Thermal Runaway

The Past, the Present, and the **Sustainable** Future

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Abstract

This paper will cover thermal runaway and how this once misunderstood and feared lion with VRLA batteries has now been turned into a tamed housecat. Covered will be the issues that cause a thermal runaway, misunderstandings of the issue, actions that can be taken by users to predict the occurrence, and actions that can be taken to prevent it from occurring, or that can even be taken after the fact, to return a VRLA battery from thermal runaway back into a useful and reliable battery.

Since this issue is now so well understood, and since there are now early detection methods and equipment to prevent this from occurring, plus methods to recover from this, is it finally the users' responsibility and not the battery manufacturers' when it does occur?

By detecting and preventing thermal runaway, and recovering structurally-sound batteries in the (now unlikely) event that thermal runaway does occur, you will reduce the carbon footprint for that battery. Extending the useful life of your batteries provides a green benefit for the environment and a financial benefit for you in lower battery replacement costs.

Introduction

There are two words that strike fear into the heart of any knowledgeable battery user, no matter if they have a data center, communication site, power plant, (or pick any important application): THERMAL RUNAWAY. You noticed that I said "knowledgeable battery user," as anyone who does not realize what can occur during one of these events is just ignorant of just how catastrophic the event can be and just how much damage can occur. Of course once they have experienced one they now become "more knowledgeable" and usually battle-scarred. However they often still are clueless that they, themselves, have control of that situation and could have prevented it.

The accepted mindset for many years has been that this insidious event occurred unexpectedly and without any warning, and that the user was at the mercy of the "thermal runaway god (or goddess)." In other words, whether or not it occurred in your battery was just a matter of your luck (or lack of luck).

Since shortly after the introduction of VRLA batteries in substantial volume into the users market, there have been sudden unexpected thermal events with the accompanying meltdowns, or fires, or explosions. Just what does occur, and how severe the occurrence is, **now** depends entirely upon the actions of the user. YES, the USER!

I emphasize **now**, because it is now so simple to avoid this issue, and to recover from it. No longer is the user at the mercy of the thermal runaway god (or goddess).

What the heck is thermal runaway?

The definition of thermal runaway is "A condition that is caused by a battery charging current or other process which produces more internal heat than the battery can dissipate." While there might be some other wording of this event, this sums it up nicely. It is no more complicated than that particular battery, at that particular moment in time, does not have the capability to dissipate the heat that is being generated internally due to current flowing through it to the outside of the battery.

We are not going to discuss the electrochemistry involved in thermal runaway. Rather we are going to explain a little about the issues that cause this, and how simple it now is to detect it long before it does any damage. We will discuss what can be done to prevent it from occurring, and also go into how to recover from it if it does occur.

The monster appears unexpectedly

A typical report on a thermal runaway event will state that "without any warning" the battery suddenly was on fire, or that someone walked in the battery room and was overcome with fumes and/or heat, or on and on with stories that thermal runaway caused this sudden and unexpected event. Always it is stated that it occurred without warning.

Bull crap! There is now, and always was, a warning. We just did not understand the warnings, or did not have the means to see them. So instead of accepting the responsibility for our failures to perform the necessary preventative maintenance checks that we should have been performing, it was much easier to blame the manufacturer and that boogeyman "thermal runaway."

What are the warnings?

There really are just two warning that anyone needs to be concerned about as they relate to thermal runaway. They are:

1. An increase in charge current in normal operation that is not the cause of a recent discharge, or rectifier/charger adjustment or issue.

2. An increase in cell temperatures over the normal ambient temperature.

What are the causes?

The causes of thermal runaway are:

1. Negative plate discharge and sulfation.
2. Increases in float current required.
3. Changes in internal resistances of the cells.
4. Dry out of the cells.

We of course are using the assumption that the float voltage is correct for the environment. We also are not talking about vented battery strings that were improperly cycled, or over-charged until so much sediment ends up in the bottom of the cells that it causes shorting to an extent that it requires severe current to flow through the battery.

What is considered acceptable?

From this point forward, I am going to concentrate on 2 volt VRLA cells as they are the easiest to monitor, control, and correct, and are often a very large dollar investment.

It is normal for a fully-charged battery that is in good condition to draw between 0.25 and 0.5 amps per thousand amp hour at its eight hour rating, at standard temperature and voltage setting. Yes, there are variations from that, but that is a good general rule.

It is also normal for this same battery in normal standard operating conditions for the cells to be within one or two degrees of the ambient. This means that if the normal ambient temperature was at 25C that the battery would be at no more than 27C (or close to that). *(Figure 1).*

What is not acceptable?

It is not acceptable in normal float operation at standard temperature for the float current to be three to four times what it is supposed to be. It is not acceptable for the cell temperatures to be more than two to three degrees C (or more) above the normal ambient temperature. *(Figure 2).*

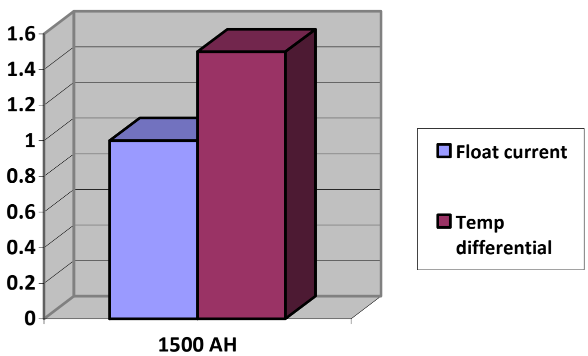

Figure 1: normal float current and temperature differential.

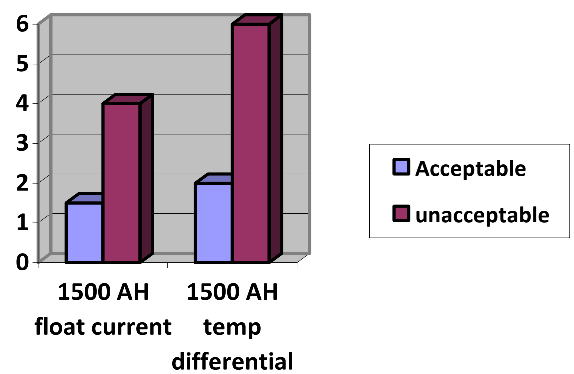

Figure 2: Acceptable and unacceptable ranges.

How to avert thermal runaway

To avert thermal runaway, follow the recommendations for periodic maintenance checks as listed in the IEEE 1188 standard under quarterly checks section 5.2.2 to also include what is required in the monthly checks section 5.2.1., with specific attention to the DC float current and the temperature differential between the cells and the ambient.

Let's assume that the float voltage is set correctly for the normal ambient temperature. There will always be an increase in the float current coupled with an increase in the differential between the normal ambient temperature and the cell temperatures long before it goes thermal. ***There are no exceptions to this statement.***

By tracking and trending those readings, you will have plenty of advance warning of an impending thermal runaway situation, with plenty of time to take corrective actions.

What corrective actions are we talking about?

The first corrective action that needs to be taken is actually two-fold. It includes restoring correct saturation in the cells, coupled with a recovering of the negative plates back into a useful condition. What this means is: Put back the water that has been lost over time, then drive any sulfates off of the negatives and restore proper polarization to them.

This will recover as much capacity or capability as possible, depending upon how deeply degraded the cells are when the corrective actions are performed. But of utmost importance is that, now that the cells are properly saturated and the polarizations have been corrected, the charge current will decrease and the temperature differential between the cells and the ambient will fall back to normal levels. You will now have eliminated the potential for thermal runaway and increased the capacity or capability of the cells. *(Figures 3 and 4).*

To preserve the results of these corrective actions a catalyst is installed in the head space to help the negatives; this then helps address the rest of the issues.

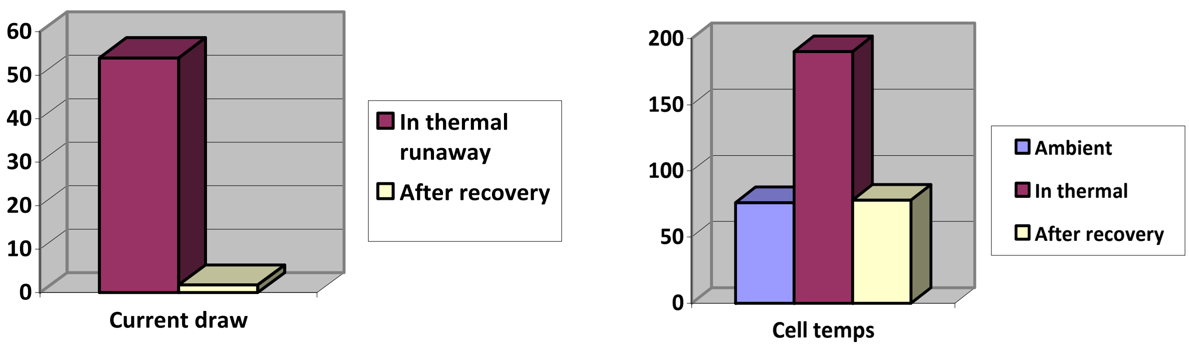

Figure 3: Typical current draw and cell temperatures during thermal runaway, and after recovery

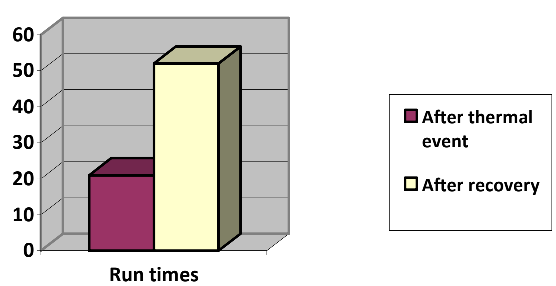

Figure 4: Run times after recovery

How can these measurements be taken?

Manually: First, there is the simple and easy method of using accurate hand-held meters to measure and record the readings. Someone will have to enter and trend the numbers, and take action when certain values are reached.

With this method it is imperative that the measurements be taken at the same points on the battery each and every time. That way the numbers are really being compared to their previous readings.

Remotely: There also now are inexpensive monitors that measure the overall voltage, charge current, and ambient temperature and can alert the user when programmed values are measured.

With either method, it is still up to the user to take the appropriate corrective actions. You can have all the data in the world, but if you do not act on the information provided by the data, you might as well not even bother to gather the information. Which is the same as it always has been, only now everyone should understand that if thermal runaway occurs in one of your batteries, you chose to let it occur by not taking preventative actions.

This is a VERY IMPORTANT statement. It is now up to you to act upon the information that is readily available to you.

Measurement cautions

The typical battery monitoring system that measures everything in the battery to include the discharge current during an outage may very well not measure float current accurately enough for it to be used as a early warning device. A device that will measure float current accurately in the 1 ampere or less range is needed to provide the information to alert you well in advance of any event.

Also, this device cannot have its accuracy affected by large discharges during a power outage or recharge from a power outage. In other words, the current measuring part of the instrument must recover to accurately measuring the float current following a large discharge or recharge current with the same degree of accuracy as prior to the large current.

Obviously, the more accurate the float current measurement the better, with some common sense involved, as you do not want nuisance alarms to drive you insane. A repeatable and accurate measurement of 0.5 of an ampere is would be plenty accurate for this measurement parameter.

Recovery steps after a thermal runaway

You can take a structurally intact battery from full-blown thermal runaway and turn it back into a usable and reliable battery, at less than the cost of buying a replacement. This reduces the carbon footprint for that battery, providing is a “green” benefit for the environment and a financial benefit for you.

To recover a battery, first inspect it according to all of the parameters in the IEEE 1188 standard. Verify the structural integrity of each cell. Consider performing an insulation breakdown test on the battery string to determine if there are any unseen paths to ground from inside any cell.

Next, re-establish proper saturation by adding water to each cell as needed, based on the cell model and internal ohmic value. Then apply a very high-rate, time-dependent boost charge to remove the sulfates from the negative plates.

Finally, install catalyst assemblies to extend the time that the internal resistance remains acceptable.

Conclusions

It is now understood and accepted universally that every thermal runaway is preceded by increases in both charge current and cell-to-ambient temperature differentials, and that these increases commence well before any thermal event.

There are simple methods available, both manual and remote, that can provide the measurements, warnings, and alarms when required. Using these methods properly will give the user adequate time to take actions to prevent a thermal runaway event.

There also are methods available to reverse the effects of impending thermal runaway, and prevent its future occurrence, and to restore batteries that have experienced thermal runaway back into useful and reliable battery strings. The benefits of this sustainable practice to the environment and the company's budget are significant.

If you have read this document and then allow a thermal runaway event to occur at your facility then there is only one person that is responsible for that thermal event and that is YOU.

About the Author

Peter DeMar has more than 30 years of experience in the stationary battery industry, including 28 years as a member of the IEEE Battery Working Group. He is a frequent presenter at industry conferences and was inducted into the BATTCON Hall of Fame in 2009.