Battery Management isn't Black and White

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Introduction

We live in a digital world where the idea of collecting data in order to facilitate reliability is now common place. As the importance of the battery in maintaining essential services is better understood, and mandatory maintenance standards such as those included in NERC PRC 005-2 are introduced. A great deal more battery data will now be collected and analyzed, and judgments made about the battery's condition. The question today is about how good that analysis is, and will the required remedial action be correctly identified in order to lessen the risk of battery failure during a discharge.

There are two ways in which this data is typically evaluated. Either using predefined limits against which each parameter is compared, or trend analysis where the rate of change is of greater interest. Both methods are used as they can easily be implemented in software. The challenge is in the interpretation.

The problem we face is that these battery parameters are not values that can be analyzed in isolation. A battery system is actually a collection of linked electrochemical analog circuits and the interaction between them can be both predictable and unpredictable.

Measured Parameters

To really understand the challenges in interpreting this data we need to look at the battery parameters that can be measured on both VLA and VRLA batteries. These parameters fall into four categories, Voltage, Current, Temperature, and Ohmic Value. Then within each of these categories there are further subsets that can be measured, dependent on the battery configuration.

- Voltage can be measured at the system, string, and unit level
- Current at the system, and string level
- Temperature either as pilot temperatures, or at each individual unit, plus the room ambient
- Ohmic values are either measured at the cell or unit level.

The value of each of these parameters is also dependent on the status of the battery, whether it is in Float, Discharge or Recharge, at the time the data is collected.

Then there is the interaction between the individual parameters:

- System Voltage affects Unit Voltages, Float Current, and Unit Temperatures
- Current affects the unit temperatures
- Temperature can affect all the measured parameters including the Ohmic value of a Cell/Unit

While the relationships between Voltage, Current, and Temperature and their impact on each other are relatively predictable, the effect of a change in the Ohmic value of a Cell / Unit is less clearly defined. This especially true when trying to establish a defined limit value above or below which a Cell/Unit should be replaced.

One Year in a Battery's Life

To demonstrate the challenges in interpreting the data, let us look at a battery system which was installed sometime during 2001. The application was a UPS installation in New York City with two strings of 12V VRLA units, installed in cabinets with no generator backup. The battery had an impedance based battery monitor installed in early 2002, and the data was collected and analyzed by the monitor manufacturer, on behalf of the customer. The battery was also included within the UPS maintenance contract, and the UPS service organization were responsible for any battery unit change outs required.

After the installation, a number of the battery units had to be replaced before the system stabilized around June 2002. After that over the next year, a further 3 units were replaced. At the beginning of July 2003, there were ten units that had increased in impedance by 30% above the initial impedances, and one that was just under the threshold. These initial impedances were recorded when the monitoring system was commissioned.

The 30% limit used was based on a graph from a document published by C&D[1] in 1999 that depicts the manner in which a cell and battery impedance, conductance and capacity may vary with age. Figure 1 shows the impedance values of both strings on the 7th of July.

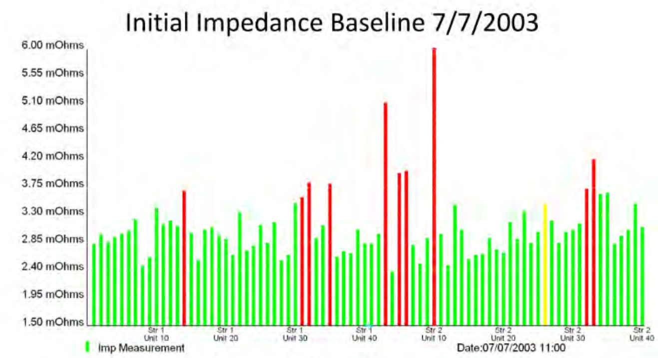

Figure 1

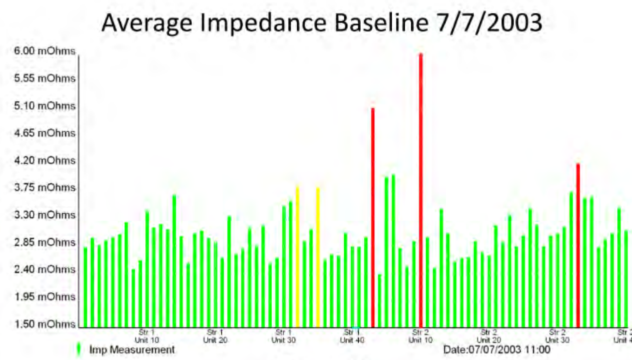

Figure 2

This information was forwarded to the UPS service company, and they checked the battery using their handheld battery tester. Based on that data, they decided that only three units actually required to be replaced. The question then is, why the difference, the answer is very simple and is demonstrated in Figure 2. Using the same data as shown in Figure 1, but simply changing one analysis parameter.

The analysis parameter that was changed, was to use the value of the current average impedance of the string as the baseline on which the 30% rise was based. Not the initial impedance values recorded for each cell at commissioning. Averaging the Ohmic values of a string, and using that value as the baseline for the analysis is quite common when handheld testers are used. This is because there may not have been any initial values collected, or they are not available to the technicians as the basis for analysis. One of the problems with using average as the baseline, is that it includes all the units in the string. Including those with the high readings, so after these units are changed, the average will be lower and may bring additional units into the alarm zone. This is shown in Figure 3, where using the new average value two new units now show as critical.

Figure 4 shows the impedance values on the 11th of August, with the alarm limits based on the initial impedances, and after the three units identified by the service company had been replaced. Five units are shown to be above the threshold, and three just below. But on the previous week's reading on the 4th of August, all eight units were shown in critical condition. This can be probably attributed to the fact that there was a 6° C change in the ambient temperature between the 4th and the 11th, and temperature affects Ohmic values.

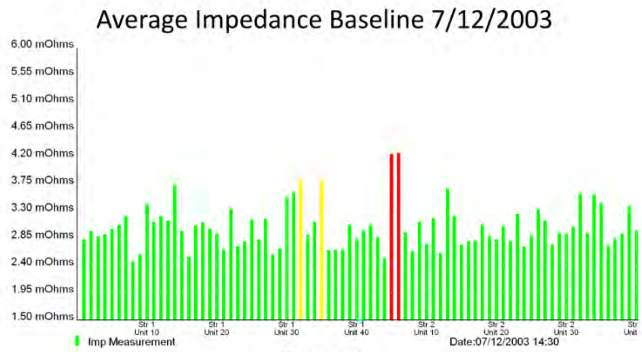

Figure 3

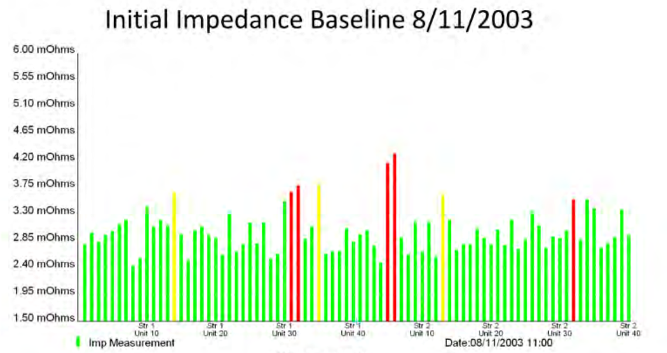

Figure 4

On the 14th of August, an event now known as the North East Blackout occurred, and the battery was discharged until it reached the UPS low voltage disconnect. The battery supported the average load of 55.6Kw for a period of 35 minutes which was far shorter than the 90+ minutes it should have achieved, at that load. So let's look at Figure 5, which shows the final unit voltages just before the UPS disconnected. Fifteen of the eighty units had fallen below 1.65 Volts per cell, seven more than the eight units previously identified. Figure 6 shows the correlation between the impedance values for each of the fifteen units, and their actual run time

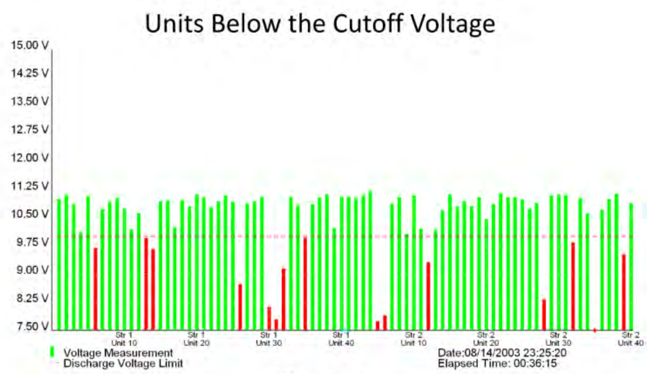

Figure 5

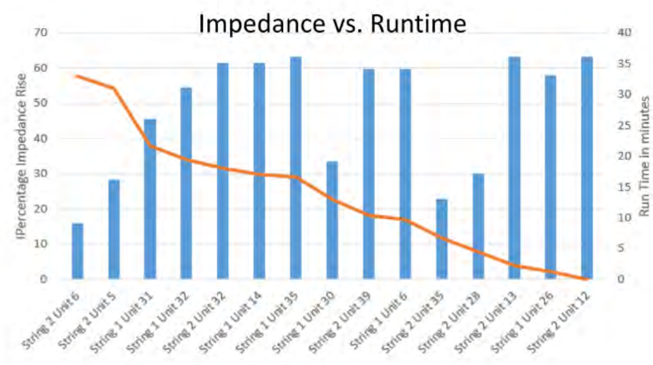

Figure 6

While the graph in Figure 6 demonstrates that there is reasonable correlation between the capacity of the individual units and their impedance rise, where that rise is at least above the 30% limit level. There are four units that have run times shorter than would have been expected, based on their rise in impedance, String 1 Units 26 and 30 and String 2 Units 28 and 35. Let's look at each of the units with respect to their discharge and impedance records, to see what can be discovered.

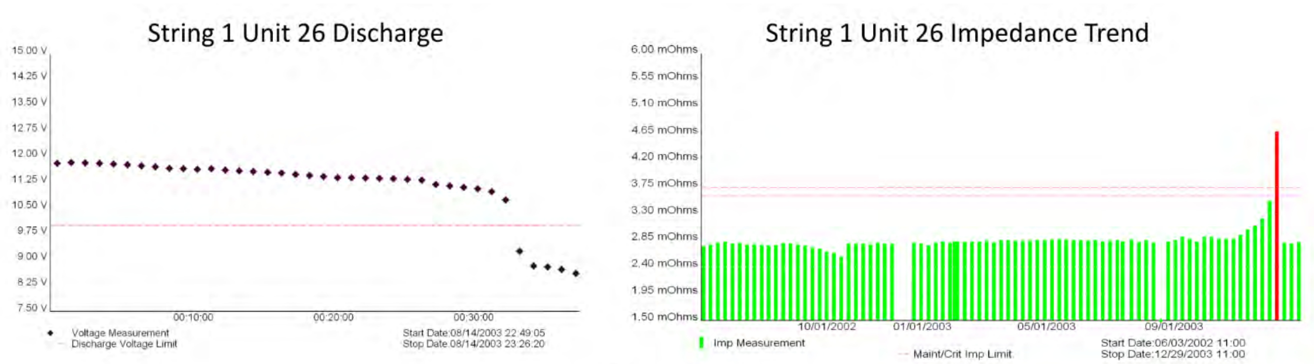

Figure 7

In Figure 7, Unit 26 followed the average discharge curve until almost the end of the discharge, at which time the voltage dropped off rapidly. As this is a six cell unit, the level of the voltage drop would indicate that one of the cells had failed possibly due to the failure of the pressure valve, and the resultant dry out, as that was a typical problem in that timescale. The problem is the rise in impedance of that one cell, if it had dried out, was not sufficient to raise the impedance value into the alarm region. That is confirmed by the impedance trend that showed very little change over the previous fourteen months, but it should be noted that following the discharge, the impedance did start to rise after a number of weeks and entered alarm territory just before the battery was replaced.

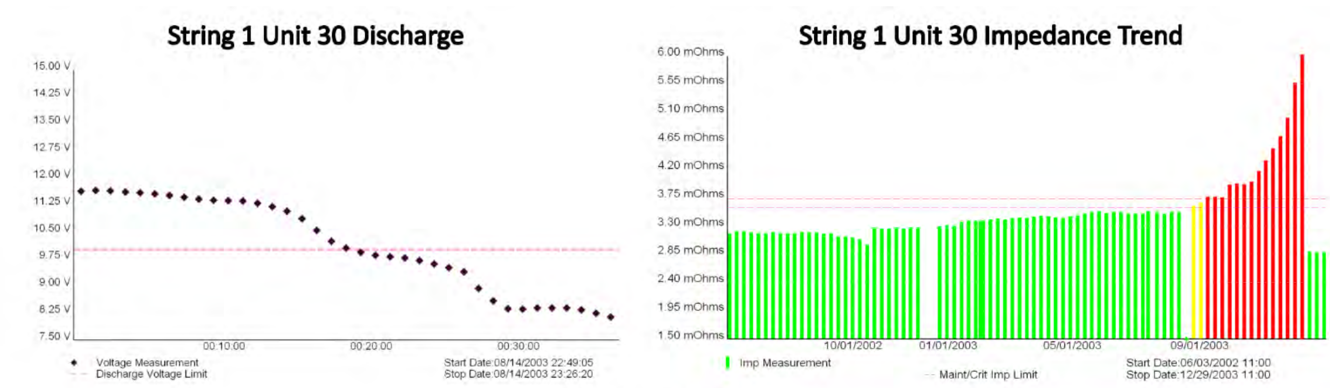

Figure 8

In Figure 8, Unit 30 also followed the average discharge curve for approximately 12 minutes before starting to drop into alarm territory. The rate of decline then slowed for a short period before dropping again. This is also typical of a battery which has lost capacity. In this case, based on the step pattern of the discharge more than one cell was failing and the impedance trend graph shows that the impedance had been rising steadily and that rate of rise increased rapidly after the discharge.

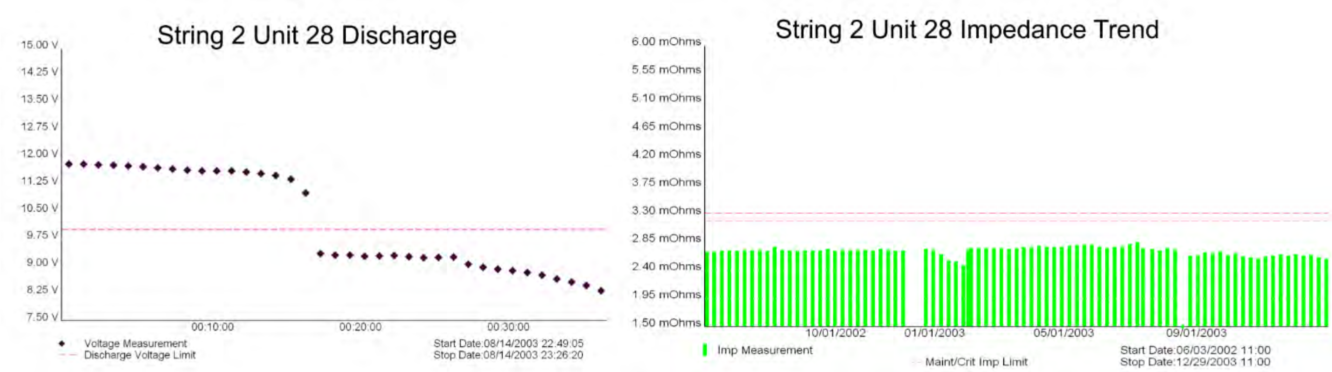

Figure 9

In Figure 9 with Unit 28, the voltage again drops rapidly part of the way through the discharge, again indicating the loss of a cell, but then stabilizes for a period before continuing a slow decline. The impedance trend graph is very stable, and remains so after the discharge. So while the unit clearly has a problem with one of the cells, the reason for the loss does not appear to accelerate the failure process in the other cells as in the previous two examples.

In Figure 10, the unit voltage continued the pattern of the previous two units, dropping into the alarm zone part of the way through the discharge. But this time it fell much further than in any of the other units, indicating multiple cell failures. The impedance had also been rising in the months previous, but had dropped again five weeks before the discharge, but then rose rapidly following the discharge requiring the unit to be replaced just five weeks after the discharge. This would tend to indicate there was some additional problems with that unit, and the failure mode was not just loss of capacity.

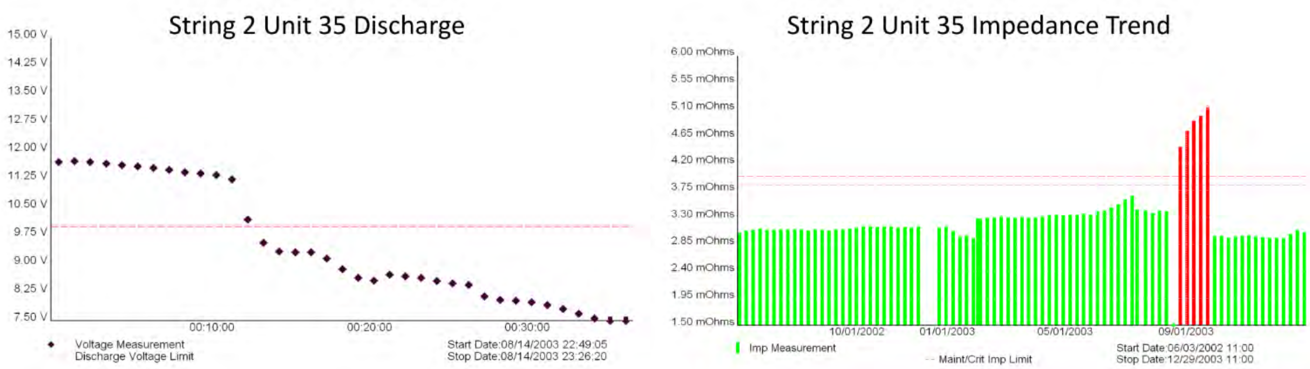

Figure 10

These four units demonstrate one of the challenges when using limit analysis based on the Ohmic value of a multi cell unit. If only one or two of the cells within the unit have risen above the 30% threshold, that rise will be masked by the other cells within the unit. That appears to be the case with the four examples above, that initial drop in voltage ranged from 1.31volts to 2.17volts, indicating different degrees of failure at the cell level within the unit, rather than an overall loss of capacity, as was the case in the other units that failed.

This clearly was a battery with problems, and six of the battery units that had failed during the discharge were replaced in September. By the end of the year as shown in Figure 11, there were 11 units that were above the 30% threshold, and a further five approaching the 30% mark, so the battery was replaced in the beginning of December.

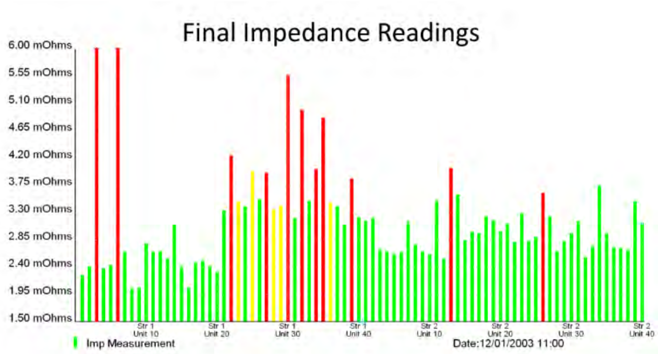

Figure 11

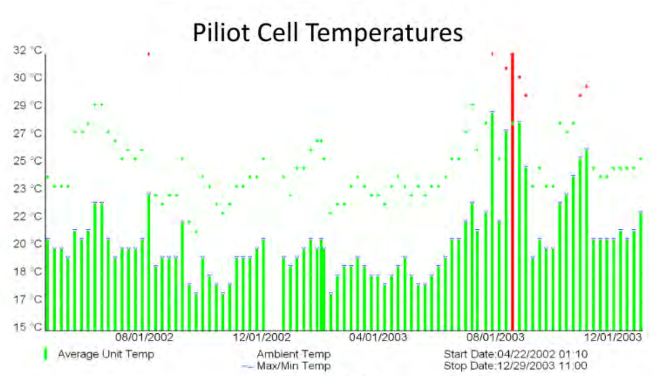

Figure 12

When a battery deteriorates at the rate this one did after a discharge, it is always worth looking further to see if there is an underlying factor that could have impacted battery life. The most obvious ones are the number of discharges, and the operating temperature. In this case other than the example shown here, there were no real discharges, but Figure 12 does show that the temperature was subject to fluctuations from as low as 17° C and up to 32° C. This could definitely have had an impact by increasing the corrosion rate and possible dry out.

What this example shows, is the importance of inspecting the battery after any reasonable discharge. While a discharge test will validate a battery's capability at that point in time, there is the potential particularly with VRLA batteries, that the discharge will actually accelerate the failure mechanisms.

The Value of String Current

Based on the preceding example, it is very clear that the more data you have particularly at the cell/unit level, the easier it is to identify potential problems. The one parameter that wasn't used in any of the previous analysis was current, and this was because on that particular configuration only system current was measured. So it was of no value in determining the response of the individual strings. When the current in the individual strings is measured, then a clear indication of the performance of the individual strings can be obtained. In the example that follows, the UPS was originally set up to automatically carry out a short duration discharge test on a scheduled basis. Figure 13 shows that during the first discharge, after the battery was installed, on the fourteenth of February there was a 5.1 amps difference between the discharge current in each string, with String 1 lower than String 2. Visually the impedances of String 1 appeared a little higher than String 2, but there were no units that stood out as being a possible reason for the variance in the discharge current.

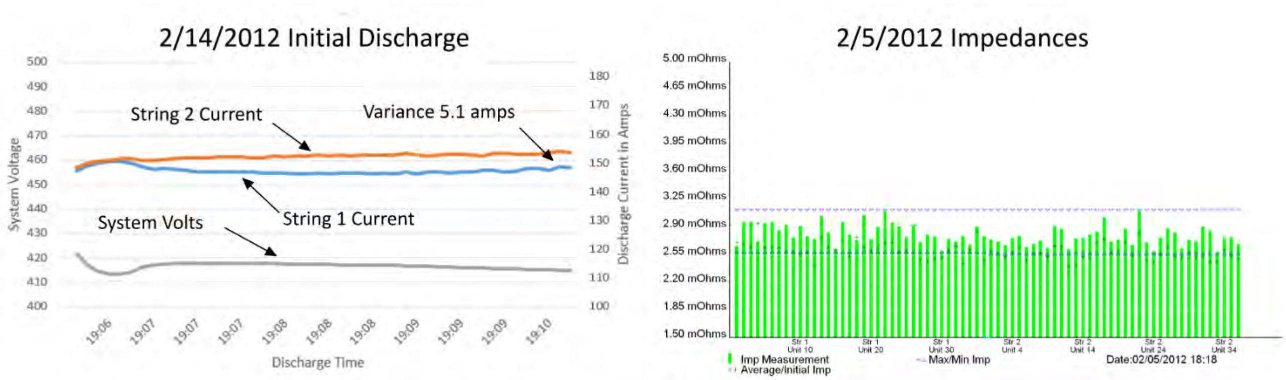

Figure 13

At the discharge on the 10th of November 2012, the variance between the two strings as shown in Figure 14 had increased to 36.4 amps, and the impedances had clearly started to rise, but as the graph shows they were still below the preset alarm limits of 30%.

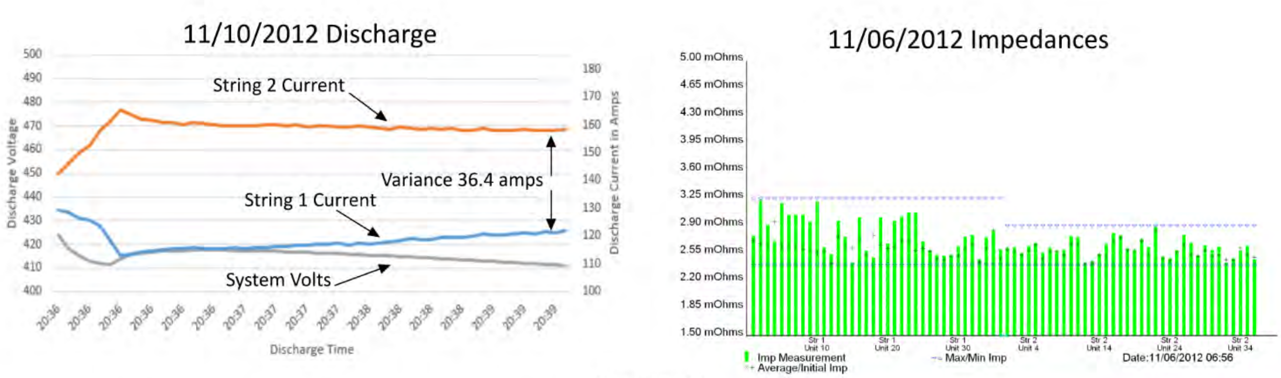

Figure 14

For reasons unknown, the automatic discharge test was turned off for a period, and the next recorded test was on the 2nd of August 2013. At this point the variance between strings was now 55.1 amps, and there were 7 units all in String 1 that were indicating above the 30% rise alarm point as shown in Figure 15

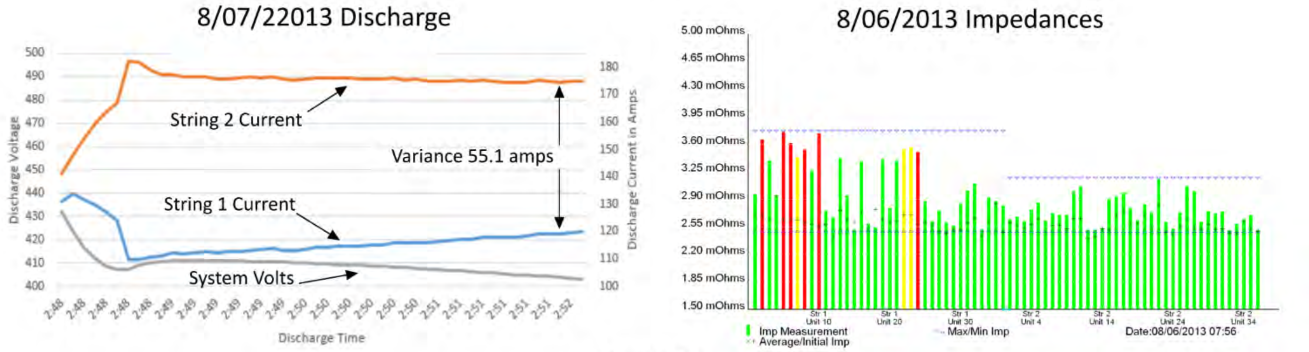

Figure 15

On the 25th of October 2013 the six units that were over the 30% limit were changed, and the automatic discharge test was again turned off. On the 27th of April 2014 a further nine units were changed for exceeding the 30% threshold, and the only other measurable discharge subsequent to that, is a 5 second discharge on the 11th of July 2014. The data for that discharge is shown in Figure 16.

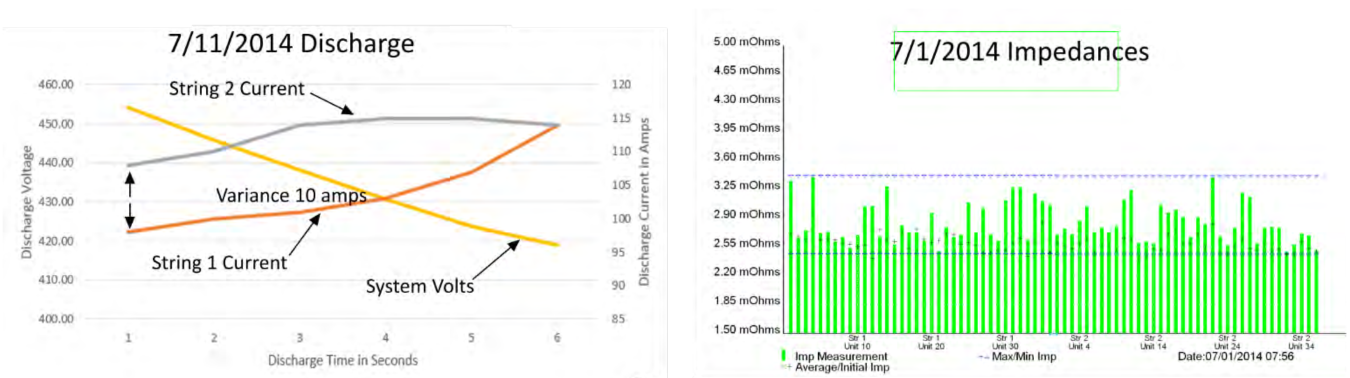

Figure 16

Although all the impedances are once again below the 30% threshold, and the string currents appear to balance at the five second mark. There is still a ten amp difference when the discharge is initiated, indicating that there is something inhibiting String 1. Since that time, a further six units have been changed out: four in String 1 and two in String 2 for a total of nineteen in String 1, and two from String 2.

It’s Murphy’s Law

When making a judgment about the viability of a battery, it is always good to remember Murphy’s Law, “If anything can go wrong it will”.

Our next example is a perfect example of this. Here we have another two string UPS battery installed in October of 2008, and monitored on a continuous basis. The first unit to exceed the 30% critical limit was in April 2010 in String 2, and during the following year a further ten units exceeded the 30% limit. Four in String 1 and six in String 2. The UPS company service group were advised in April 2011 that a number of batteries required replacement. So they did their own assessment, and reported that they found no units that exceeded their specifications, (a 50% increase in impedance over the average baseline).

The impedance plots for April 2011 are shown in Figure 17

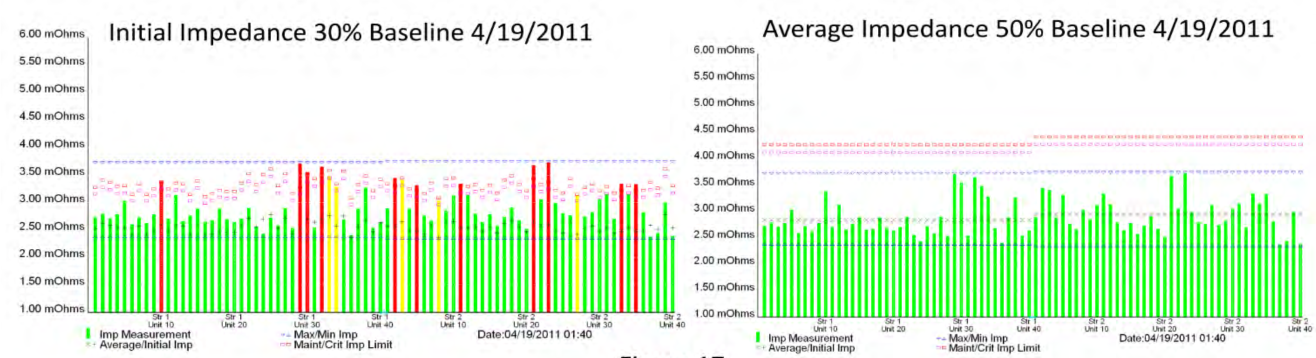

Figure 17

The number of units over the 30% threshold continued to increase, and on the 17th of April 2012 there were six units in String 1, and seventeen units in String 2 as shown in Figure 18. The UPS company service group were again notified, and when they checked they found one unit that exceeded their specification, but advised the customer that it didn't present a risk to the system, so it could be replaced at a later date.

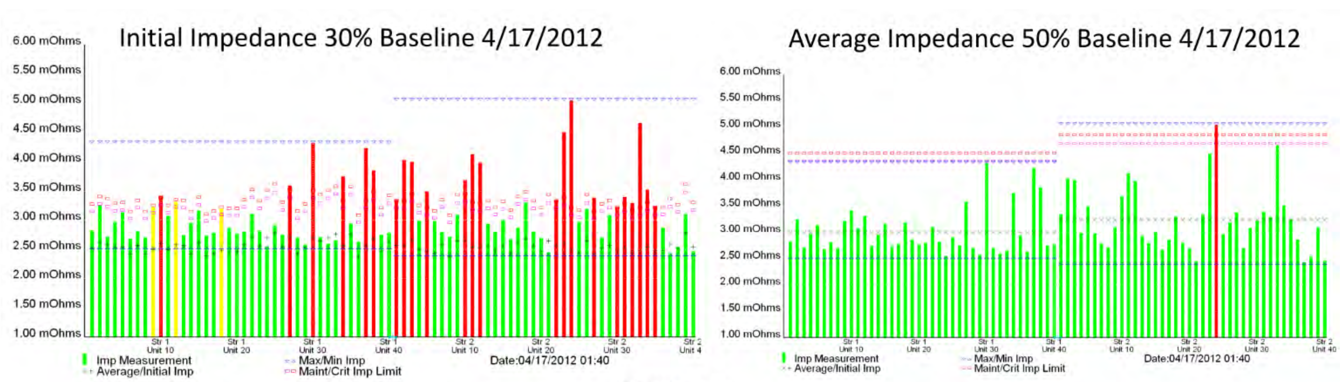

Figure 18

By July of that year the impedances had continued to rise, and the UPS company service group again checked the battery. They now found four units as shown in Figure 19 that they considered required replacement, and this was done.

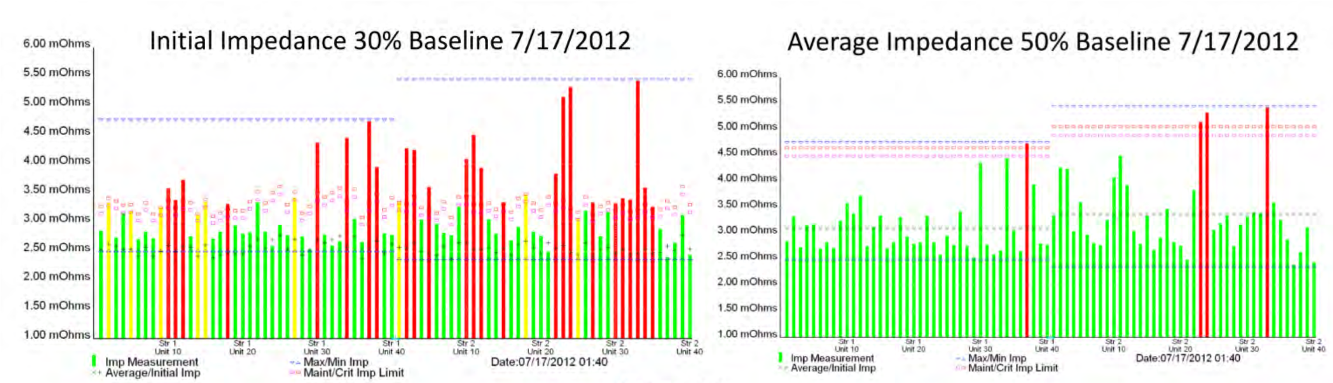

Figure 19

At the customer's request, a discharge test was carried out on the 19th of July, and as can be seen in Figure 20 the results were catastrophic. At approximately 30 seconds into the discharge the current in String 1 dropped to zero, and String 2 assumed all the load. After a further 39 seconds the load dropped completely.

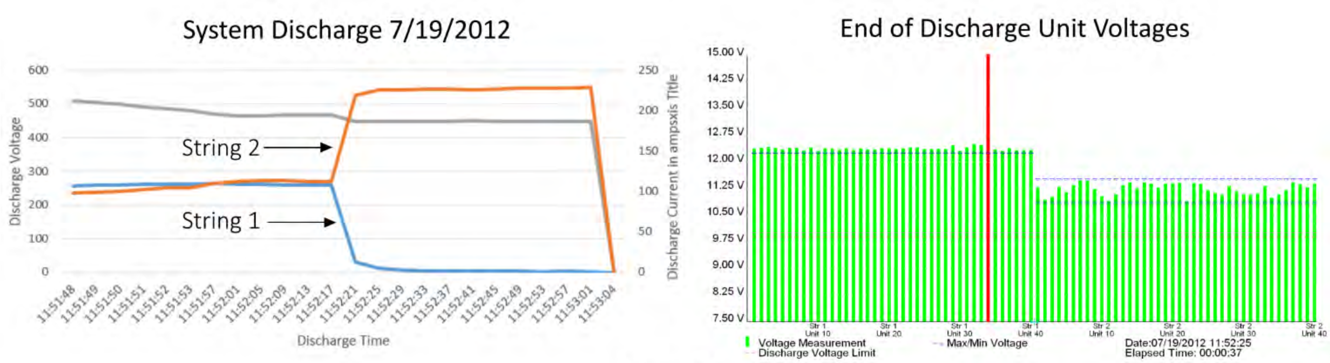

Figure 20

So what happened? As noted earlier String 2 had the most units over the 30% limit, so it would have been reasonable to believe that any early failure would occur in that string. But as I indicated at the start of this example, "Murphy Rules" and indeed he did. It was unit 34 in String 1 that went open circuit, which was a unit that had never been identified as a potential failure. By the manner in which the Voltage and Current in String 2 also dropped rapidly, it is reasonable to assume that a unit in that string also went open circuit. But as this would also have removed power from the battery monitor before the next scan occurred, the actual unit in String 2 that failed cannot be identified.

Summary

Based on the three examples in this paper, it is very clear there is no simple good or bad determination possible, when evaluating the condition of a Lead Acid Battery. While limit based alarms can be used to warn the user about a change to a measured battery parameter, the context in which that change has occurred is often of greater worth than the actual value of the parameter. The 30% rise over baseline used in this paper as the basis for the ohmic value analysis is based on an early version of the C&D technical bulletin[1] 41-7271, published in 1999 that discussed Impedance and Conductance Testing. In that document there was a graph that showed that a 30% rise in impedance and recommended that any unit that exceeded 25% of its original impedance value should be evaluated further. In the latest version of that document published in 2012, although the graph still shows the 30% rise relating to a 20% loss of capacity, the text now states 50% as the value at which further evaluation is required. This was obviously the basis for the UPS service group's analysis in the last example. As the title of the paper says Battery Management isn't Black and White it's actually a lot closer to "Fifty Shades of Grey" just not as sexy.

1. C&D Technical Bulletin 41-7271 8/99