MEASURING VLA/VRLA DC FLOAT CURRENT IN A SEMI-DETERMINATE ENVIRONMENT

Bob Shaw
President
Ohio Semitronics, Inc.
Hilliard, OH

Lew Miller
VP, Engineering
Ohio Semitronics, Inc.
Hilliard, Ohio

Abstract
Battery Monitoring Systems use an array of techniques to evaluate system and cell health; however, all are dependent on the accuracy of the electrical, thermal and mechanical sensors employed. This is particularly true when measuring DC parameters across a wide dynamic range. This discussion examines the measurement uncertainty impact on battery health assessment, with special emphasis on the impact of residual and temperature effects, and provides a visual tool to evaluate and understand actual performance under those conditions.

Introduction
Some stationary Battery Monitoring Systems measure the charge and discharge currents and strive to optimize and predict VLA/VRLA cell life. These systems may also measure the float current between the two large flow states.

Peter DeMar was one of the proponents of thermal runaway detection[1] and identified two early warning signs of thermal runaway:

1. An increase in float current in normal operation not caused by a recent discharge, or rectifier/charger adjustment issue.
2. An increase in cell temperatures over the normal ambient.

Temperature measurement is not our forté; however, we recently received the following question:

"Are these low float current measurements sufficiently accurate and repeatable to fully impact operational economics and safety?"

The general answer is, "Maybe not."

Defining the Issue
The referenced paper identified accuracy and resolution as issues and stipulated repeatable measurements in the 0.25 to 0.5-Amp per 1000Ah DC range would be required. Which sounds straightforward – until we examine the dynamics.

Please note: We will use a 600-Amp DC bank as the example throughout the discussion; however, smaller sized banks will require commensurately smaller repeatable measurements. If, for example, we sized the bank for 100-Amps, repeatable measurements of 0.083 to 0.166-Amps would be required.

If the discharge current is 600-Amps, but we must measure ~ 2.5-Amps with repeatable precision, then we are specifying a <u>240:1 dynamic range</u>. This is achievable with lab instrumentation, but it hardly seems appropriate (or economical) for what are generally unattended installations. The issues of accuracy and resolution at these low levels remain.

Figure 1 shows the error or uncertainty as a percentage of the measured current value. The notations are associated with a common configuration, discharging a peak current of 600-Amps, charging at 200-Amps and maintaining a float current below 5-Amps. This reflects a device accuracy of 0.5% of Full Scale.

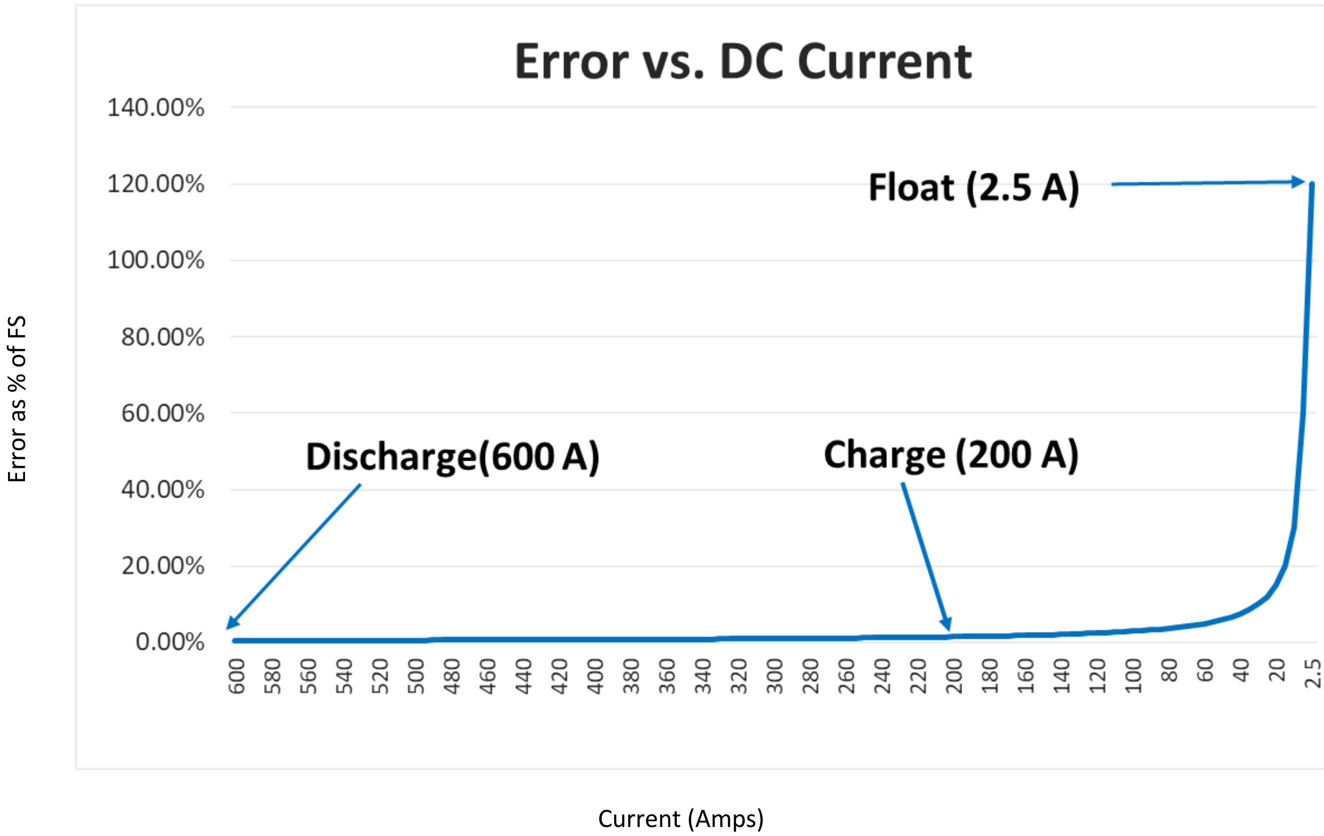

Figure 1. Error at Key Current Levels

The uncertainty is acceptable for discharge and charge currents, but approaches 100% at the 2.5-Amp point. Unfortunately, DeMar proposes the system should resolve changes of 0.5-Amps or less.

What can we do about accurately monitoring float current to the required level?

First, we'll need common terminology to discuss measurement uncertainty. A full list of the defined terms and errors is included in a pullout appendix at the end of this paper, but we will limit our discussion here to only a few critical parameters impacting this measurement. These are Accuracy, Precision, Residual and Temperature.

The Basics

Let's begin with Accuracy and Precision.

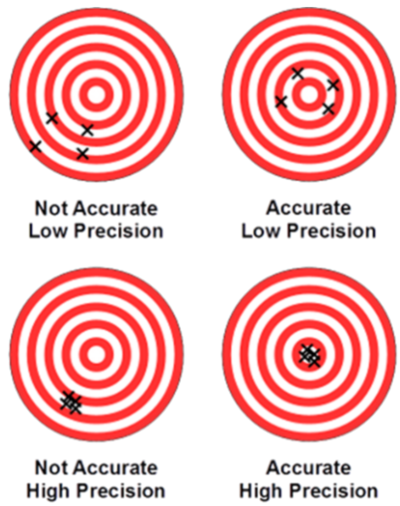

Figure 2. Accuracy and Precision

Figure 2 offers a visual distinction between the two terms and illustrates the four general cases encountered in measurement. The importance of each varies with the measured parameter. Most monitoring systems look for changes in the overall level of float current, so Precision (or repeatability) gets the nod here over Accuracy.

If, however, you are using the measurement for billing or load allocation, then Accuracy becomes more important.

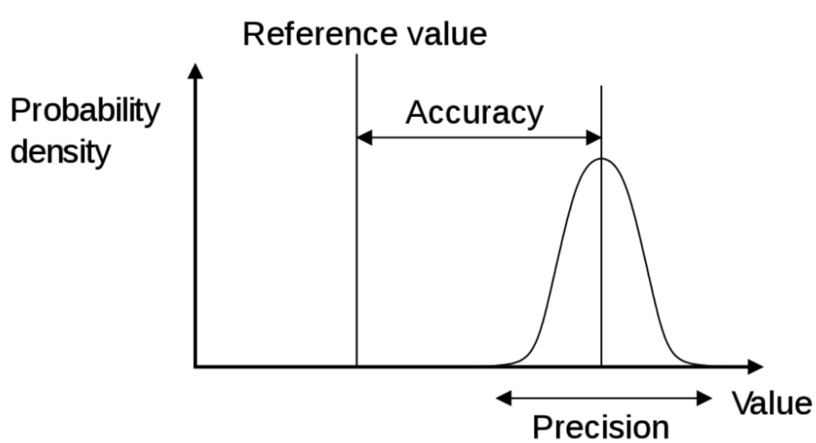

Figure 3. Accuracy and Precision as Statistical Expressions

Figure 3 translates these parameters into statistical terms. We consider Accuracy as the mean distance to the actual or standard value, while Precision is the standard deviation of the measurements. It is also our measurement of repeatability.

Need for a different approach

These two parameters are commonly combined and expressed as a percentage of Full Scale. In our example, a 600-Amp full scale device has a base accuracy of ± 0.5% at 600-Amps, meaning the actual value will be found within ± 3-Amps.

We must account for the same ± 3-Amps when trying to measure a 5-Amp current (see Figure 1),which gives rise to the > 100% error at float level. This clearly demonstrates the need for a different approach to mitigating this large error.

One approach is to incorporate an additional sensor sized for the float current, rated for a nominal 5-Amp DC current. There are multiple devices available with these ratings; however, the device must also withstand an overload of up to 120 X rated, and surges of such magnitude can introduce a more insidious error.

Impact of Residual Magnetism

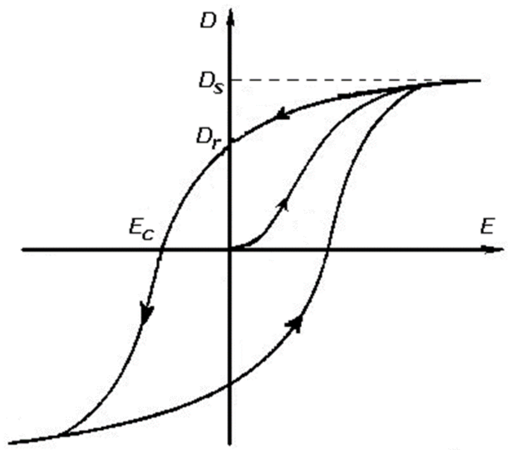

Figure 4. Hysteresis in Measurement

Engineers may recognize Figure 4 as a magnetic-core hysteresis curve and it can help us understand the residual magnetism phenomena. While there are numerous details to slog through (including Maxwell's 4 Equations), the simplified explanation is, when the magnetic field is removed from the core, some of the magnetic domains retain a degree of orientation relative to the magnetic field was applied to the core. We know this phenomenon as residual magnetism.

The phenomenon is generally not a factor in AC measurement, where the continuous reversal of AC currents tends to minimize the effect; however, large DC currents can create a "set" within the device's magnetic core, which appears as a semi-fixed offset in the current measurement. The magnitude of the offset varies with the size of the surge, the residual present before the surge, and other factors.

In other words, the offset is difficult to predict with any confidence, which is a problem for those trying to reduce uncertainty. Worse, the laws of physics specify a DC current inrush in the opposite direction does not remove the offset. It simply changes its direction and possibly magnitude, again, in a less-than-predictable manner.

In critical applications, degaussing may return the core to a non-residual state; however, neither manually applying AC flow nor degaussing are practical or economic solutions for unattended energy storage systems.

What is the magnitude of this error and how can one identify it? As in most engineering questions, "It depends."

Start with a careful examination of the device's specifications. You should uncover a statement roughly entitled Magnetic Offset Voltage, which should read something close to: "± 30 mV (0.75% uncertainty) after an excursion of 3X Nominal Current." This shift becomes a semi-fixed offset until the next surge. It is possible the residual will bleed off over time but, again, it depends on multiple factors. The practical solution is to specify a device, which has low residual effect at the levels you need to measure.

The challenge in our example is the "surge" is either <u>40 times</u> (200-Amps) or <u>120</u> times (600-Amps) the rated 5-Amps. The resulting residual magnetism is not 40 times the 30 mV but it may be quite substantial again, approaching the 100% uncertainty we faced at the outset. It's best to specifically ask the manufacturer to define the impact of a 120X DC surge on the overall accuracy to determine its acceptability.

Recent advances in "high overload capable" sensor design have made it possible to reduce this error to ± 2-4% of full-scale (5-Amps) without extraordinary measures. Designers can achieve narrower uncertainties with internal and even automatic degaussing circuits but, to date, the market has not demonstrated interest in the additional expense.

Temperature Effects

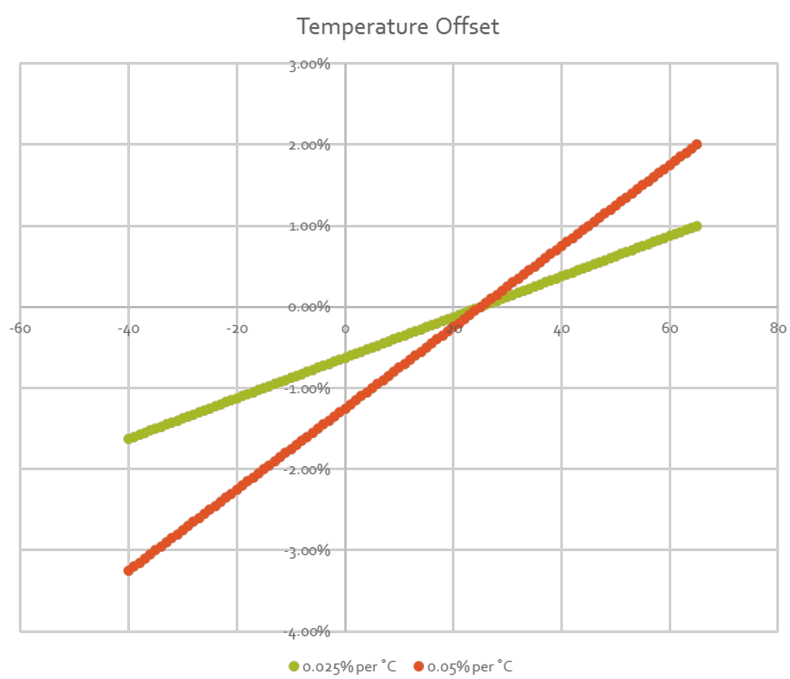

Figure 6. Common Temperature Offsets

Temperature should not have a large impact for Stationary Battery applications, but it may need to be considered. Most temperature curves look like Figure 6. They are generally centered at 25°C and stated in terms of 0.XX% per degree C or K. Here we show two different but common temperature specs for comparison. It's worth noting these measurement variations are additive to the other uncertainties.

By now, the reader is wondering when this all became so complex and how to assimilate and evaluate all of these errors. Trying to calculate the total effect of all of these uncertainties is daunting (roughly 60,000 calculations per device), so we created a simple tool to do the work for us. Figures 7 through 9 were generated by an online calculator (www.ohiosemitronics.com/Accuracy-Calculator), which is available to any user. The user must manually enter the specifications to maintain manufacturer agnosticism.

Entering specifications into the input page produces a visual "map" of total uncertainty. The map is nothing more than a spreadsheet, with the cells programmed to take the color of the uncertainty in each cell (also known as a heat map). We would offer the spreadsheet behind it, but most of us are unable to install files containing macros onto our company-owned computers.

The X-axis represents temperature from 0°C to 50°C while the Y-axis displays measured current as a percentage of full-scale rating, from 0 to 100%. We formatted the cells to turn green for an error of <5% of Full Scale current, yellow for errors from 5-10% and red for errors >10%.

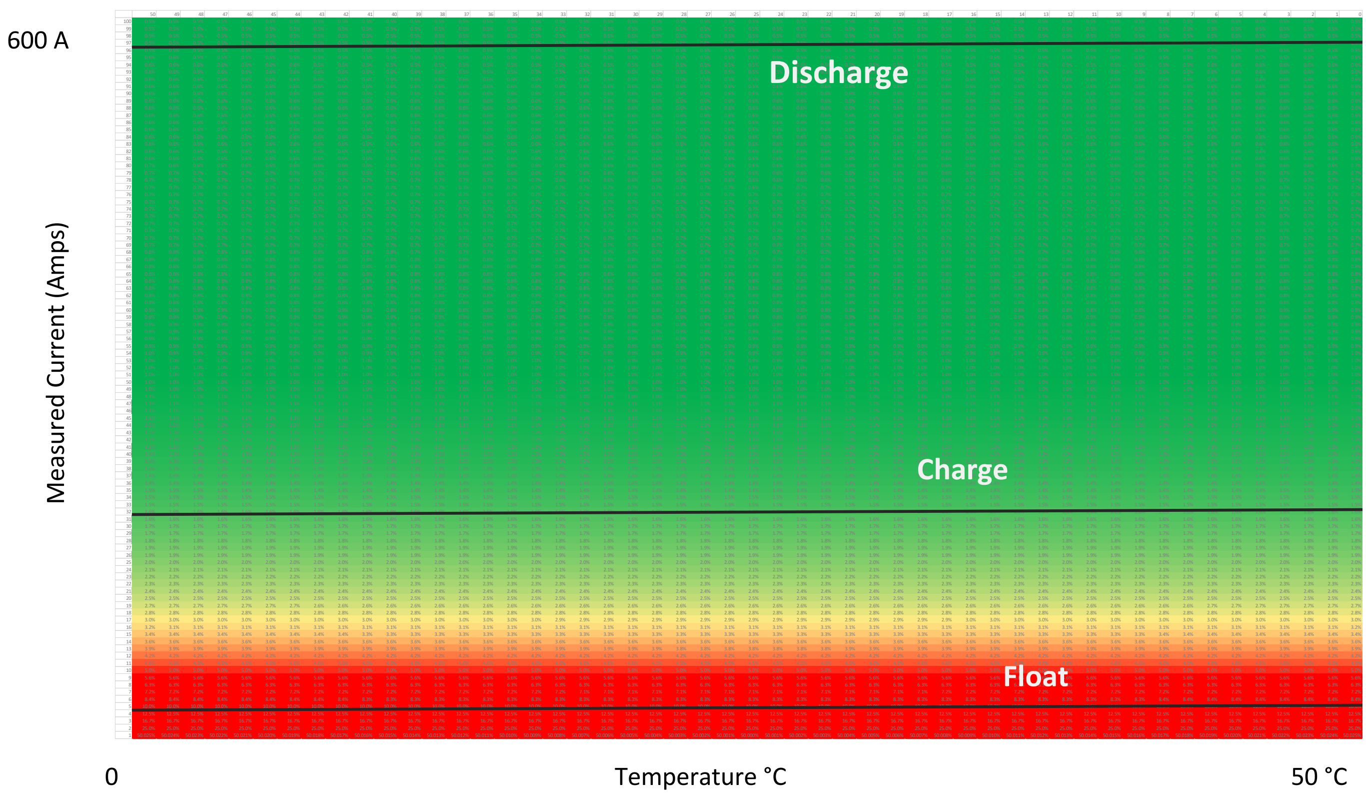

Figure 7. Accuracy with a single, 600-Amp sensor

Figure 7 visualizes the impact of measuring float current with a 600-Amp sensor, having ±0.5% Full Scale accuracy. We've suppressed Temperature effects for illustration purposes so the temperature appears as if at a constant 25°C. As we stated before, the accuracies are acceptable for charge and discharge levels but not truly useful for capturing float current deviations.

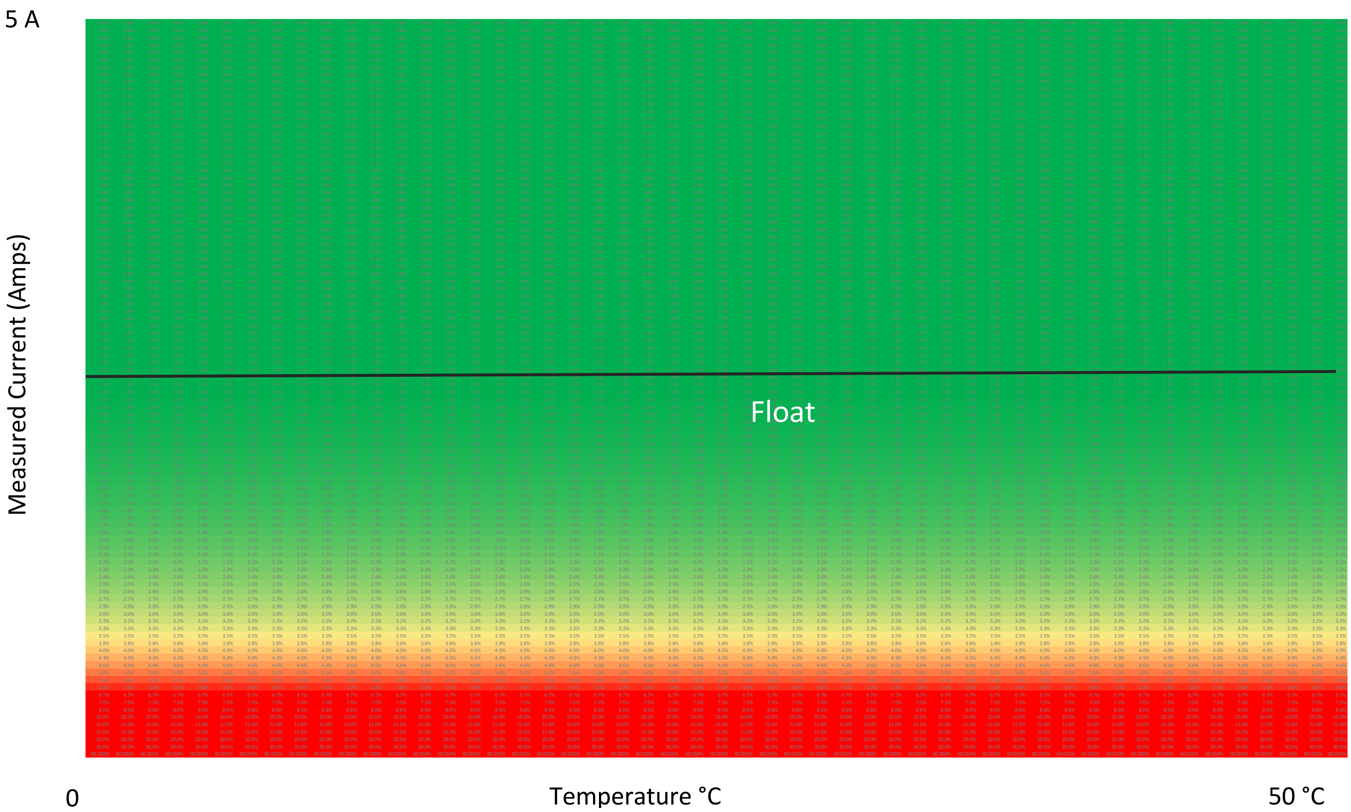

Figure 8. Float Current Accuracy with additional 5-Amp sensor

Figure 8 illustrates the impact of using an additional 5-Amp device with high overload capability. Its other characteristics are identical to the 600-Amp device above it. Again, for illustration purposes, we ignored temperature. This device exhibits the desired accuracy and resolution for discerning small float current increases.

Conclusions

What can we learn from this analysis?

1. If detecting changes in float current is an important part of your monitoring system, then it's worth closely examining the system uncertainty to ensure the measurements are truly effective. There <u>may</u> be a false sense of security regarding cell and system health if normal charge and discharge current can mask the incremental changes of float or maintenance currents. An additional sensor to accurately measure float currents may be very inexpensive insurance.
2. Use of simple calculations and a mapping tool can visually reveal significant challenges, which were previously undetected. We applied the tools here to the simpler problem of a single measurement; however, they are equally applicable to analyzing other more complex issues, such as multiple stream revenue metering on the DC side of the inverter.

3. Every accuracy or uncertainty specification will have an impact of some magnitude on the resulting uncertainty, which you may now assess visually.

For our final example, Figure 9 adds the impact of temperature effect to the **Figure 7** heat map, using a common commercial specification of ±0.1% per °C from 0°C to 50°C.

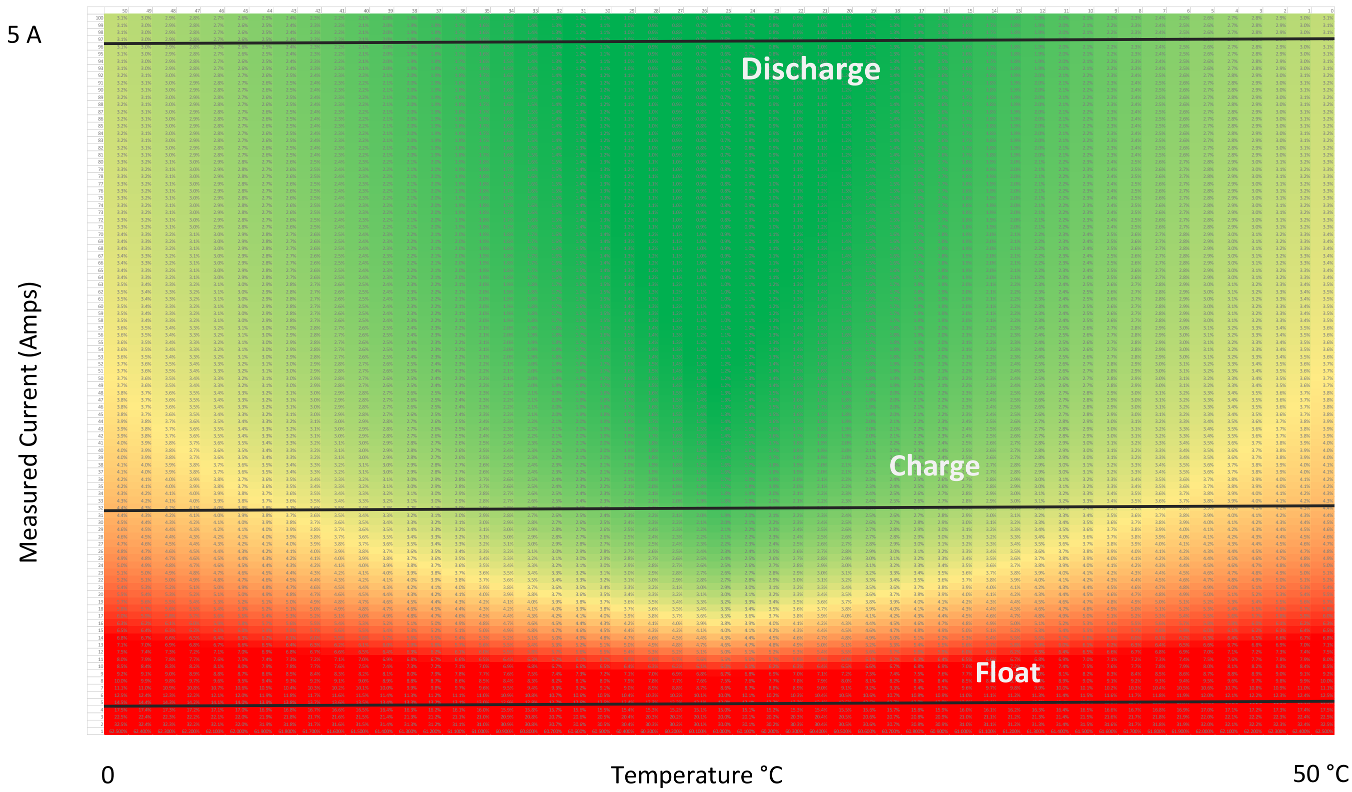

Figure 9. Impact of adding Temperature Effect of ± 0.1% per °C

The reader can now see the impact of a small change, rendering even the charge current measurement somewhat questionable at the ends of this limited temperature range. The cells will seldom experience 0 °C, but the higher temperatures shown are certainly possible.

4. Thus, the final learning - in Engineering as in Law - the large print giveth and the small print taketh away. Read carefully.

References

1. DeMar, P. "Thermal Runaway: The Past, Present and Future." Presented at INFOBATT 2010. April 11-13, 2010.