A Comprehensive Study of
Battery Monitoring Failures and How they can be Avoided

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Abstract
Automated battery monitoring has long been accepted as a suitable method of monitoring auxiliary and back up batteries. However, we have studied the behavior of the users of those systems and have determined that not all users are realizing the full value of the systems they have installed.

Why is this happening and what can be done about it?

Introduction
From 2005-2015 we gathered data from over 300 companies across the globe that deployed a battery monitoring system. This data includes well over 100,000 containers. Many battery technologies were represented including VRLA, VLA and NiCad systems. This paper will not evaluate the various battery manufacturers or technologies but rather how users interpret battery data.

As we studied user behavior, several distinct patterns emerged. These patterns were consistent regardless of the battery monitoring system deployed and regardless of the specific features of the products or technologies. We will present several case studies that demonstrate user behavior, and then characterize the nature of the performance gap, and lastly we will identify a process change or other solutions to improve the effectiveness of the customer's battery monitoring performance. We will not only explain why these issues occur but we will discuss proven solutions that will alleviate and potentially eliminate them altogether.

The distinct patterns are:

* Lack of proper installation and commissioning of the monitoring system

* Lack of user attention to the systems or information they provide

* Lack of proper training on how to utilize their systems

* Service providers' behavior

The goals of this paper are:

1.) To draw attention to the battery monitoring system in an effort to get users to take an active role in the management of their asset,
2.) To get end users to take full advantage of the battery systems they have,
3.) To educate service technicians on how battery monitoring systems are complementary to the services they provide and how they can adapt their service to be more valuable to their customers.

We will also provide a model of a highly effective battery monitoring solution where all of the goals listed for this paper can be reached regardless of previous experiences with battery monitoring.

Where complementary, actual end user data from discharge, float voltage, and ohmic value readings will be presented for each case study.

When referenced, a container refers to the lowest changeable component of the battery. In the past this has been referred to as a jar, cell, block, or even battery.

Identifying Behaviors

Battery monitoring has gained acceptance around the globe for monitoring batteries of various chemistries. Portable monitors have been used within the industry for many years and provide proven results. Continuously affixed monitors have been used in the industry for over 30 years after being introduced to monitor the terminal voltage of the cell [1][1]. Affixed monitoring and portable monitoring have progressed in recent years and if well designed can provide accurate, reliable and often repeatable data. Regardless of the monitoring method used at a customer site, we found users that file battery reports into a folder and never review them, or never take action on the findings of the report.

A battery monitoring system identifies issues early enough that corrective action can be taken to ensure the battery is functioning as intended. Considering the value of the battery monitoring system and the criticality of power assurance, it is perplexing that the measured results of these systems are often ignored. We found several instances of egregious disregard of important information and proper procedure to utilize the battery monitoring systems they owned. This behavior along with several others will be identified in this document and presented as customer case studies.

Case One: It Must be the Battery Monitoring System's Fault?

In this case the customer found two failing cells during the battery monitor installation and commissioning. Both cells were immediately replaced. Months later, additional failing cells were identified. Within the first year, approximately one cell in each string was replaced. Due to the number of alarms, the customer contacted the battery monitoring manufacturer and requested an engineer from the company come to the site to address the issues with the battery monitoring system. To definitively prove the battery performance of the strings, the customer decided to conduct a discharge test. After evaluation of the discharge data, the cells were confirmed faulty based on discharge voltage, float voltage and ohmic value. We call this phenomenon "blame the messenger."

We characterized this under the behavior pattern for "lack of proper training" because from our follow up discussions we determined that the reason many of these customers didn't attend to their system and analyze the results was that they were often not properly trained. Had the customer been trained on their battery monitoring system it is clear they would have understood the results presented by the system and their focus would have shifted immediately to the battery not the monitoring system. We also discovered that many companies are losing their battery expertise due to retirement or from job mobility. If someone is taking over the battery monitoring system and they haven't been trained, it will be a challenge for them to understand what needs to be done.

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[1] "Storage battery monitoring and recharging control system with automatic control of prime mover driving charging generator," 09 03 2015. [Online]. Available: http://www.google.com/patents/US3991357.

One can observe from the data presented that the failing batteries follow the expected behavior of failing cells and that the battery monitoring system was reporting an issue that needed to be addressed. However, with the skepticism towards the measurement instrument the user failed to identify a significant problem and at a minimum, a portion of their back up power source was at risk.
The recommended best practice is to have all operators of the battery monitoring system fully trained on the system they are using. While this seems far too obvious more than 50% of all noted issues found in this study were due to the lack of proper operator training.

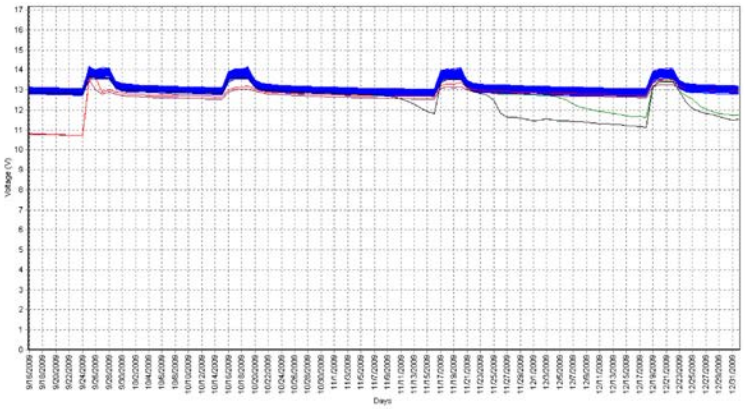

Figure 1. Voltage of Battery Case One

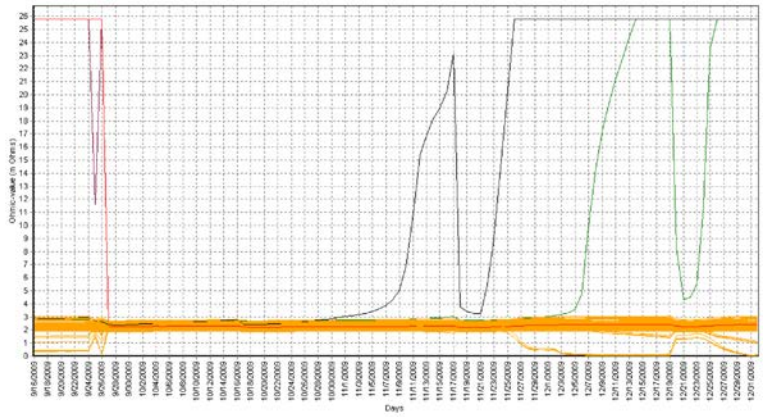

Figure 2. Ohmic Value of Battery Case One

Case Two: Assumed that Batteries are the Same

The graph below depicts three failing containers that were rapidly replaced over the course of ten months. Across the 20 strings monitored at the facility for case two, a total of nine cells were replaced in the first two years of the battery life.

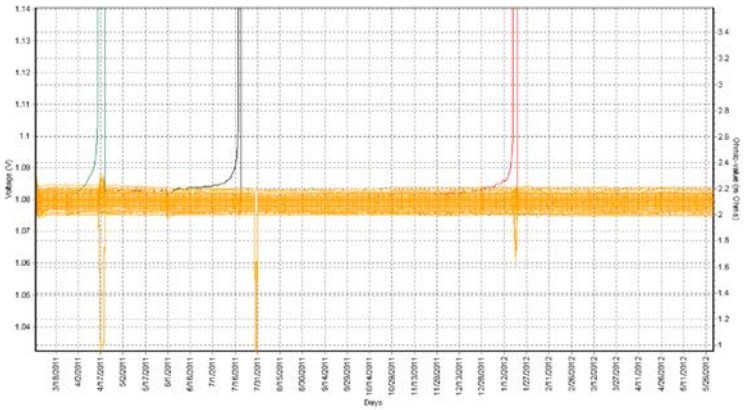

Figure 3. Case Two – Ohmic Value of Battery from 2011 to 2012

Due to the volume of cells that rapidly failed (drop in float voltage, increase in ohmic value, and poor discharge performance) within the battery string, all 20 strings were replaced. Within two years following the battery replacement, ohmic value data indicates that the entire battery system (20 strings) was increasing in ohmic value at a remarkable rate.

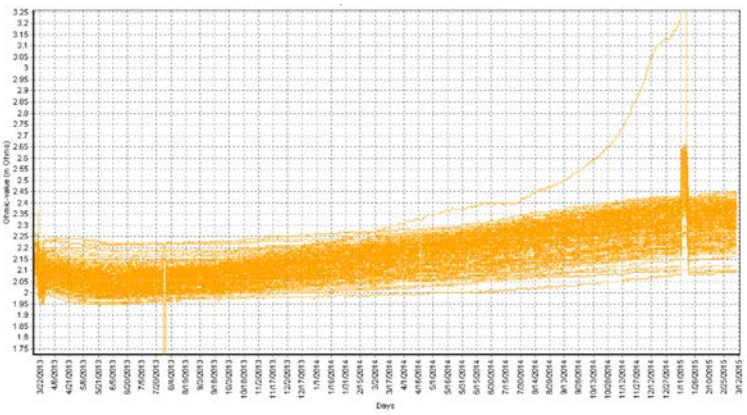

Figure 4. Case Two - Ohmic Value of Battery from 2013-2015

Coupled with the combination of several increasing high and low cell voltages and increased temperature in several cabinets, the customer was unknowingly in the early stages of thermal walkaway and had been so for months.

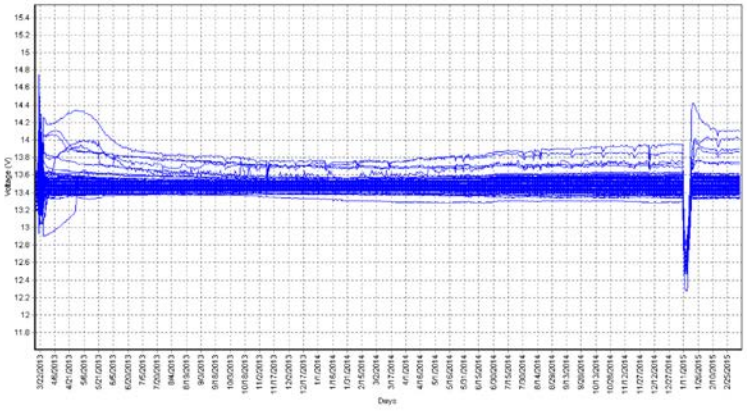

Figure 5. Case Two - Voltage of Battery from 2013 to 2015

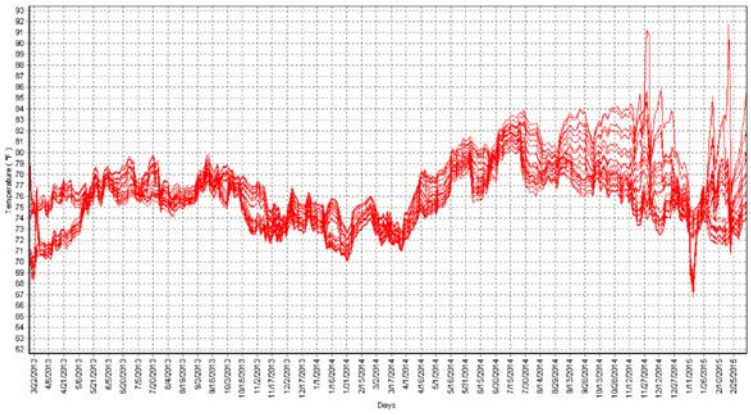

Figure 6. Case Two – Cabinet Temperatures of 5 Batteries from 2013 to 2015

Here the customer assumed that all batteries are the same. The battery manufacturer replaced the strings after an unusually high occurrence of failing cells within the customer system in 2013. While the number of individual failures within the strings decreased significantly, the individual cells show a different aging characteristic than the prior installed cells and from that of an average system.

The recommended best practice is to validate the battery manufacturer's environmental and charging requirements prior to installation and commissioning of the battery. It is also a further best practice to review the same manufacturer's requirements prior to commissioning the battery monitoring system since the battery and the monitoring system are symbiotic and the monitoring system must be programmed appropriately for the battery it is monitoring.

Case Three: The Improperly Commissioned System

In some cases, systems are left commissioned and may not have alarm settings configured correctly. Regardless of the battery monitoring system, improperly configured alarms can mask failing cells. For other systems, battery modules may be inappropriately assigned or labeled, probes may be reversed, or power might be inadvertently removed from the battery monitoring system. Regardless, an improperly installed or configured system can leave the customer without knowing the state of the battery. In the customer situation below, ohmic value alarms were left at default value, shown in red, and were not tailored to the cells that were monitored.

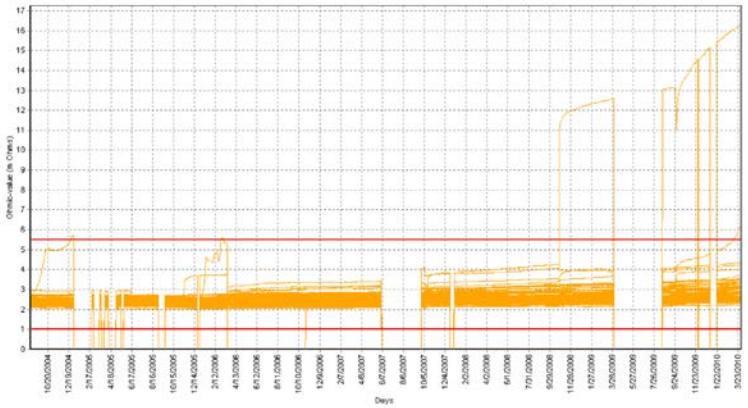

Figure 7. Case Three - Ohmic Value of Battery

Additionally, gaps in the data spanning the course of four months indicate that the battery monitoring system had been turned off, even when the system was identifying failing cells.

While improper alarm settings can be considered an absolute failure on the part of the person commissioning the system, the operator should at a minimum review the alarm settings to verify their system is properly configured. In some cases we noted systems were left not commissioned and there were others where alarms were not configured correctly. Our Investigation also found modules that were inappropriately physically labeled and in the software or probes were reversed. Regardless, an improperly installed or configured system can leave the customer without knowing the state of the battery.

The most concerning case involved a battery monitoring system that was turned off and not powered on for a full year following a battery failure. The system was powered off due to maintenance and wasn't turned back on due to employee turnover at the customer location.

The recommended best practice is to review all alarm settings at the time the product is accepted. It is also a good practice to review the alarm settings if any work is done on the system that might have changed the configuration or where alarms might have been altered. Battery monitoring systems should be observed at least once per day unless they provide email or SMS alerts to ensure they are continuing to run. Lastly, it is recommended that multiple persons be trained at a customer facility.

Cases Four and Five: It's OK, I have a Battery Monitoring System

Our final cases have supporting data that looks very similar to the customers above. Case Four includes a customer whose alarms were never taken care of until the fire department arrived. At this location, someone had access to a battery monitoring system every day. Multiple times per day, someone walked by the battery monitoring system, but it was assumed that the alarms indicated were someone else's problems. Regardless of the reason, an alarm was triggered six months before a smoke filled room got someone's attention.

The recommended best practice for all monitoring systems is to "pay attention." If one takes the total investment made in power protection including the UPS, the batteries, the installation and the maintenance; the cost is obviously substantial. All of this investment had a purpose and that purpose is completely countered if an operator decides to ignore the system. At that point the return on that investment is ultimately in the hands of the user.

Case Five unfortunately doesn't have much of any battery data to analyze. This company installed a battery monitoring system in 2008, however, after installation, the battery monitoring system was unpowered, but left connected to the batteries. For this customer, the battery monitoring system was installed to meet a requirement, but the data was never used or reviewed. Upon additional investigation, the service provider performed regular maintenance testing on this battery and while it was evident a battery monitoring system was installed they never took advantage of the system.

The authors felt this was the ultimate bad practice exhibited by all of the systems evaluated. The recommended best practice is to use every tool at your disposal to protect your power systems. If a battery monitoring system is available it is almost *criminal* that the system not be used. It is also an important consideration for anyone conducting manual preventive maintenance procedures. Any good doctor will request the records from your previous doctor when they see you the first time. They know that the data provided in those records is extremely valuable in determining your current health and without those records they are only seeing a small portion of the total medical picture. A battery monitoring system's history is a powerful record showing what is working well and where you have had problems in the past.

Conclusions from Case Studies

In conducting this research it was discovered that we were not studying battery systems or technology but the results are actually a telling story of human behavior. While these cases have been summarized in brief, significant issues were identified and are common across multiple manufacturers and they have repeatedly occurred in numerous power systems around the world. While the authors have highlighted the most drastic cases there are less memorable but equally impactful cases identified in the study. In spite of the efforts of the battery manufacturer and the monitoring system manufacturer, unfortunately for some customers, their batteries just don't perform as expected. The final proof of the value of both the technology companies is "Does the battery perform or does it not?" Battery monitoring systems have been proven from a technology perspective for many years and have been embraced successfully, however, this study proved that there are some examples where companies need to adopt a better process for commissioning and then using their systems.

Effective Battery Monitoring Application

Applying the lessons learned from this study can make a difference in the overall reliability of a power system. Often times, the focus of studies is on technology and how to improve the design and to make the product better. The lessons learned from this study started the same but ended with an unexpected conclusion–it is how you use a tool that makes you a master craftsperson. A practical application is provided herein:

Commission the Battery Monitoring System

Every battery monitoring system is designed to give the user information pertaining to their battery. If the BMS isn't physically connected properly, readings may be inaccurate. Ensure the system is configured properly and commissioned. Commissioned systems should have the data output evaluated to ensure the discharges are captured properly (if applicable to the BMS) and historical data is recorded properly. This also ensures that ohmic value, impedance, resistance, or conductance tests performed by the monitoring system are properly conducted. This commissioning should also include validation that the alarm settings are configured for the battery and customer requirements.

Evaluate the Data Regularly

There is a great deal of information that can be captured from a battery monitoring system, either a manual or fixed point monitor. Evaluate the data regularly. For some users this requires taking an active role in managing the battery asset. For others that can't assume the weekly or monthly task of reviewing battery data, this could include soliciting a third party provider to review the data and provide a data evaluation. This could be through automated means that push the data to a third party server, sending data to the provider for review, or soliciting the assistance of the battery service provider to review the data from the monitoring system during a scheduled preventative maintenance.

If you Don't use it, you Lose it

There is a technique to using any tool and a battery monitoring system is no different. It only takes a few minutes a day to monitor thousands of containers. Many systems will even alert the administrator in the event of an issue. There are many examples of good practice and there were more good examples than bad examples. An affixed battery monitor is like a heart monitor in the operating room. The doctor doesn't need to spend every minute staring at the screen, but if an alarm goes off every doctor is trained to focus their attention to the alert and prompt action is necessary.

Backup and Integrate the Data

Some systems print data for historical purposes, others make live and historical data available in a user interface or from a webpage, and others allow data to be integrated into an existing building management or data center infrastructure management system. Users should capitalize on the advantages of having this data integrated and actively managing the battery asset. Alerts can be configured for email notifications, dry contact closure, LED indicators, Modbus TCP/IP, SNMP, BacNET, DNP3 protocols, and other protocols.

Backing up the data allows a historical record to be maintained should a catastrophic event occur on site. Data is often backed up for every other system and the battery monitoring system shouldn't be an exception.

Get Training

Battery data can be daunting, but often problem cells are not hard to interpret. To understand historical data, knowledge of what maintenance occurred is usually all that is needed to understand inconsistencies or abnormalities in data. Users should contact the battery monitoring system manufacturer for lessons on how to use the software and how to understand and interpret battery data. Data can often be easily reviewed and quickly interpreted by the experienced teams at each of the manufacturers or trained in-field service techs. Some even offer classes for reviewing battery data.