Thermal Runaway Prevention Using Per String Measurements

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Introduction

There are thousands of strings of VRLA battery systems is service that have no protection from a possible thermal runaway. Many of these installations are in situations where owners want to be (or are required) to be protected from thermal runaway but do not want to (or cannot) implement monitoring on per cell or per jar basis.

First let me say that thermal runaway is almost always a result of customer abuse or a total lack of attention to VRLA battery systems. That being said, many users buy VRLA batteries as a part of a UPS or telephone system and forget about them unless or until there is an obvious problem. Many VRLA batteries remain in service well beyond their design life, hidden in cabinets or power closets, out of sight and out of the mindset of the user.

The occurrence of thermal runaway has come to the attention of the fire safety community. Both the International Code Council in the IFC, Section 608 and the National Fire Protection Association in NFPA 1. Article 52 have identical wording that states that "VRLA Battery systems be provided with a listed device or other approved method to preclude, detect and control thermal runaway".

I will propose a technique whereby thermal runaway can be detected in the very early stages and can be automatically controlled if the warnings provided by the system are not heeded.

Basic Understanding Thermal Runaway in VRLA Batteries

As VRLA battery systems near their end of life through age, abuse or shorted cells within a string, the float current will increase. A large percentage of this float current supports the recombination of oxygen at the negative plate that as an exothermic reaction generates heat. This causes the battery temperature to rise which in turn causes the float current to increase resulting in even more heat being generated. Depending on the geometry and materials in the battery system and the ambient temperature of the system, there will come a time where the batteries cannot dissipate the heat being generated within and thermal runaway takes off very dramatically.

Most cases of thermal runaway begin relatively slowly and if a trained battery professional were to be involved with the site the battery system would have individual cells or the entire system replaced.

Thermal runaway is a function of the float voltage, battery temperature and float current. Float voltage can be measured at one spot for multiple parallel strings. Battery temperature and float current is measurable on a per string basis. By using these three variables, early stages of thermal runaway can be easily detected. It is more difficult to detect the early stages of thermal runaway if it becomes very important to avoid false alarms.

Temperature Compensation

Many installations over the past decade have rectifier systems that will automatically raise or lower the float voltage with changes in the measured temperature of a battery. This should make thermal runaway much more difficult if not impossible at almost any conceivable ambient condition.

I believe that properly implemented temperature compensation is the most effective single step that users can take to improve VRLA system life (if the temperature of the battery environment cannot be rigorously controlled). As a byproduct, likelihood of a thermal runaway is decreased dramatically.

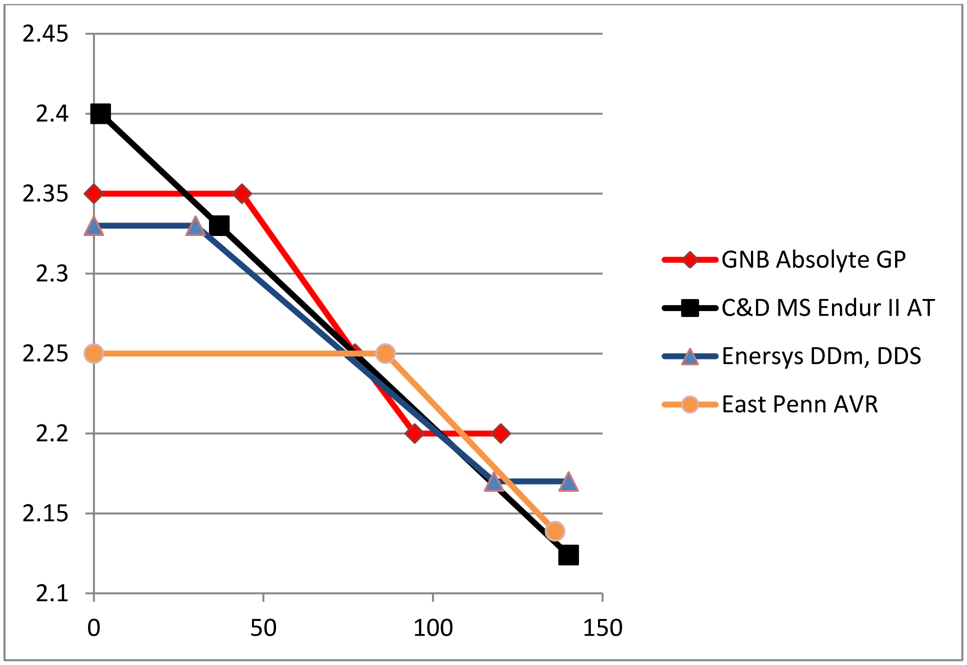
The algorithms for temperature compensation vary by battery manufacturer and product line but they typically have a maximum float voltage, a minimum float voltage and a slope between these end points. Please refer to the table below:

MANUFACTURER Product Line	Suggested Float Voltage/ Cell at 77*F	Float V Slope mV/*F	MAX. Float Voltage	MIN> Float Voltage	Temp. Comp. Begins Above	Temp. Comp. Begins Above
C&D Technologies						
MSEndur II AT	2.27	-2.00	None	None	77*F	77*F
MSEndur II ATL	2.20	-2.00	None	None	77*F	77*F
Liberty 1000	2.26	-2.00	None	None	77*F	77*F
Dynasty (All Products)	2.28	-2.80	2.40	2.21	77*F	77*F
East Penn						
DEKA Unigy 1	2.26	-2.22	None	2.25	86	None
DEKA UNIGY II AVR	2.25	-2.22	None	2.25	86	None
DEKA UNIGY II AVR LG	2.21	-2.22	None	2.21	86	None
DEKA UNIGY High Rate Series	2.25	-2.22	None	2.25	86	None
Enersys						
m Series DDm, DDS, DDX, DDV, SC	2.25	-2.22	2.33	2.17	77	77
Powersafe V	2.26	-1.67	None	None	77	77
Powersafe Front Terminal	2.25	-1.67	None	None	77	77
Hawker SBS	2.27	-2.22	None	None	77	77
GENESIS XE & XP	2.25	-2.76	None	2.20	77	77
DATASAFE 16 HX	2.26	-1.67	None	None	77	77
Exide (GNB)						
Absolyte IIP/XL	2.25	-3.00	2.35	2.2	77	77
Absolyte GP/GX	2.25	-3.00	2.35	2.2	77	77
Marathon, Sprinter, Relay Gel	2.28	-3.00	2.4	2.21	77	77
FIAMM						
UMTX	2.26	-1.43	None	None	77	77
Highlite SP & FLB	2.27	-2.78	None	None	77	77
SMG OPZV)	2.22	-1.36	None	None	77	77
Northstar Battery						
All Monoblocs	2.25	-2.2	2.52	2.17	77	77
Power Battery						
CV VRLA Series	2.25	-1.67	None	None	77*F	77*F

The values shown in this table were developed from the Operating Instruction Manuals that were available on the manufacturer's websites in March of 2012. Some of this information is the author's best estimate of data that was tabular over limited temperature ranges or partial data without clarification.

A graph showing a number of the battery manufacturer's recommendations follows:

Recommended Float Voltage (per Cell) vs. Temperature (Degrees F)



Please note that the recommendations vary dramatically by battery manufacturer and product line. Also the temperature compensation schemes offered by the members of the DC Power System community are not uniform. Some rectifier systems have a fixed slope for temperature compensation while others offer a variable slope. Some rectifier systems have no limits as to maximum or minimum charge voltages while others have variable set points for maximum and/or minimum voltages.

Knowing that many sites have a mixture of battery manufacturer's products and product lines being charged by a system with a single controller, it is easy to see that battery site personnel may have difficulty properly implementing the temperature compensation for the batteries supported by the power system.

Another issue with temperature compensation comes into play if the temperature probe fails or the probe connections fail open or become shorted. Different control schemes will react differently and some may dramatically increase the charge voltage to the batteries under one of these circumstances. This could instigate rather than mitigate thermal runaway.

Early Detection of Thermal Runaway

Thermal runaway is almost always preceded by excessive float current. However, float current is an exponential function of both voltage and temperature and therefore is subject to much higher than normal readings that could be generated by nominal increases in voltage and/or temperature. By correcting float current readings (on a per string basis) for the actual temperature and float voltage, detection of early and advanced states of thermal runaway can be made while minimizing the risk of false alarm.

Float current in VRLA batteries will increase 100% for a 15 to 18 degree Fahrenheit rise in battery temperature. Float current for VRLA batteries will increase up to 1000% for an increase of float voltage from 2.25 volts per cell to 2.35 volts per cell. Both of these relationships are exponential and therefore can be characterized in firmware.

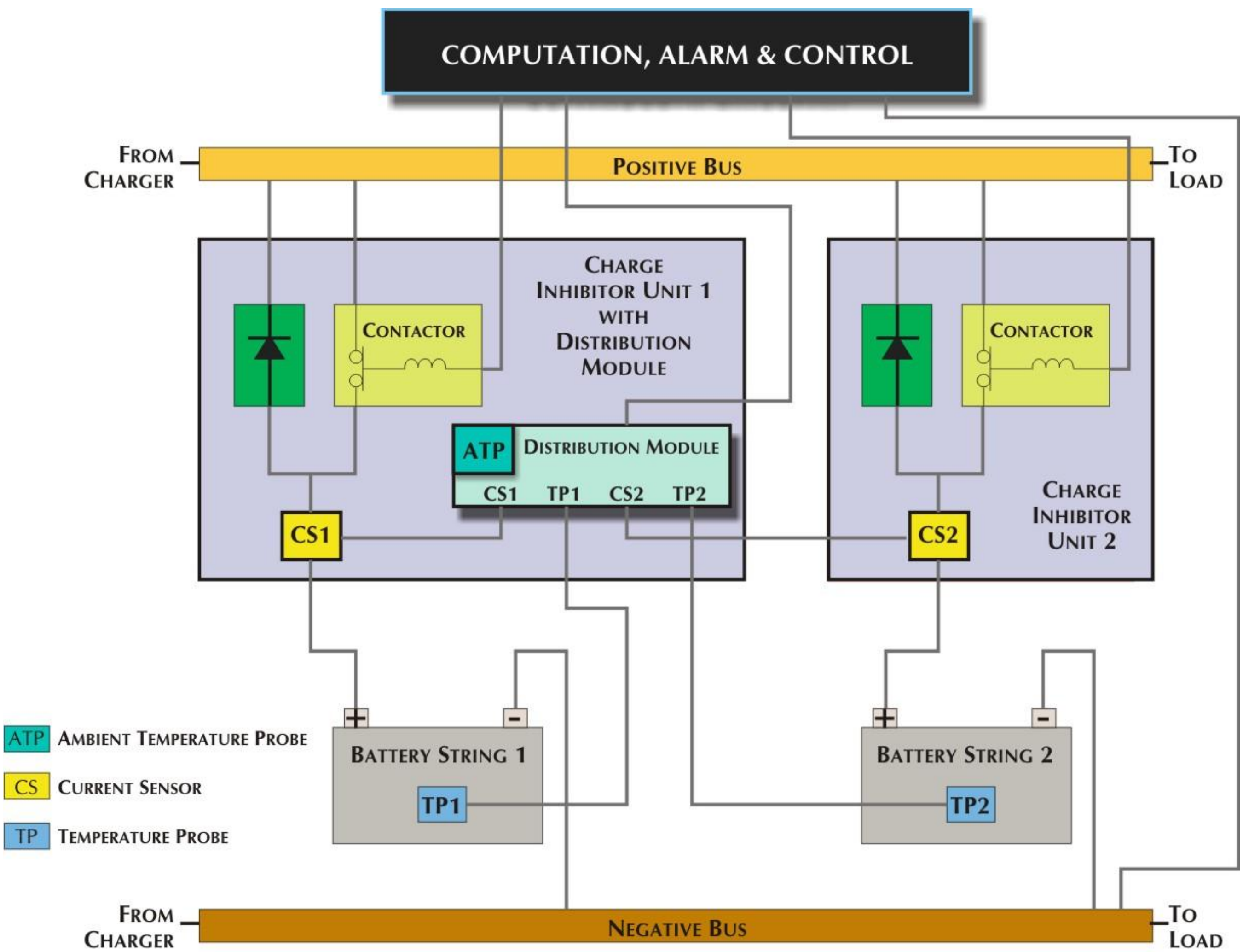
The proposed system algorithms include measurement periods of 24 hours or longer in order to detect long term degradation of the battery string while ignoring short term system anomalies that could otherwise result in false alarms. Since we are proposing a system that is independent of the DC Power System that charges the battery, any failure or unintended operation of the charger will not cause the thermal runaway protection to be compromised.

By correcting the measured float current for both voltage and temperature, the system can compare the adjusted current level to normal levels and alarm set points can be entered in multiples of normal float current. We are suggesting that a minor alarm be initiated by an adjusted current that exceeds four to ten times the normal level. This setting would be programmable and would be at levels that are way below danger for immediate thermal runaway but would clearly indicate that problems are present within the string.

We propose that a second level of alarm be detected at a higher multiple (20 to 40 times on average for 24 hours) of normal float current disconnect the charger from the battery system for a fixed time period. If the battery string temperature were to reach dangerous levels (programmable), the system would disconnect the charger from the battery with no time delays. The charger would be reconnected to the battery once the battery temperature had decreased by ten degrees F.

In either of these cases where the battery is disconnected from the charger, the critical loads would continue to be supported by the battery through a diode. The system would sense battery discharge and close the contactor to protect the diode and to prevent the voltage drop resulting from the insertion of the diode between the battery and the load and the loss of support time the diode might cause.

System Block Diagram



String Float Current Measurement

In order to read float currents at very low levels we are using a temperature compensated Hall Effect sensor in a gapped toroid arrangement. The current sensor is mounted in the enclosure containing the charger disconnect circuitry. This allows for calibration to provide an accuracy of two percent of reading from 100 mA to 10 Amperes and the calibration will be compensated for the actual sensor spacing of the conductor through which the charging current passes. The two percent of reading is more than adequate for sensing the float currents when compared to set points of 4 to 40 times normal float current to bring in an alarm.

Summary

By measuring the voltage, battery temperature and float current for a VRLA battery string over long periods of time, the measured float current can be corrected to the nominal float voltage and string temperature to determine what the float current would be at 77 degrees F. This corrected current can be used to generate alarms and control action with little chance of generating false alarms. By disconnecting the battery under the most abusive conditions, the catastrophic thermal runaway can be averted and at the same time the load can be protected by whatever capacity remains in the battery.