PBT
PHOENIX BROADBAND TECHNOLOGIES

Remote Battery Monitoring: Advanced Failure Prediction through Trend Analysis

There are substantial advantages that consistent and continuous monitoring provide over manual battery maintenance techniques. This paper will describe how trending data can be used to paint a far more complete picture of the battery's present and historical performance. In addition, the paper shows how trend data is used to predict events such as thermal runaway or battery end of life failures with months of advance notice to allow scheduled corrective actions.

Predicting Thermal Runaway

Manual maintenance only gives an operator a snapshot in time, which lacks any historical context. It's like a trip log that only shows where you are, not where you've been or where you're headed. On the other hand, consistent, continuous and stored measurements can be analyzed to show trends, informing the operator not only where things are, but also where they've been and when they'll become problematic.

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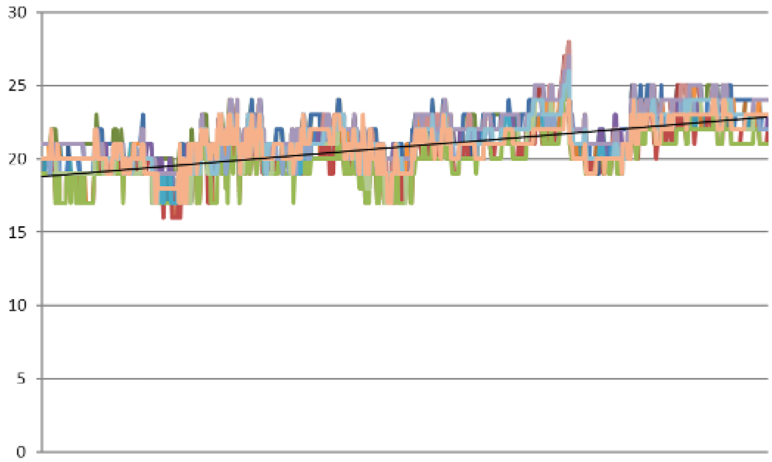
For instance, thermal runaway is a slow, regenerative condition that can be defined as a battery generating more heat than it can dissipate. It starts off as a slow rise in float charging current and eventually results in rapid battery heating, resulting in battery damage and possibly building damage and personal injury if not corrected in time. Although single spot measurements usually miss this, long term trending and correlation of involved parameters, like temperature and float charging current, can identify this issue months in advance.

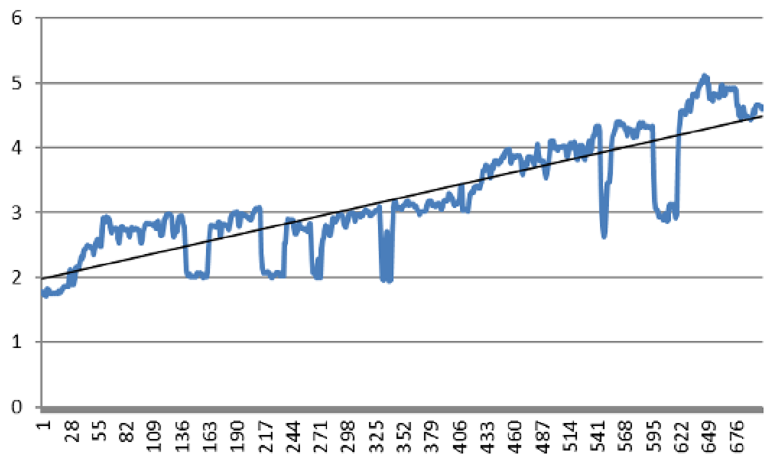
As a real-world example, the graph in **Figure 1** shows jar temperatures over time. Strangely enough, though the battery is barely above 25ºC (77ºF), this is a thermal runaway in progress. Thermal runaway is typically a slow process that takes months to become a crisis. Near the end of this process, battery temperatures will rise quickly over a short period of time.

FIGURE 1: Jar Temperatures Over Time



Because this operator employed a monitoring system that makes consistent, continuous measurement, thermal runaway was identified, and the operator had several months' notice to schedule a correction, instead of reacting to a crisis.

FIGURE 2: Float Current Over Time



The horizontal axis is time, displaying well over a year and a half of data. The vertical axis is temperature in Celsius. During this entire time, ambient temperature showed almost no change. While we are seeing a thermal runaway in progress, the individual jar temperatures have not yet increased to a point that would cause alarm using manual maintenance techniques.

The thermal runaway event becomes clearer as we view the float current chart in **Figure 2.** This chart shows the float current on the same string as the chart of battery temperatures in Figure 1. The horizontal axis is time in one day increments, and the vertical axis is float current in amps. It's interesting to see considerable dips in the float current occasionally, though the trend is clearly increasing.

We don't fully understand what the dips mean, but out-gassing is one theory. Depending on when the technician performing manual maintenance made a float current measurement (IF they made such a measurement), they might have caught the significant long-term increase. As we can see from Figure 2, there are days when the float current increases and days where it dips by an amp or more. However, because this operator employed a monitoring system that makes consistent, continuous measurement, thermal runaway was identified, and the operator had several months' notice to schedule a correction, instead of reacting to a crisis.

FIGURE 3: **String Voltage During Discharge**

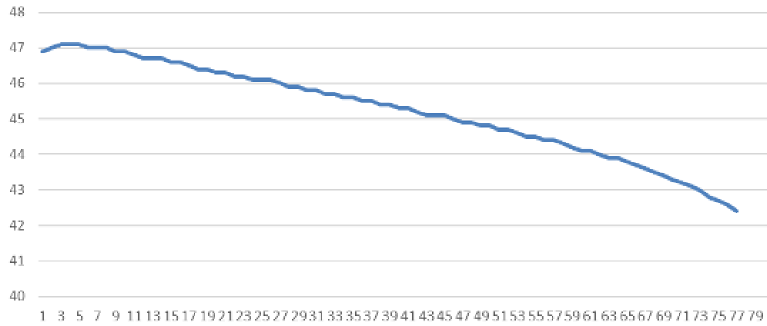


FIGURE 4: **Battery Temperatures During Discharge**

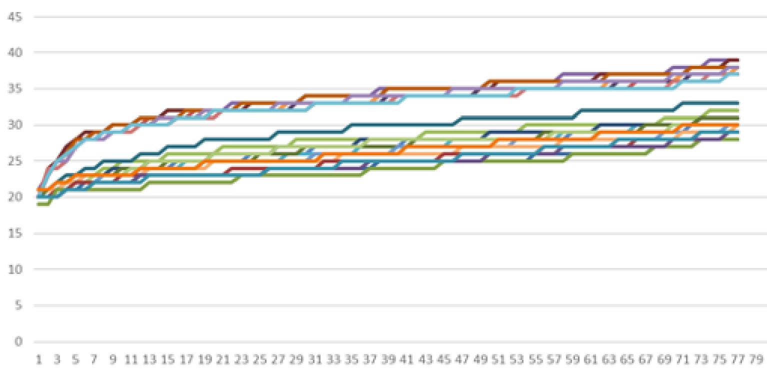
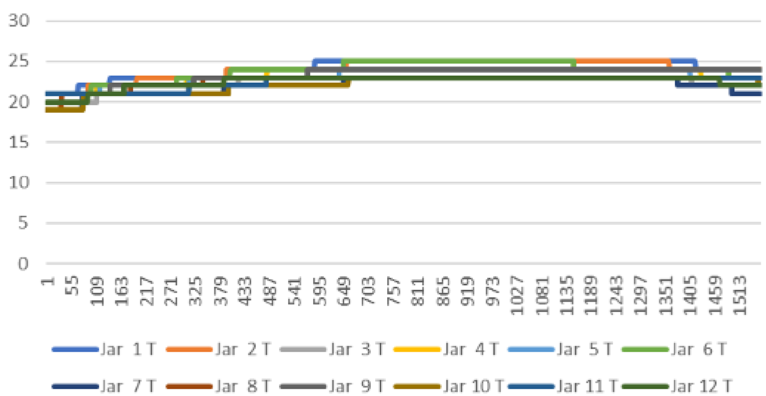


FIGURE 5: **Normal Jar Temperatures During Discharge**



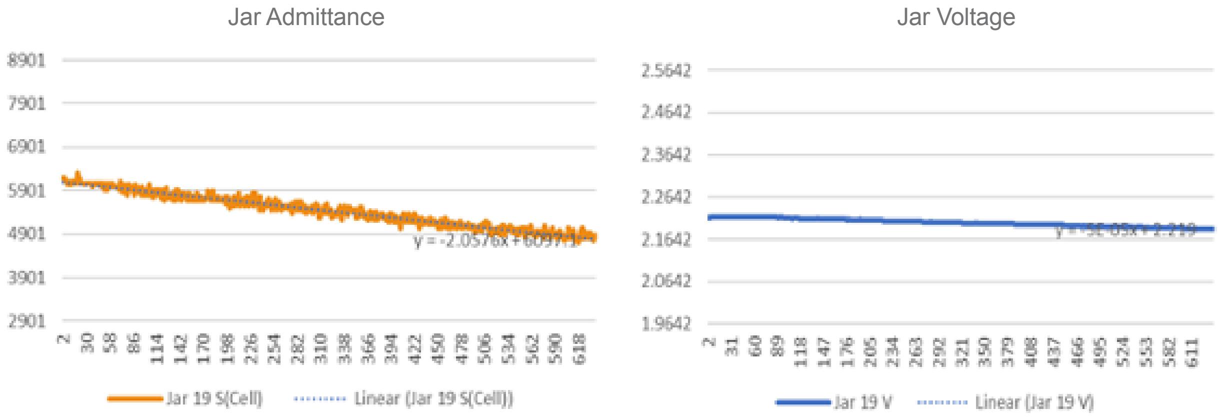
An added advantage of remote monitoring systems is that when there is a discharge, the battery's performance during the discharge is captured. Seeing this data can provide visibility into the health of the battery. **Figure 3** shows a string in discharge. At the start of this discharge, the string voltage is significantly lower than expected (47 VDC as opposed to 50 VDC). This graph starts just after the coup de fouet event. This lower than expected string voltage indicates a weak battery. Five jars had gone below cut-off voltage by the end of discharge, which did not meet its run time expectation.

The graph in **Figure 4** shows individual cell temperatures in degrees Celsius for a string of 2-volt cells during the discharge. At close to 40ºC (104ºF), this battery is heating more than expected during this discharge. This is another indication of a weakening battery.

These typical temperatures depicted in Figure 4 for 2-volt cells during discharge show the battery heating by 5 degrees C or so. For this battery, load and ambient temperature, the temperature rise in **Figure 5** is more typical of what we see.

As another example, manual maintenance techniques were performed on the cell in **Figure 6**. It was deemed satisfactory and rightfully so, based on the information that could be obtained via manual techniques. However, by looking at roughly two years of trend data, we clearly see a

FIGURE 6: Jar Admittance, Jar Voltage Over Time

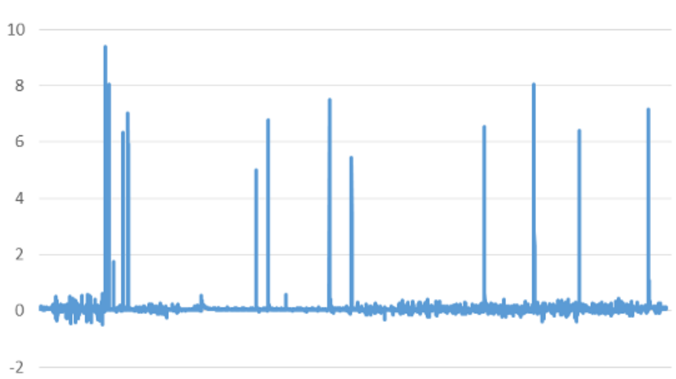


By looking at trends, we know that if this cell continues the trend on its present course, it will fail before the next twelve months have elapsed.

cell in decline. For close to two years, the cell's voltage has been below 2.2 volts (even after attempts to equalize) and its admittance (inverse of impedance and internal resistance) declined by more than 20% in just these two years.

The rate of decline is greater than expected and far greater than any other cell in the string. This cell admittance wasn't low enough for the manual maintenance crew to call the cell out. However, by looking at trends, we know that if this cell continues the trend on its present course, it will fail before the next twelve months have elapsed.

FIGURE 7: Float Current Spikes After Discharge



Discharge

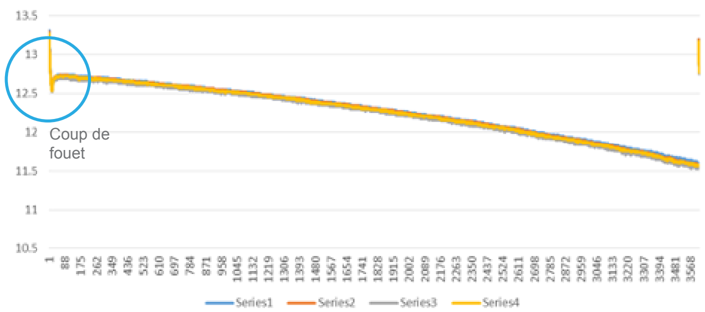
Often overlooked in the effort to analyze logged parameters traditionally examined (such as ohmic measurements and float current) is discharge data. Recording the number of discharge events over a given period of time, the duration of the event and the battery's performance during the discharge provide valuable information about the battery.

Batteries are designed for a certain number of cycles. A cycle is a discharge and recharge event. Simply understanding how many cycles have occurred since installation gives the operator an indication of where the battery is in its life cycle.

The chart in **Figure 7** shows a number of float current spikes over a short period of time. The logged float/charge current spikes follow discharge events. The discharge log files associated with this chart confirm discharge events, and the float current spikes reflect the recharge after the event. In this instance, there were 15 discharges in several weeks, which was abnormal and led to an investigation and resolution of the problem.

The chart in **Figure 8** displays the performance of four 12-volt jars, configured as a 48-volt battery, during a roughly ten-hour discharge. You can see the coup de fouet event at the beginning of the discharge, including the rebound in voltage (sampled every 10 seconds).

FIGURE 8: Jar Voltages During Discharge



When the monitoring system measures or has information about the load, it combines that with other measurements, such as temperature, voltages and duration of the discharge, to obtain a strong indication of the state of battery health. During the entire discharge, all four jars remained very close in terms of jar voltage measurements, and only near the very end does the group begin to spread apart in voltage (weak jar indication). In this case, the discharge revealed that this battery is very close to 100% capacity.

The Moral of the Story

Spot measurements often lack a historical context that might allow an operator to predict where things are headed. On the other hand, continuous and consistent logging of multiple indicators provides a data set that allows a clear indication of degradations.

Phoenix Broadband Technologies is developing algorithms that correlate thousands of measurements on multiple battery parameters to provide concise decision-making information, allowing operators to proactively schedule their maintenance assets. We're using these algorithms in the automated data analysis service we provide to our larger customers, saving them hundreds of thousands of dollars per year by reducing their maintenance costs and avoiding costly down time.

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