, the aging margin is often ignored because it is assumed that the UPS itself will be operating at less than 80% of its rated capacity which provides sufficient margin.

2. Temperature – Lead acid batteries lose capacity at lower temperatures so if the battery is going to operate at less than 77°F (25°C) then a temperature margin should be included. Again, this is often ignored in commercial UPS battery sizing based on the actual % ac load on the UPS.

3. Design Margin – The final load on a system is not always known when the battery is sized and ordered. For this reason it is prudent to include some margin (typically 10-15%) for load growth and less than optimum operating conditions.

In general, it is not advisable to use the Aging and Temperature margins when determining the return to service limit. This is to ensure that the return to service limit applies over the range of battery life and expected minimum temperature. Some users do use all or part of the temperature margin when determining the return to service limit, because they have sufficient operating history to know the actual operating temperature range of the battery is above the minimum temperature value used in sizing the battery.

1. To establish the return to service limit, the available battery capacity margins are evaluated to determine the percentage of remaining charge required to give reasonable assurance that the selected recharge limit will ensure the battery is capable of performing its design function. As an example using the battery in Figure 2, a 25% aging margin, a 5% temperature margin and a 20% design margin are assumed. Since there is sufficient design margin, a 15% return to service limit is selected.

2. The next step is to obtain actual recharge data for the specific battery system being evaluated. This is done to establish the initial value for the exponential charging current. This will normally be the battery charging current when the charger is in the current limit mode (Battery Charging Current = Charger Current – House loads). Using the graph in Figure 2 the charger output current is approximately 300 amps at current limit and the battery current is approximately 270 amps.

3. Next multiply the charge level determined in step 1 by the initial value of exponential charging current from step 2 (in our example 270 amps). This establishes the initial return to service limit. If you are a nuclear user, then additional conservatism is added to ensure that the return to service limit is applicable in all conditions.

Using the example outlined above,

Case 1 – Aging Margin 25%
Temperature Margin 5%
Design Margin 20%
Selected Return to Service Limit 15%
Initial battery charge current 270 amps

Multiplying 270 by 15% the initial return to service limit is 30.5 amps, which is much less restrictive than the 2 amp limit required by the license for most nuclear plants. Continuing with the example, an allowance is added for the accuracy and readability of the battery current meter and a final limit of 25 amps is selected.

The preceding battery current analysis can be applied to any battery system where the user needs to know the state-of-charge or when the battery is capable of performing its design function. As previously stated, this is critical information for nuclear power plants. With the proliferation of large scale battery plants to back up critical infrastructure for banks and other business, where reliability is just as important, it can be critical to know when a battery has been sufficiently recharged (such as following a test discharge) so that it can perform its design function (and safety design function in the nuclear industry). Using an extension of the analysis above, the user can also determine an expected recharge time for each battery for various depths of discharge.

CONCLUSIONS

The preceding discussions provide the bases for changing from S.G. measurements to float current measurements for determining the state-of-charge and can be summarized as follows:

- For most users, S.G. is limited to determining the state-of-charge to the fully charged condition.
- S.G. is limited to determining the state-of-charge to vented lead-acid batteries.
- Float current can be used to determine the fully charged state-of-charge of most battery technologies
- Battery charging current can be used to determine the state-of-charge for battery systems employing constant voltage chargers.
- Using the battery sizing information, a user can establish a return-to-service limit for a battery system employing constant voltage chargers.

RECOMMENDATIONS

Stationary battery users should:

1. Understand your battery system from the sizing to the installation and how the components interact.
2. Understand the impact of the connected equipment on battery performance
3. Do discharge tests to monitor the aging of your battery.
4. Add float current monitoring to your routine battery inspections.
5. When unsure about something, contact your battery manufacturer for assistance.
6. Stay abreast of stationary battery developments to learn more about a subject that is as much art as it is science.
7. Build a network of other battery users and share information and your experiences.
8. If something doesn’t look right, take pictures to share with your colleagues and the manufacturer.

REFERENCES

Kyle D. Floyd, A Proposed Method For Selecting The Return To Service Current Limit For Safety-Related Batteries, Prepared for Technical Specification Task Force 360, March 2000.

ACKNOWLEDGEMENTS

The author wishes to thank Mr. K. Floyd and Ms. L. Ramadan for their inspiration and support in developing this paper.