FLOAT CURRENT – CRITICALLY IMPORTANT - OFTEN OVERLOOKED, MISUNDERSTOOD, AND/OR ERRONEOUS

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Abstract
Float current is the only individual measurement that can provide you with a wealth of information regarding the condition of your battery string at that moment in time. It by itself can inform you of whether you have a structurally intact battery circuit or do not. Float voltage, or most charger meter readings will not tell you this. It also can inform you if you are in a discharge or recharge condition, plus it can provide you with advance warning of internal conditions that can lead to string failure. It, when coupled with ambient temperature and cell temperature, can alert you of an impending thermal runaway issue, with adequate time to take preventative measures.

Float current has been known about and generally understood for decades, but what was not so well understood was just how much it could tell us, and just how important it is for that reading to be accurate and repeatable. The first time that any IEEE standard or any battery manufacturer's maintenance manuals, mentioned/acknowledged that float current was important to be understood, and that it can provide valuable information to a knowledgeable user was not documented unit the IEEE Std. 1188™-2005[1] the "IEEE Recommended Practice for Maintenance, Testing, and Replacement of Valve-Regulated Lead- Acid (VRLA) Batteries for Stationary Applications" added monthly float current readings to its recommended maintenance practice.

This paper is going to explain how to learn/determine what the float current should be for any battery model you have, how to and how not to take float current readings, and explain differences between manually taken readings and those from a permanently mounted device. In addition, we will show how easy it is to use float current as a guiding light, and we will explain why erroneous readings are misleading and can be dangerous.

If this reading is not clearly evident in every battery inspection you perform or have performed for you, then you are missing out on a very important tool that will benefit you in numerous ways, both in this moment in time, and as well as going forward to observe degradation in your battery.

Background
Back before 2000 not many of us really understood just how we could use float current to help us understand our batteries. Of course, everyone understood what float current is, but most of us did not yet understand just how much information that one measurement could provide us. Knowledgeable users now know, that float current can provide us with much more information than just what the current is that is passing through the cells at that moment in time.

In the early 1990's when the VRLA products were relatively new, there was a substantial amount of early life failures due to PCL (Premature Capacity Loss), thermal runaway, and to cells failing open when loads were applied to the battery systems. All three of these failure modes appeared to occur without warning, or at least back then we thought there were no warnings. As knowledgeable stationary battery individuals now know, there are always warning signs of VRLA cell problems.

When we wrote the IEEE Std 1188-1996[2], IEEE Recommended Practice for Maintenance, Testing, and Replacement of Valve-Regulated Lead-Acid (VRLA) Batteries for Stationary Applications, we did not have the benefit of the years of experience with internal ohmic measurements or the knowledge that is gained through years of experiences with something new. The VRLA products were still relatively new, and everyone at that time had knowledge based upon VLA (Vented Lead-Acid) batteries, and these new batteries were not acting like the VLA systems. Everyone was trying to learn on the fly what activities/checks were required to perform actual preventative maintenance. IEEE 1188 was written to address those differences, and to provide users with methods to be able to assure that their VRLA batteries would operate as expected when called upon.

Measuring float current was not thought of back then, and was not included in that document as a maintenance activity, nor had it been included in any of the IEEE 450 documents prior to that time. Because of the substantial number of battery failures where the cells would open under load, there was a need to be able to easily check to see if the battery would function when it was called upon. In order to have some means that a user could use that could at least assure them that their battery would not fail open when a load was applied, we added into the "Test description and schedule" section of the document, a fourth type of test. Back then in the IEEE 450 , which we used as a guide when creating this document from scratch, there were the three standard types of tests (Acceptance, Performance, and Service). In order to address the opening of cells when a load was applied, we added in a "momentary load test" as a way to determine the integrity of the conduction path.

The IEEE Std 1188-1996 the IEEE Recommended Practice for Maintenance, Testing, and Replacement of Valve-Regulated Lead-Acid (VRLA) Batteries for Stationary Applications had the following definition for a continuity test: 3.5 continuity test (battery): A test on a cell/unit or battery to determine the integrity of its conduction path. It then in section 6.2 explained what the test was as follows. "Continuity test: A continuity test will determine the physical integrity of the battery system, but not necessarily the performance of the battery (see 7.6). This test is done with the semiannual maintenance described in 5.2.3, in accordance with the manufacturer's recommendations, or when internal ohmic measurements cannot be performed."

Float current also can be used to determine the continuity of the battery string, which can be used to satisfy the requirement in NERC (North American Electric Reliability Corporation) Standard PRC-005-6[3] for "battery continuity". In the NERC TPL-001-5.1[4] Transmission System Planning Performance Requirements document, it also can be used to satisfy a requirement. Table 1 – Steady State and Stability Performance Footnotes (Planning Events and Extreme Events) Line item 13 states the following: "For purposes of this standard, non-redundant components of a Protection System to consider are as follows: c. A single station dc supply associated with protective functions required for Normal Clearing (an exception is a single station dc supply that is both monitored and reported at a Control Center for both low voltage and open circuit)." It is my interpretation of this to mean that if one has a single DC supply (one battery and one charger system), but they are required to have redundant DC systems, that by having a permanent installed system that monitors and reports to a Control Center for low voltage and an open circuit, that they are not required to have redundant systems installed. The float current will satisfy the open circuit requirement.

The requirement for measuring float current did not appear in any of the IEEE documents until IEEE 450™-2002[5], then IEEE1188™-2005[6], and finally IEEE 1106™-2015[7].

INTRO

Three items that the author considers essential for a battery maintenance program are:

1. Existing capability/operability – is the battery functional right now?
2. Risk/failure alerts – is there or are there problems or failure causing issues within the battery?
3. Predictability/advance warning/budgeting – is there information that alerts me to the need to budget monies for additional service or battery replacement?

The importance of measuring float current is often overlooked or misunderstood in many battery inspection programs, but its importance is not overlooked in any of the applicable IEEE standards that relate to VLA (vented lead-acid), VRLA (Valve-Regulated Lead-Acid), or Ni-Cd (Vented Nickel Cadmium) batteries for stationary applications.

IEEE Std 450™-2020[8] The IEEE Recommended Practice for Maintenance, Testing, and Replacement of Vented Lead-Acid Batteries for Stationary Applications recommends monthly measurement of float charging current.

IEEE Std 1106™-2015 The IEEE Recommended Practice for Installation, Maintenance, Testing, and Replacement of Vented Nickel-Cadmium Batteries for Stationary Applications recommends quarterly measurement of the float current. Of note is that the IEEE 1106 does not have a section for monthly readings of any sort, at this time.

IEEE Std 1188™-2005 The IEEE Recommended Practice for Maintenance, Testing, and Replacement of Valve-Regulated Lead- Acid (VRLA) Batteries for Stationary Applications recommends monthly measurement of the float current.

That all three of these industry standards recommend measuring float current on their most frequent measurement interval should make anyone reading this understand that knowing the float current in your battery system is critical to understanding the condition of the battery.

Definition of float current

Float current is the current flowing through a battery during float charge. Sounds simple enough, but what does it mean? Every battery requires a certain amount of charge current to be provided to keep the plates fully charged, which is why each battery manufacturer has a recommended float charge voltage range for differing battery models. The definition of a float charge is “A constant-voltage charge applied to a battery to maintain it in a fully charged condition, while minimizing degradation or water consumption.” These different float voltage ranges provide enough of an over-potential to each of the plate groups to keep them above open circuit voltage and to prevent self-discharge. In other words, so that the battery is continuously fully charged and ready to operate when called upon.

What can understanding the float current do for you?

Knowing the current that is flowing through a battery can provide valuable information as to the condition of the battery at that moment in time. This can be discharge current, recharge current or float current. It is my objective in this paper to explain the benefits that you can obtain by understanding what the float current in your battery can tell you, and what it cannot. It will explain why accurate and repeatable measurements are important as well as how inaccurate ones are misleading.

Some meaningful benefits of accurately knowing what the float current is supposed to be and what it is right now, are as follows.

- Having a value that can be used to trend changes in the string over time. Knowing what it is supposed to be allows you to compare all future readings to known good ones.
- Knowing the state of charge of the string at that moment in time – is it where it should be as compared to what it is supposed to be for a fully charged system, or is it in a partial discharge state.
- Gaining information that the battery recently underwent a discharge event. The current will be elevated as compared to normal.
- Learning/knowing that a thermal walkaway/runaway is approaching, or occurring. Thermal events are always preceded by an elevated float current that continues to increase over time, and is coupled with an elevated cell temperature as compared to the normal ambient.
- Being able to eliminate or reduce taking specific gravity readings. With lead calcium cells, if you use float current to determine state of charge, you can eliminate the need for specific gravity readings.
- Provide information on the state of health of a battery system. With VRLA cells a float current that is continuously increasing is an indicator of internal issues that lead to PCL (premature capacity loss) or thermal runaway.
- Provide proof of battery continuity, which is one requirement of NERC PRC-005-6, as well as one part of Exception 13.c in the NERC TPL-001-5.1 document. A float current value proves that the battery has continuity.
- Satisfy some of the requirements of NFPA 1. Article 52[9] regarding thermal runaway detection and prevention for VRLA batteries.

Sadly, there are still battery inspection reports that do not show the float current, and sadder still that those that are responsible for reviewing the reports do not understand their value, and demand they be in every inspection report, and that they be accurate.

How can you learn what your battery's float current should be?

1. Very general old rule of about 50mA per 100AH of battery rating. Not the best way, but does provide guidance. Item 2 is closer, and item 3 is the most accurate.
2. Use the IEEE 1635 / ASHRAE 21[10] (Guide for the Ventilation and Thermal Management of Batteries for Stationary Applications) battery gassing calculator. Much better than just using item 1, but still not the most accurate. The direct link to purchase that calculator is as follows. (note that IEEE PES members can download it for free): https://resourcecenter.ieee-pes.org/technical-committees/tools/PES_TP_CALC_080218.html

3. Contact the battery manufacturer and ask them what the normal float current should be for your model, and age. This is the most accurate way to determine what your battery should require under normal circumstances.

How do you measure float current?

Manually measuring float current: You use a clamp on ammeter that will read low currents accurately. Ideally you would want one that will read less than 100 MilliAmps accurately, preferably 10s of MilleAmps, or even accurate down to 1mA for smaller batteries. The jaw opening width can determine which ammeter you can or cannot use. There are some meters that will accurately measure 1 mA accurately, but often they cannot encircle the connection straps or cables, nor is that accurate a reading required for a battery maintenance program. You must be able to encircle the connectors or cables, either individually or in groups. Often with multiple connectors or cables you will need to measure each individual one and total the readings to arrive at the total current flow through the battery. The three ranges of accuracy that I am aware of are 1 mA, 10 mA, & 100 mA.

Do not use a meter that only measures AC current. Do not record a reading if the jaws are not fully shut. Do not use a reading as a trending value if the battery has recently been under discharge, and not yet returned to its previous known normal float value.

Figure 1. Measuring current flow.

The first step is to be standing at the battery, and prepared to start the measurement/s. Now that you are ready, ZERO the meter and then take your reading. If there are multiple readings that need to be taken, ZERO the meter before each and every reading. Follow the instructions on your meter for zeroing and polarity guidance.

Ideally you want to use the same meter for all readings, but as long as the meters are accurate then this is not as critical as it might seem.

For consistence, it is a good idea to mark the location where the readings are taken and to only measure the float current in that location. This is not critical, but can be beneficial when multiple individuals are performing the measurements. Of course, the current will be the same wherever you measure it at within the string.

For a visual instruction on measuring float current both with a larger jawed meter and with a smaller one, you should download the video that Curtis Ashton made a few years ago. I highly recommend watching it as for anyone not familiar with taking these readings, it is very informative. That video is available for download at
https://www.dropbox.com/s/1vgsijm3dx9dba3/DC%20float%20current%20only.mp4?dl=0

When not to take a float current reading

Measuring the float current shortly following a discharge event can be misleading, as depending upon the depth of discharge, and the charger capability, it may take several days for the battery to become fully charged and for the float current to return to where it was prior to the event. Yes, within 24 hours usually, the battery should be recharged to over 95%, but the last few percent of recharge can take longer and the float current will not be back to its normal state until the battery is fully recharged.

Tracking the float current over time

Keep a running track of the float current measurements over time. You do this so that you can see if there are any changes over time. With lead calcium and pure lead, there is very little increase in the normal float current over the life of the battery, but with lead antimony and lead selenium (low antimony) there is a normal increase of up to about 100% in the required float current as they age. It is wise to check with the manufacturer to learn a more precise increase value.

If you observe an increase in the float current above what is expected, and there has not been a recent discharge, you need to investigate as to the cause. With VRLA cells, an increase might be an indicator of PCL, or dry-out. A continuously increasing float current also can be an indicator of a thermal runaway event beginning. Remember that thermal runaway occurs in all types of cells (vented lead acid and vented nickel cadmium also [although it is extremely rare in Ni-Cd]), not just VRLA cells (although it is more common in VRLA, and especially in AGM VRLA), and that there is always an increase in the float current, many months before the event occurs.

Float current chart 2/1/17 – 2/1/23

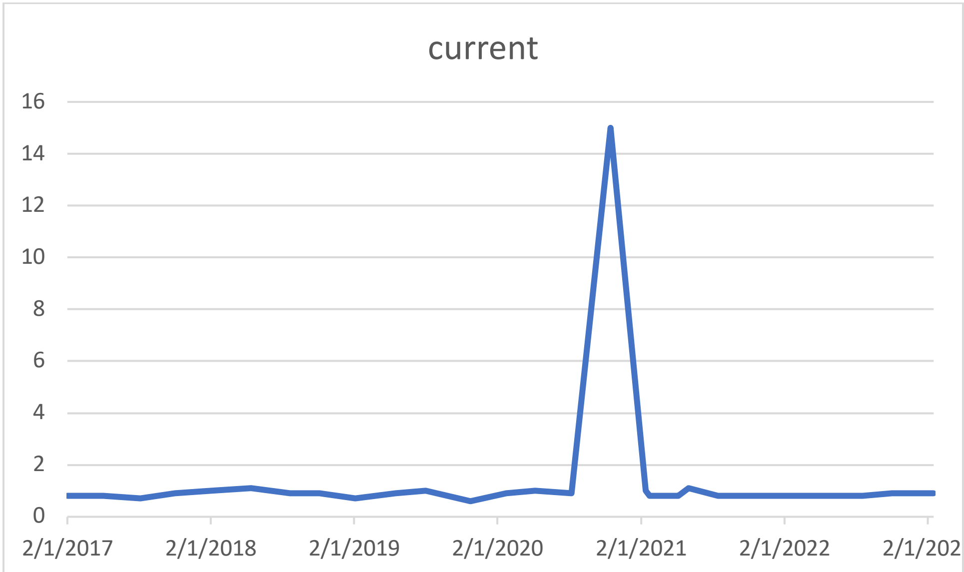

Figure 2. Graph of quarterly float current record.

Notice the spike in the 11/14/2020 reading. Just prior to that inspection the site load had gone onto the battery for a short period of time. The battery was still in a recharging state when that reading was taken.

Measuring float current with permanently installed monitoring: The range of permanently installed monitoring systems that have the capability to measure current flow through the battery have a wide range of capabilities. These devices, depending upon the system, can measure just float current or all the way up to any number of the following items, and provide alarms or alerts as programmed or applicable. Their individual means of measuring the float current, and other items and providing the alarms, depends upon the individual device.

- Float current
- Discharge current
- Recharge current
- OAV (overall DC bus voltage)
- ICVs (individual cell voltages)
- Cell temperature
- Ambient temperature
- Internal ohmic values
- Electrolyte levels.

The price of the individual machine/implement, depends upon what is required and provided. There are devices that will measure just float current which can be purchased for less than $1,000.00. Then there are units that are leased for less than $1.00 a day, which are really a service that monitors the four key items for thermal runaway protection. Those four items are the OAV (clarified above), the current, the ambient, and the cell temperature. Then there are units that can measure a number, or all the items listed above, in addition to the float current, and those units can run in the tens of thousands in US dollars. The price just depends on what you want to accomplish.

Some of these devices are stand alone, and some are an accessory or a part of a battery charger or charging circuit scheme. Some can be installed without taking the battery out of service, and some require that the battery be isolated to install the monitoring system. No matter how they are configured, their purpose is to provide you with a means of understanding the condition of your battery at all times 24/7.

Since this paper is about the value of float current, we are not going to discuss any items that are not directly related to understanding the float current and what information that it can provide.

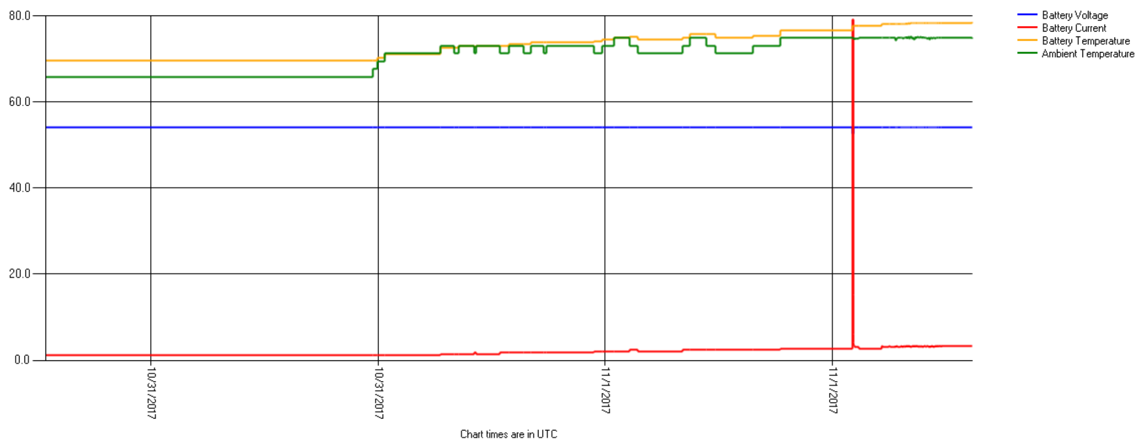

Figure 3. Continuously monitored float current increase related to cell/ambient temp – this graph shows the float current increasing (bottom line) and the cell temperature (top line), increasing over the ambient temperature (second line from top). This indicates a thermal issue is beginning.

Whenever there is a gradual increase in the float current over an extended period, coupled with a gradual increase in the temperature of the cells as compared to the ambient temperature, the battery is entering a thermal walkaway/runaway situation. The fastest way to halt the increasing current and to lower the temperature differences is to lower the float voltage to just above open circuit voltage, get either spot coolers or fans blowing onto the cells, and if a 2-volt VRLA string, to perform the IEEE 1188a™ Special Recovery Process[11] on the cells.

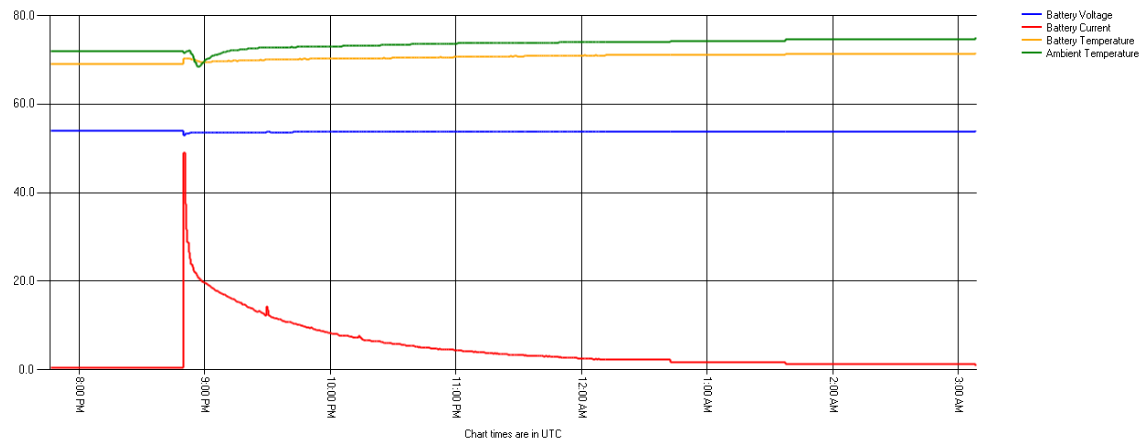

Figure 4. Continuous monitor shows a momentary loss of power to the charger at about 8:45PM, which caused an increase in recharge current of approximately 50 amps, and then a gradually declining recharge current until 3AM, at which time the float current is almost back to where it was before the discharge event.

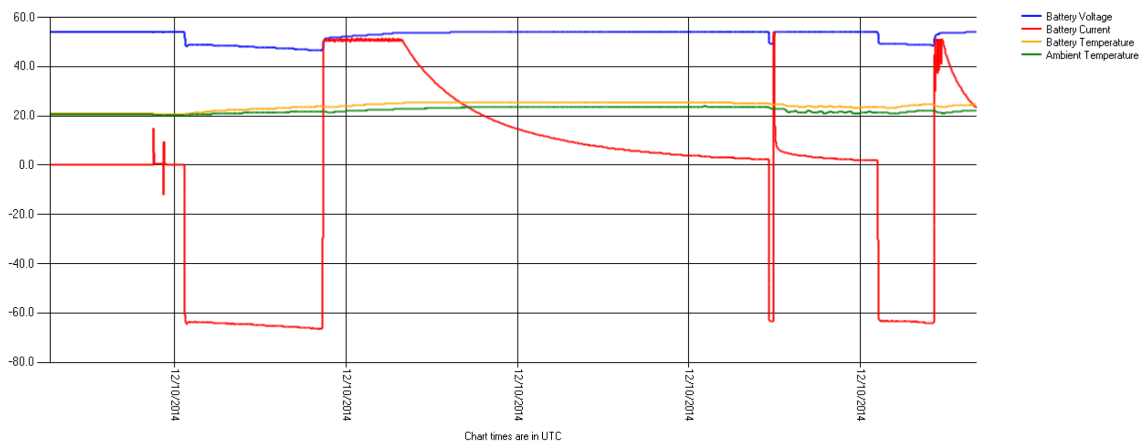

Figure 5. Continuous monitor shows an extended loss of AC to the charging source as evidenced by the discharge current of approximately 65 amps, and when the AC is restored the recharge current maxed out at about 55 amps, at which time you can see the gradual return of the OAV of about 54 volts. The recharge current stays at that 55 amps until the OAV has reached that 54 volts and then slowly decreases until it is almost back to normal, then another short loss of AC to the charger, and a quick decline back to about normal, and then another discharge followed by a recharge. This information is also provided in a tabular form, with precise values for the current, cell and ambient temps and the OAV, throughout the differing events.

Note that dc current is commonly measured with either a shunt in series, or with a Hall Effect transducer clamped around the conductor(s). Regardless of the method used, it is difficult to appropriately size one device that can monitor both float current and the orders of magnitude larger discharge/recharge currents accurately. Figure 6 shows a shunt device, which is not going to be extremely accurate for float currents if it needs to be sized so as to be accurate for discharge or recharge currents that are extremely high. Figure 7 shows Hall Effect transducers. In order to measure both float currents and high discharge/recharge currents accurately, two different Hall Effect sensors must be placed around the conductor(s). At least two manufacturers have devices that look like a single transducer, but are actually two transducers in one.

Figure 6. Float current monitor that works in conjunction with a battery charger. To install this the circuit needs to be interrupted so that this can be installed in one of the cable circuits that goes from the battery to the charger. The current value is relayed to a monitor or alarm relay.

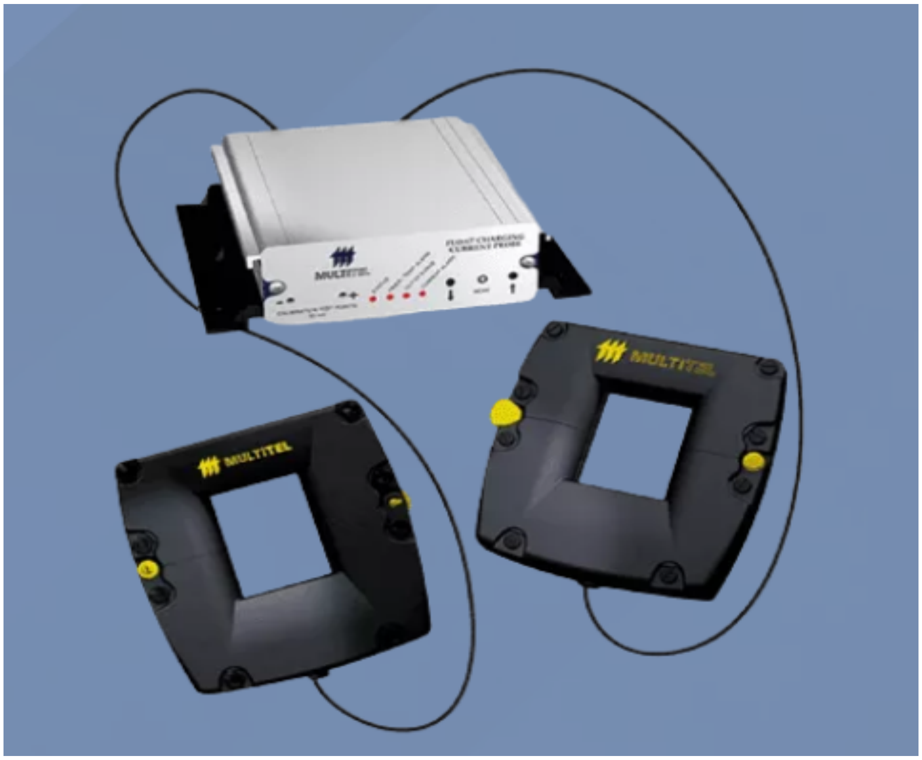

Figure 7. Float current monitor that can measure the float current of up to two strings. This unit uses split core transducers, which allows installation without interrupting the battery circuit.

Figure 8. Current sensing part of a BEM (Battery Event Monitor) unit, which also monitors the OAV (overall voltage), cell temp, and ambient temp, and has adjustable alarm thresholds for each value, and can be installed without interrupting the circuit.

Frequency of readings

The IEEE documents recommend that float current be measured every month for the 450 and 1188 documents, and every quarter for the 1106.

However, NERC PRC-005 does not require measuring float current to determine the state of charge. It does state in Table 1-4 (a) which is for vented lead acid batteries, that on a maximum 18-month interval that users must verify that the station battery can perform as manufactured by evaluating cell/unit measurements indicative of battery performance (e.g. internal ohmic values or float current) against the station battery baseline. It also requires that you verify battery continuity on a maximum 18-month interval. Float current can provide proof of continuity.

In Table 1-4 (b), which is for VRLA batteries it requires that the user verifies that the station battery can perform as manufactured by evaluating cell/unit measurements indicative of battery performance (e.g. internal ohmic values or float current) against the station battery baseline. It also requires that you verify battery continuity on an 18-month interval. Float current can provide proof of continuity.

In Table 1-4 (c), which is for vented nickel cadmium batteries it requires that battery continuity be verified on a maximum 18-month interval. Float current can provide proof of continuity.

In Table 1-4 (f), there are some exclusions to the periodic battery continuity verification requirement that are allowed when there is a permanent float current monitoring and alarming system installed. They are as follows.

1. Any battery-based station dc supply with monitoring and alarming of battery string continuity (See Table 2) will not require periodic verification of the battery continuity.
2. Any Valve Regulated Lead-Acid (VRLA) or Vented LeadAcid (VLA) station battery with internal ohmic value or float current monitoring and alarming, and evaluating present values relative to baseline internal ohmic values for every cell/unit (See Table 2) will not require periodic inspections of the condition of all individual units by measuring battery cell/unit internal ohmic values.

NERC Standard TPL-001-5.1

Title: Transmission System Planning Performance Requirements

Purpose: Establish Transmission system planning performance requirements within the planning horizon to develop a Bulk Electric System (BES) that will operate reliably over a broad spectrum of System conditions and following a wide range of probable Contingencies.

It is my understanding that TPL-001-5.1 goes into effect on 7/1/23 and there existing TPL-001-4 is in effect presently and contains the same verbiage. I reference this standard because it references single points of failure within a site's protection system. For example, if there are redundant DC systems (two batteries and chargers), then that is not considered a single point of failure. With sites that are non-redundant, such as a station DC supply with one charger and one battery, that system is considered a single point of failure.

This requirement creates a potentially costly situation for sites that are required to meet this rule. There is one exception to this requirement, that allows sites with a single DC system to not be required to install a second system, but which will still provide the security required. That exception is listed in Table 1 – Steady State & Stability Performance Footnotes (Planning Events and Extreme Events).

The exception is item 13. For purposes of this standard, non-redundant components of a Protection System to consider are as follows:

Item c. states the following. A single station dc supply associated with protective functions required for Normal Clearing (an exception is a single station dc supply that is both monitored and reported at a Control Center for both low voltage and open circuit).

The key words are that that single station dc supply is both monitored and reported at a Control Center for both low voltage and open circuit.

Float current cannot determine low voltage, but can provide information as to an open circuit, under a normal float condition. A device that monitors float current provides half of that requirement. A device that either alone or in conjunction with another device, such as a charger with alarming capabilities would possibly meet both of those requirements and will allow a single DC system to remain in place and be compliant.

Float current explanations from IEEE 1188-2014 and IEEE 450-2020 annexes

Annex C.6 from IEEE 1188-2014 in conjunction with the amendment IEEE 1188a-2014

C.6 Float current: Internal problems may cause a battery to require substantially more float current than under normal conditions. This increased float current will eventually generate more heat than the battery can safely dissipate and will lead to further degradation. If left uncorrected, the abnormally high float current will lead to early cell or string failure. The abnormally high float current may also cause a thermal runaway condition, leading to catastrophic battery melt down, explosion, and/or plant destruction.

A fully-charged battery has an average float current that is dependent on the chemistry, average temperature, and float voltage. For example, under normal conditions, a typical lead-calcium VRLA cell might require about 50 mA of float current per 100 Ah of capacity (at the 8-hour rate) but this can vary based upon manufacturer specific items. The manufacturer should be contacted to provide an estimate of normal float current based upon the respective site conditions. If a battery is requiring more than three times the normal float current, there are several possible causes. Those that result from internal cell problems include excessive dryout, negative self-discharge, and cell internal short circuit. Improper float voltage setting or abnormally high ambient temperature may cause abnormally high float current and premature cell failure, but they are not the result of internal cell problems.

When excessive float current is noted, the following steps should be made immediately:

a) Check battery float voltage to ensure that it is within the manufacturer's guidelines.

b) Measure both room ambient and individual cell temperatures. If either is abnormally high or if cell temperature significantly exceeds room temperature, take steps to reduce float voltage or limit current to prevent thermal runaway, while correcting the cause, wherever possible.

c) Using ohmic techniques, ensure that no cells show unusual departures from expected values.

d) Check individual cell voltages to ensure that no cells have developed internal shorts.

e) A discharge test can pinpoint unexpected positive or negative self-discharge, with resultant capacity loss. If item b) through item d) are noted, a discharge test may be essential to ensure that battery capacity has not been compromised.

Annex A.2 from IEEE 450-2020

Some methods for determining the state of charge are better suited for certain plate metallurgies than others. Therefore, the type of cells (e.g., lead-calcium, pure lead, or lead-antimony) comprising the battery system is a factor in selecting inspection procedures for determining the state of charge. Stationary batteries are normally kept fully charged at a float voltage that supplies enough current to replace internal losses and keep the cell plates at an optimum state of polarization (charge). At the positive plates, a small portion of the charge current corrodes the grid metal and the remainder produces oxygen gas. At the negative plates, some of the current reduces oxygen that diffuses from the positive plates, and the remainder produces hydrogen gas. The amount of hydrogen liberated, and thus, the amount of water the battery will consume, are functions of the charging current. In practical terms, cells with lead-antimony grids will draw more charging current to maintain a given voltage than cells with lead-calcium or pure lead grids. Float charge current and gas evolution are proportional to the antimony content of the grids. Furthermore, as antimony grids age, they release increasing amounts of antimony to the electrolyte, which then migrates to the negative plate to form local cells and a subsequent self-discharge, which results in an increase in the charging current. Calcium, unlike antimony, does not migrate from the positive grid to the negative plate, so the negative electrode remains essentially pure, and the required charging current remains constant over its service life.

Float current is a useful indicator of battery condition when the battery cells have constant float characteristics throughout their service life. (e.g., cells with pure lead or lead-calcium plates). In cells requiring additional charging current as they age, such as lead-antimony, this assessment is more difficult to make. Cell float voltage measurements alone are not a reliable state of charge indicator. The higher gas evolution rates of lead-antimony cells make specific-gravity measurements a better indicator of the condition of the cells than for non-lead-antimony designs. The low rates of gas evolution in lead-calcium and pure lead cells means the electrolyte is slow to diffuse after charging or water additions and an accurate indication of the cells' condition may not be available for several months. Therefore, for cells with lead antimony plates it is recommended to measure the float voltage and the specific gravity of the pilot cells to characterize the state of charge. It should be noted that for the purposes of the preceding discussion, lead-antimony refers to designs in which the antimony content in the positive grid alloy is greater than 3%. Antimony cells with less than 3% antimony are referred to as low antimony or lead-selenium cells.

Summation

Float current can easily be measured either manually or automatically, and will provide you with valuable information as to the condition of your battery. By trending your float current readings, you can easily see detrimental changes to your battery. It is critically important that the readings that you receive are accurate. Any battery inspection report that does not include the float current, is not acceptable.

References

1. IEEE Std. 1188™-2005 the "IEEE Recommended Practice for Maintenance, Testing, and Replacement of Valve-Regulated Lead- Acid (VRLA) Batteries for Stationary Applications
2. IEEE Std 1188-1996, IEEE Recommended Practice for Maintenance, Testing, and Replacement of Valve-Regulated Lead-Acid (VRLA) Batteries for Stationary Applications
3. NERC Std PRC-005-6 Protection System, Automatic Reclosing, and Sudden Pressure Relaying Maintenance
4. NERC Std TPL-001-5.1 Transmission System Planning Performance Requirements document

5. IEEE Std 450™-2002 IEEE Recommended Practice for Maintenance, Testing, and Replacement of Vented Lead-Acid Batteries for Stationary Applications
6. IEEE1188™-2005 IEEE Recommended Practice for Maintenance, Testing, and Replacement of Valve-Regulated Lead- Acid (VRLA) Batteries for Stationary Applications
7. IEEE 1106™-2015 IEEE Recommended Practice for Installation, Maintenance, Testing, and Replacement of Vented Nickel-Cadmium Batteries for Stationary Applications
8. IEEE Std 450™-2020 The IEEE Recommended Practice for Maintenance, Testing, and Replacement of Vented Lead-Acid Batteries for Stationary Applications
9. NFPA 1. Article 52 Section 52.2.2.2 Thermal Runaway. VRLA systems shall be provided with a listed or other approved method to preclude, detect, and control thermal runaway.
10. IEEE 1635 / ASHRAE 21 Guide for the Ventilation and Thermal Management of Batteries for Stationary Applications
11. IEEE 1188a™-2014 IEEE Recommended Practice for Maintenance, Testing, and Replacement of Valve-Regulated Lead-Acid (VRLA) Batteries for Stationary Applications Amendment 1: Updated VRLA Maintenance Considerations