Design Life Versus Service Life in Batteries: *It's all about the charging!*

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The Mission Critical industry appears to concede to the fact that the service life of batteries never reaches published design life. In the field, battery systems tend to fail after 50-60% of design life. Why? In calculating published design life, manufacturers typically take into account *optimal* operating conditions as concerns float voltage, temperature, and discharge cycles. Battery manufacturers usually stipulate that their products be maintained at a temperature of 25°C, that they not be cycled more than 'X' number of times in their lifecycle, and that they be charged at a float voltage of 2.25 vpc. Where the first two of these conditions are typically under the control of the user, for the most part, the latter—float voltage—is not.

Batteries are designed to remain on a float charge for their lifecycle. A float charging voltage range is established to ensure that the battery remains charged and maintains the internal electrochemical state closest to the original condition. The float voltage specification is also established to minimize positive grid corrosion. If battery float voltage runs below specification the battery is under charged and sulfation occurs, causing a loss of capacity. If the battery remains undercharged, sulfation may be permanent. On the other hand, the most common failure mode on a battery is positive grid corrosion brought on by *overcharging*.

Batteries fail owing to a number of factors: excessive cycling, temperature fluctuations, install errors, manufacturing defects, *etc*. (Edward P. Rafter, 2005) Yet, where most of these factors are easily mitigated by proper maintenance and monitoring, one is typically thought unavoidable: improper charging. Why is it that even with a quality maintenance system, a temperature controlled environment, and proper installation, batteries tend to last no longer than half the design life? It's all about the charging.

Failure Mode	**Solution**
Excessive Cycling	Use of Backup Generator, Proper UPS and Load Sizing
Temperature	Temperature Controlled Environment, Redundant HVAC systems
Install Errors	QA program, Use of Certified Quality Installers
Manufacturing Defects	Issues with battery detected at an early stage
Improper Charging	Observe float specifications. (Most Common Failure Mode is due to the charging)

Batteries are improperly charged largely because the design of the charging system in the UPS/Rectifier. The UPS/Rectifier charges the battery as a single unit. This means it supplies a high overall string voltage to charge the individual cells. It does not take into account that the battery is made up of multiple cells in order to meet the voltage requirement. The individual batteries are connected in series and make up the battery string. Each battery in a string is constructed with a fixed specification but each battery has its own unique internal electrochemical properties. This will cause some batteries to charge at levels more quickly than other batteries. The slightest deviations in the internal chemical properties may imbalance the voltages in the string. Voltage imbalance causes batteries in the string to be overcharged or undercharged. Voltage imbalance becomes greater as more batteries are in the string.

The problem with voltage imbalance is further enhanced when batteries in the string are replaced. Whenever this happens, as newer batteries are in a more optimal electrochemical state than older ones, they overcharge. Conversely, the older batteries undercharge. *When 20-25% of batteries in any given string need to be replaced, industry standards suggest replacing the entire string.* The reason: the unbalanced voltages that inevitably occur when old batteries are mixed with new batteries.

In order to minimize grid corrosion, an optimal voltage is determined by the battery manufacturer. Studies have shown that, as the voltage skews away from the optimal voltage, each individual battery loses its availability to the string as a whole.

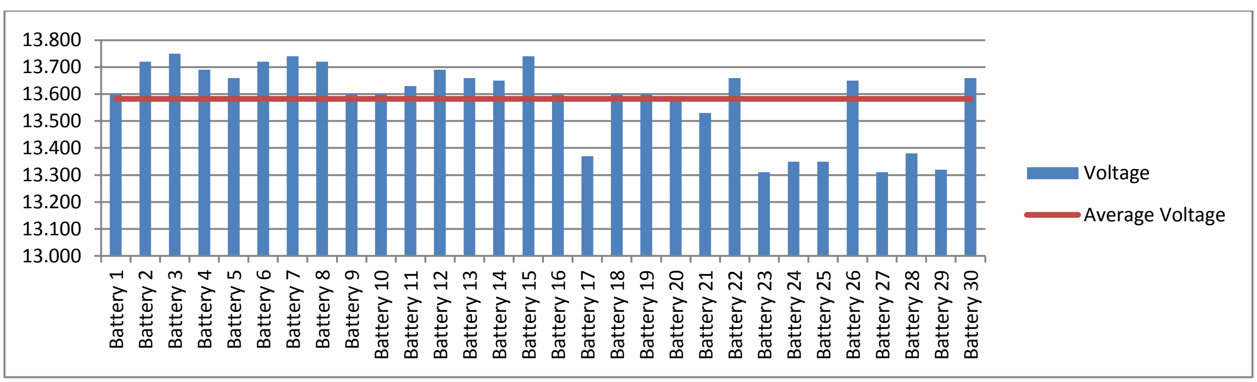

Figure 1- Battery Systems (3 years old Date Code 7/2013)

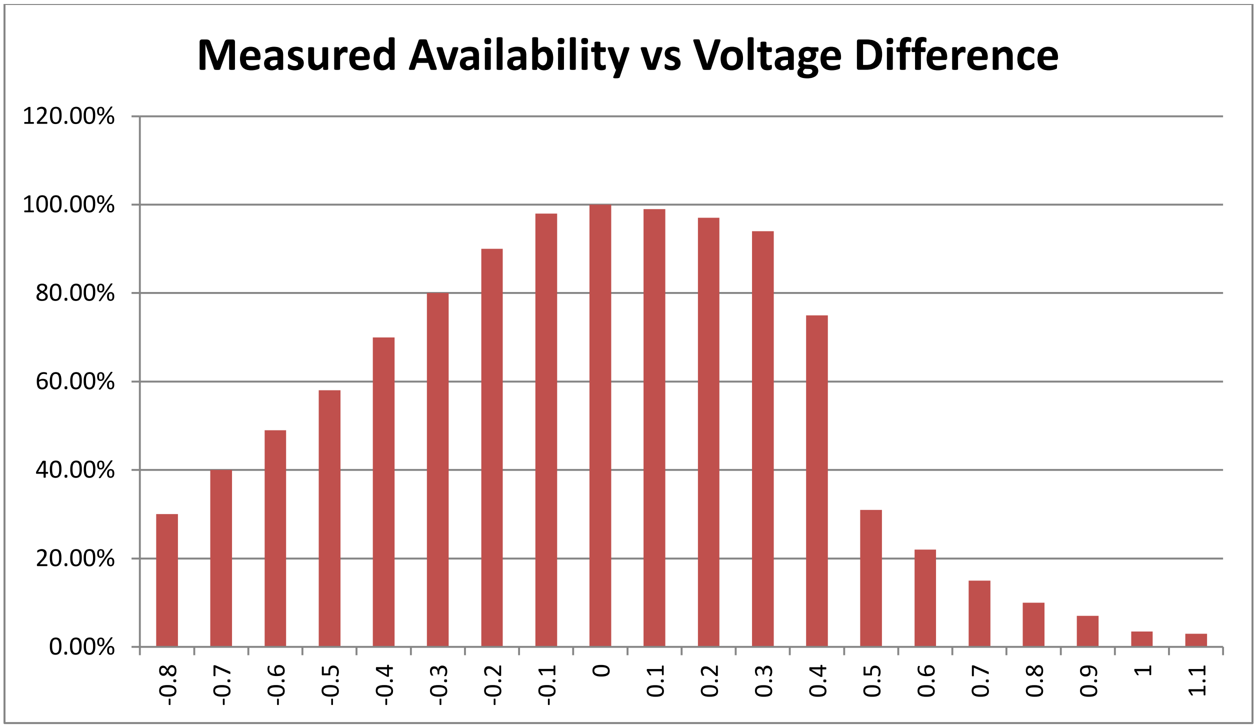

Figure 2- Measured Availability Vs Voltage Difference from Average (Kuhn, Spee, & Krein, 2005)

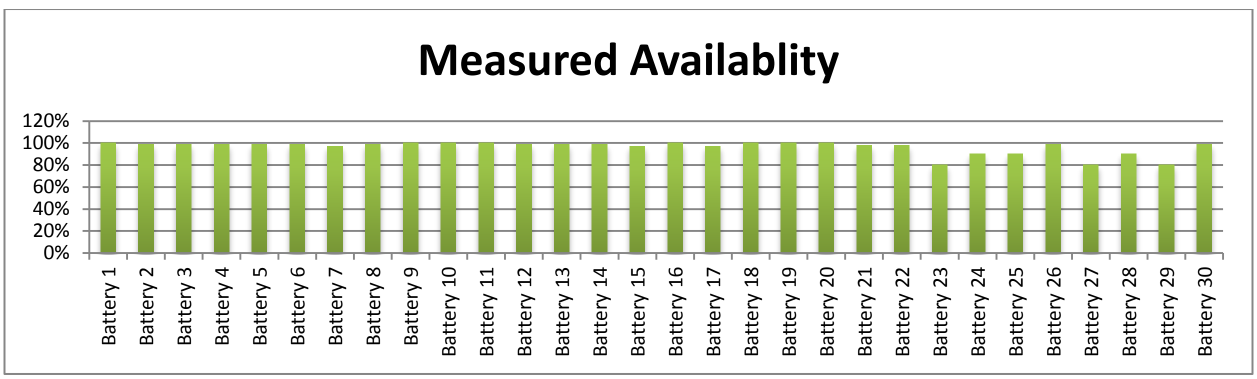

Figure 3- Battery String and Measured Availability (3 years old Date Code 7/2013)

Availability for a series system is calculated by the product of each component in the series system. (Gunther, 2000) Based on the studies conducted by Kuhn, Spee, and Krein (Kuhn, Spee, & Krein, 2005) the availability of the battery string shown in Figure 1 and 3 would leave the battery string availability 29.3% (See Table 2).

$$A_{String}=A_{batt1} * A_{batt2} * A_{battn}$$

Battery No.	Measured Availability
1	100%
2	99%
3	99%
4	99%
5	99%
6	99%
7	97%
8	99%
9	100%
10	100%
11	100%
12	99%
13	99%
14	99%
15	97%
16	100%
17	97%
18	100%
19	100%
20	100%
21	98%
22	98%
23	80%
24	90%
25	90%
26	99%
27	80%
28	90%
29	80%
30	99%
Total	**29.3%**

Table 1- Total String Availability

This is one of the principal reasons battery service life never measures up to design life, even when temperature and number of discharges are scrupulously controlled. On most occasions, when batteries fail, manufacturers, design engineers, and end users are not at fault. The fact is, today's charging system design does not take into account the fact that that the battery system is made up of individual cells.

Philip Krein states: "Lead acid batteries obtain their maximum lifetime if they are charged at the proper voltage". (Krein, 2002) If voltages are balanced throughout the string, service life and state of charge are greatly optimized. State of charge is a surrogate of voltage balance. It has also been found that keeping the batteries within the optimized float charging specification increases the reliability of the battery system as a whole. The only way to *guarantee* that each battery is charged within the specified window is to implement a single source charge, to match internal electrochemical properties in each battery contained in the string or balance the individual battery float voltages.

What is the Solution?

Given the designs of UPS and rectifier systems, there is no way to single source charge each battery. It also is nearly impossible to sort through each battery in a string in order to match internal chemical properties. The only practical step available to us is to balance the voltage on the battery system.

A system designed to address the issue of voltage imbalance will stabilize the battery string regardless of the varying internal electrochemical components within the battery. Balancing voltage prevents each battery in a string from overcharging or undercharging, thus increasing reliability and service life (by as much as 50% over present industry standards). Balancing voltage also ensures that each individual battery remains at an optimal state of charge, thereby increasing the capacity of the battery string.

The lifecycle of a UPS is about 20 years. After that time, it becomes necessary to renew the equipment. The battery strings during that time frame are typically replaced three times after the initial install. By properly balancing voltage, we stipulate reducing replacement to two times only.

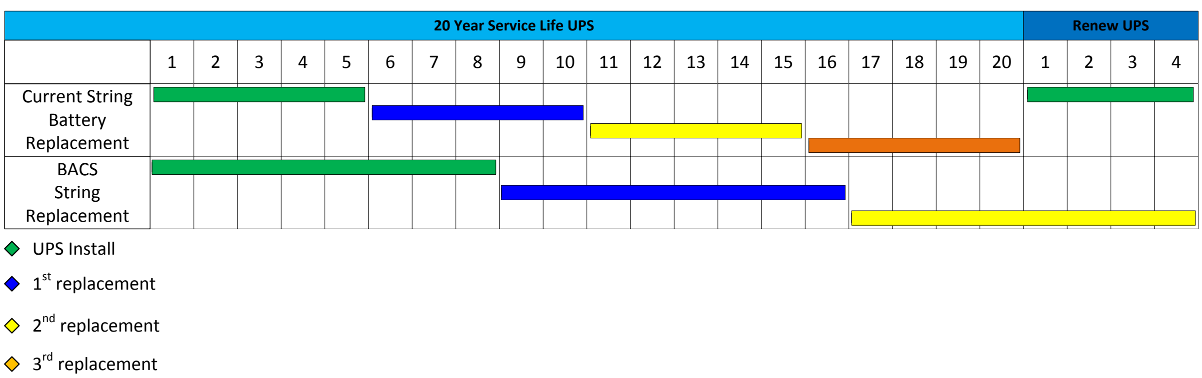

Figure 4-Battery Replacement Schedule

A system providing a voltage balancing feature should also be a fully functioning battery monitoring system. It should measure cell/battery level voltage, impedance, and temperature as well as string level voltage and current. The system should also include battery trending history as well as alarming and notification. Generex's BACS© system does all of these things.

BACS© Technology

Generex's BACS© system is a 3rd generation battery management system that provides voltage balancing of each cell or battery. The BACS© system is also a web-based battery monitoring system. It provides the same trending, alarming and notification offered by most competitive battery monitoring products. It can stand-alone or can easily be integrated into a building management system.

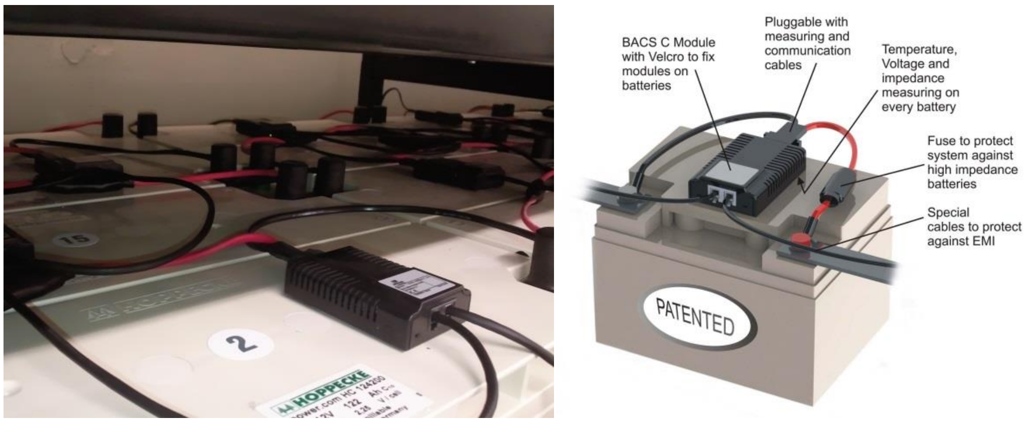

Figure 5-BACS©

The BACS© modules are installed on each battery in the system. The modules are connected through a communication bus network back to a web-based controller (BACS© WebManager). The BACS© system measures each individual cell voltage and determines the target voltage (average voltage) for the string. The BACS© system uses a passive voltage balancing technique which utilizes a shunting resistor system. If a battery is **above** the target voltage (overcharging), the BACS© module activates a bypass current to provide enough float current to keep the battery charged while preventing overcharging. A battery that is **below** the target voltage (undercharged) is *not* bypassed and the voltage on that battery rises naturally toward the target voltage at the same time the voltage of potentially overcharged batteries is allowed to moderate. BACS© functions by virtue of Kirchhoff's current laws.

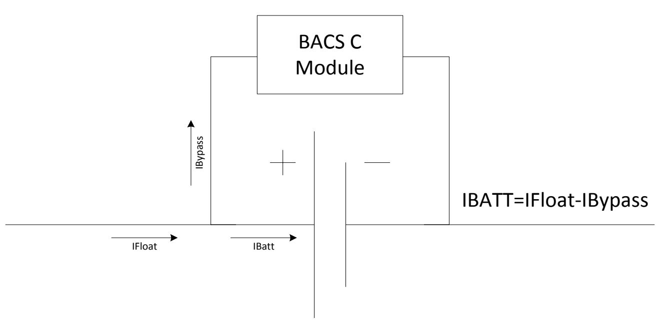

Figure 6-Kirchoff's Current Law

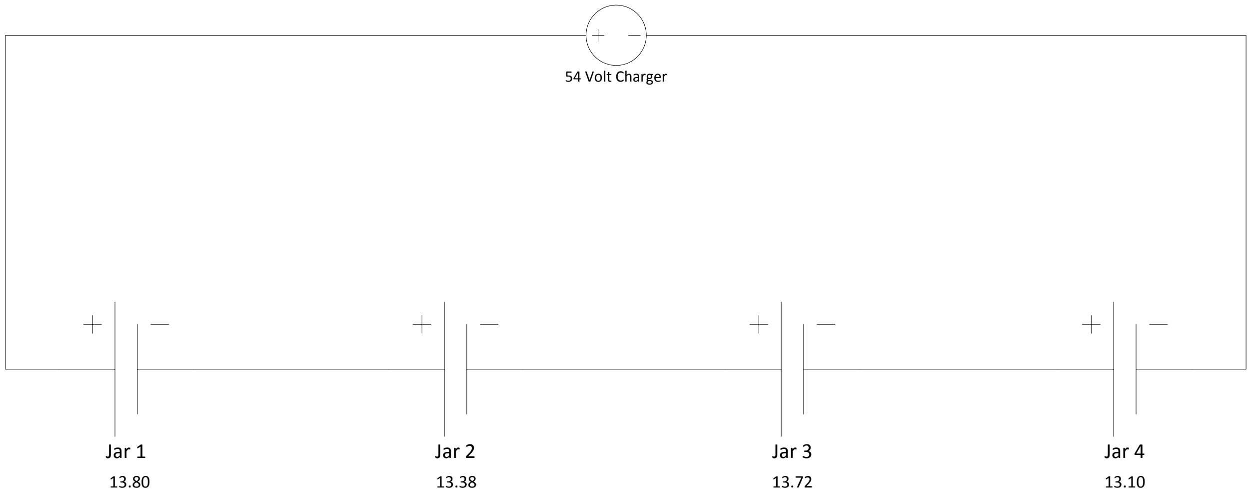

Figure 7-Typical String without BACS©

Figure 7 shows a typical battery system with a 54vdc rectifier. Batteries 1 and 3 are overcharging while 2 and 4 are undercharging. Figure 8 shows that the BACS© modules are installed and connected in parallel with the batteries. Communication is established with the BACS© WebManager which assigns the target voltage of 13.50 on each BACS© module. In order to maintain the target voltage, Battery 1 only requires 20mA of charging current to maintain the target voltage 13.50vdc while Battery 3 requires 50mA. Batteries 2 and 4 have the full charging current applied and the battery voltages are balanced.

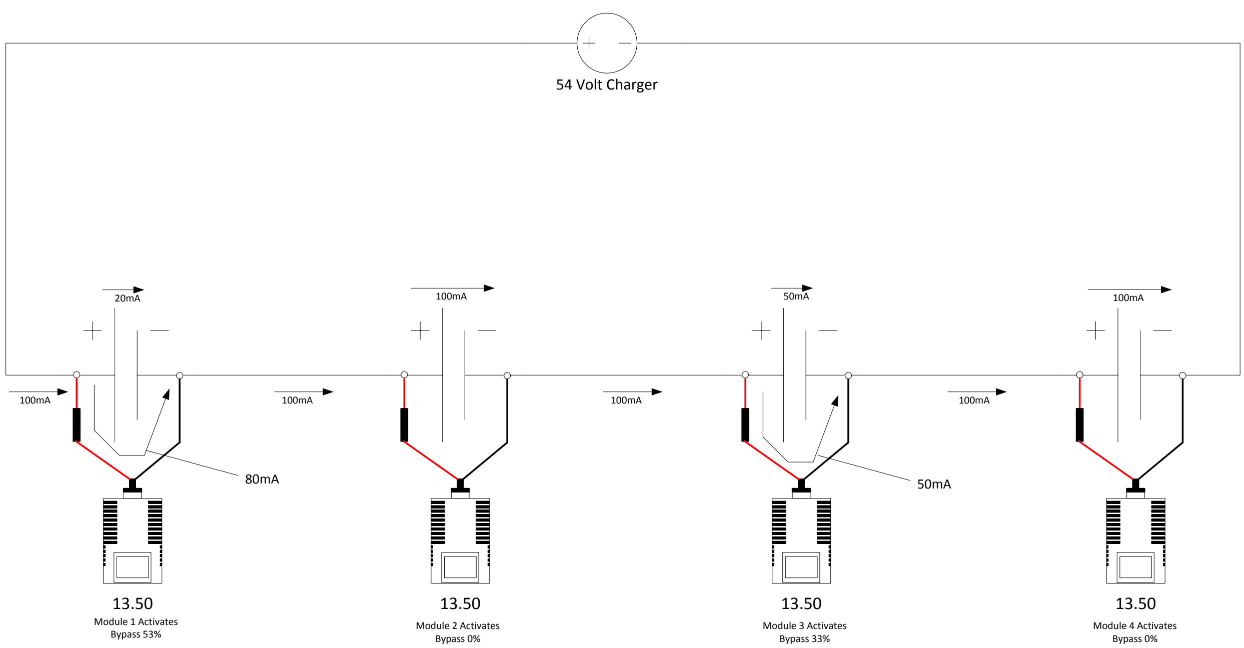

Figure 8-BACS© system bypassing

The BACS© system is designed to automatically adjust the target voltage on the systems as the UPS/Rectifier changes the string voltage. This is utilized when the UPS/Rectifier is equipped with temperature compensation. The UPS/Rectifier system is still responsible for charging the batteries; what BACS© does is *distribute* the charge throughout battery string in such a way as to *balance* the voltages. Thus the primary and lead cause of reduced service life and battery failure is effectively mitigated. When new batteries replace failing batteries in the string, the BACS© system ensures that old and new batteries maintain their proper float charging levels. Each battery remains at its ideal float voltage and state of charge.

The BACS© system optimizes the float charging level of each battery (See Figure 10). As a result, total string availability is increased. If we refer back to Figure 2 the measured availability of each battery is 100% with the BACS© system installed. Therefore, the total string availability is 100%.

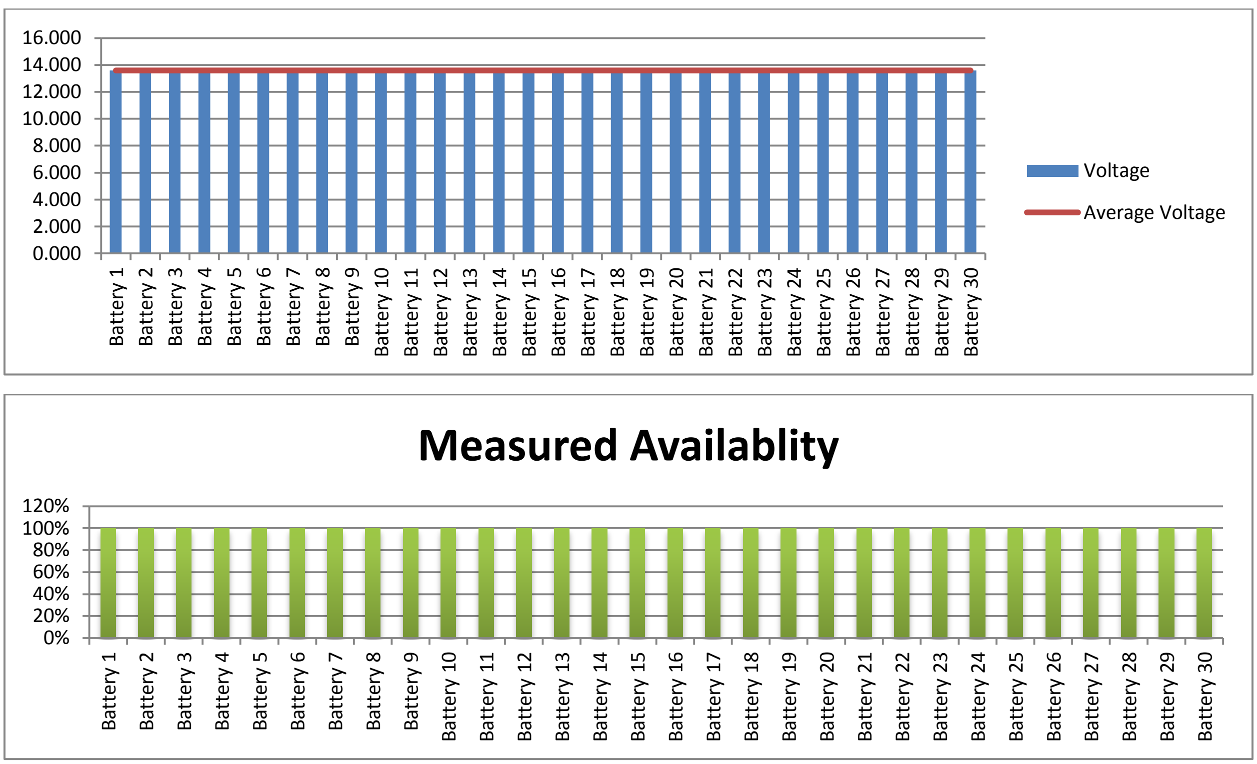

Figure 9- BACS© Measured Availability

Conclusion

Batteries maintained at optimal float voltage—in addition to being held at reasonable operating temperatures—are likely to provide a service life reasonably comparable to the published design life. The BACS© system is an ideal battery monitoring solution that provides voltage, temperature, and ohmic value of each battery and manages the battery system in order to keep the batteries at their optimal voltage level. As a result, the battery service life is extended by up to 50%. The BACS© system allows newer batteries to be replaced into the string without the concern of jar interaction. The BACS© system also increases the capacity and reliability of the battery system that supports the mission critical operation. Equally important is the cost saving benefits due to the increased service life and the environmental aspects of reducing battery replacement cycles.

References and Acknowledgements:

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