TECH NOTE:
THERMAL RUNAWAY IN FLOODED LEAD CALCIUM BATTERIES

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What is thermal runaway?

In its most basic definition, thermal runaway is the internal generation of heat at a higher rate than a battery can dissipate. This heat can result in temperatures so high that the battery will be completely destroyed. The active material of the battery will be chemically damaged, thus necessitating replacement. Also, thermal runaway can result in melting of the plastic components of the battery, in releasing of undesired acidic and combustion gasses and possible heat, smoke and acid damage to adjacent equipment.

What triggers the beginning of thermal runaway in lead calcium batteries?

Heat generated by gassing during float or equalization charging can trigger thermal runaway in lead calcium batteries. All lead-acid batteries generate heat during normal operation. There is a small amount of joule heating simply from the currents flowing through the battery components. Also, lead-acid batteries are exothermic on charge, meaning the cell generates heat from the chemical recharge reactions. Under normal operating conditions, this generated heat is easily dissipated to the surroundings. However, after a battery is fully charged, the energy from the ongoing charge current breaks down the water in the electrolyte in a process known as electrolysis. The breaking down of the water into hydrogen and oxygen gasses is an endothermic process, which means that energy is required or absorbed during this reaction. However, if the oxygen migrates to the positive plate, it will immediately react and ultimately recombine back into water. This reaction is exothermic and will evolve heat. As with all normal chemical reactions, the resulting temperature rise will increase the rate of the reactions, thus causing the cell to accept an increased amount of charge current and that, in turn, causes more gassing and heat, thus precipitating the runaway condition.

Normal float voltage conditions will not trigger a runaway condition because the gassing is very minimal and does not cause any temperature rise within the cell. Gassing that starts resulting in more heat generation than the cell can dissipate occurs somewhere above a cell voltage of 2.33 volts when the ambient temperature is 77 degrees F. As the ambient temperature rises, gassing begins at a lower voltage. That is why it is important to maintain the battery room temperature at the manufacturer's recommended value. For VRLA cells, it is imperative that the chargers be temperature compensated. During equalization charging, it is also important to monitor temperature rises within the battery string.

How do thermal runaway conditions develop?

Thermal runaway conditions can develop because of variations in cell-to-cell voltages or user abuse. In an ideal world, with a fully balanced battery string, the charger voltage would divide equally across all the cells. However, all cells are not created equally and there is expected to be variations in their internal resistances. They will, therefore, not float at the same voltage. Some cells may be as low as 2.12 volts, and others may be as high as 2.45 volts. In this case, the low cells are slowly discharging and building sulfate crystals on the plates, and the high voltage cells are gassing excessively, with the potential for thermal runaway. Battery manufacturers provide a fairly wide cell voltage range that must be observed in order to avoid battery deterioration. Obviously, a full time monitor will alert the user of any potential problems well before any harm is done.

With respect to user abuse, some users float their batteries at too high a voltage or may forget to reduce the voltage after an equalize charge. Many users ignore cell voltage differences that develop without realizing that as one or more cells begin to drift out of the acceptable low level, other cells will be absorbing the voltage difference and will therefore be pushed out of the high end of the acceptable float range. Most manufacturers now recommend that strings of lead-calcium cells not be automatically equalized unless there is a problem with the cell voltages.

What causes cell voltage imbalances?

Typically, it is the difference in internal losses that causes cell voltage imbalances. The overall charger voltage controls the amount of current that flows through the string. Some cells require a higher amount of current than others to keep up the terminal voltage, and these cells will have a lower float voltage compared to the other cells. There are many reasons why cells will not float properly. The more important ones are discussed below.

Manufacturing problems - In their haste to deliver product, manufacturers do not always form the plates fully before shipping the product. Formation charging takes time, which equates to money, and sometimes this process is not finished properly. This is not considered a defect, as the cells will typically complete their formation during the first 6 months after installation. It is, however, difficult to predict how a cell will float before it is fully formed. Also, manufacturers do not traditionally match cells prior to shipping unless it is specified in the purchase contract. One can take a tip from the nuclear industry for this. Nuclear plants normally insist on a string that floats within 0.04 volts per cell at commissioning time, so they pay for and receive fully-formed batteries with matched cells.

Differences in the manufacturing process also result from the paste (active material) consistency not being properly controlled. Making a pasted plate is like baking a cake. The ingredients have to be consistently the same, as does the baking or curing process. It is important to note that most studies have shown initial float voltage variations to be caused by variations in the negative plate. Since the positive plate generally determines the capacity, manufacturers ague the cells will perform to specification and no action is necessary. There may be truth to this position, but it is the long term effects within an unbalanced string that will cause the problem for the end-user.

Another problem, which is not too common, are differences in specific gravity. If the acid content within the cells is not balanced within certain tolerances, the cells with the higher acid content will float low and the others will float high. This defect is easily measured and corrected in the field.

Temperature differences - Large installations may have more than 5 degrees F ambient temperature differences within the string. These differences develop from variations in the standing air temperature in multitier strings (three tiers or higher should be avoided) and also due to cooling fans blowing on one part of the string. This can also easily occur due to the solar load coming through a window, or from the heat of adjacent electronic equipment.

Shorted cells - As a normal part of aging, cells can develop an internal conduction path, or short, between two adjacent plates. Active material may have been trapped in the separator and, eventually, it may grow across to bridge the two plates. This causes the voltage of that cell to droop over time. One or more low floating cells will cause the voltage to increase across the other cells. These shorts can grow slowly over time, and this small, growing drop in voltage in the shorted cell can be easily overlooked if the cells' voltages are not continuously monitored.

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Cell replacement - As part of a normal maintenance program, replacing a few old cells with new cells within a string will cause imbalances, as the new cells will float differently. Also, the new cells may not be fully charged when installed. If the new cells float outside of the recommended voltage range or cause the older cells to float outside the range, the manufacturer should be contacted for specific instructions in balancing the string.

What can be done to help protect against thermal runaway?

There are a few things that can be done to help protect against thermal runaway. These are described below.

Commission properly - Make sure that a new battery is commissioned properly. Do not accept the battery unless all cells are floating within the manufacturer's published values. A lot of problems start with the commissioning of the battery. The battery may have been stored improperly for a long period of time (six month or more) and may require some special charging procedures. Also, in today’s busy world, the battery may have some built-in formation and/or acid adjustment problems.

If corrective action is required, have the manufacturer do the acid adjustment or polarization voltage adjustment, then observe these changes over the first few weeks to make sure that the voltages stay in line.

Installation - As part of commissioning, the physical installation should be checked. All cell-to-cell connections should be verified and their heat generation under load should be checked. Ambient temperature within the room should be checked, and the heat loads from adjacent equipment should be checked as well. Connections to and the voltage settings of the charger should be verified at this time, as well as the auto-equalize settings.

Control temperature - Control the ambient temperature. The ideal is 77 degrees F, and it should be maintained within less than 5 degrees F across the entire string.

Equalize correctly - Do not over equalize. Equalization is required following a medium to deep discharge and also if the string voltages drift apart over a long period of time. Equalization to balance cell voltages should not be necessary more than once a year or less.

Monitor regularly - Monitor all cell voltages and ambient temperature samples at regularly scheduled intervals. Ideally, a permanent monitoring system should be employed. A monitor can detect developing problems long before a critical situation develops. The user must, of course, pay attention to all alarms and perform the required corrective actions. It is particularly important to measure and record values during the installation and to look for trends over time. Changes in values over time, even though they may be within the manufacturer’s allowable ranges, may be cause for concern and may require action.

Summary

Ultimately, it becomes the user’s responsibility to understand battery problems, how they develop and how to prevent them. Albér has a formal two day Battery Basics Seminar that is taught all over the country, and some of the battery manufacturers have started some training at their facilities.

Prevention starts by specifying the correct battery for the application. Do not let the purchasing department specify; let them buy the lowest cost battery that meets the specs.

The next step in the cycle is to make sure the battery is properly installed. Consult the IEEE standards and make sure the installer is qualified to deal with batteries and is not just an electrical contractor. Also, make sure that the battery room has the proper cooling and ventilation systems.

Commissioning/acceptance testing - Batteries should be properly charged and capacity tested per IEEE standards. All cell voltages prior to the capacity test must be within the battery manufacturer's specified range; if not, make him take the proper corrective action. Do not accept the battery with float voltage problems.

Ongoing maintenance should follow IEEE recommended practices. Make sure that cell voltages, ambient temperature and internal cell resistances are monitored at least once a month. Ideally, these parameters would be monitored by a permanently connected monitor that notifies the user of any unusual conditions that develop.

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