The Complete Guide
To
Battery Monitoring
V3.0

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Contents

Introduction

Thank you for taking the time to review BTECH's Complete Guide to Battery Monitoring, over the last twelve years the guide has been downloaded many thousands of times. This revision, Version 3 includes new data on trends in battery monitoring technologies, battery safety and information on new standards. We hope you find the guide useful in ensuring industry best reliability and availability from your back up DC battery plants.

Background

The ***Complete Guide to Battery Monitoring*** newly published in 2004 and now in its third revision, gives valuable insight to the inherent unpredictability of batteries. An industry first, this document identifies operational efficiencies gained by automated battery monitoring; this guide will provide an overview of current technologies, industry standards and identify various battery failure modes.

The examples detailed in this guide are culled from data collected by many thousands of BTECH battery monitoring systems over the last 25 years. We hope this guide helps you better understand the actual battery risks you may be vulnerable to and improve your chances of avoiding catastrophic failure in a power outage.

What we know

Battery systems are inherently unpredictable and can fail without warning, industry studies confirm that the root cause of most system failures can be traced to the DC plant and can be the reason for 85% (1) of catastrophic DC plant failures. It has also been proven that scheduled battery maintenance programs do not always avoid the risk of catastrophic failure. This is due to many factors including defective new batteries that remain in service undetected, maintenance routines postponed because of availability issues, maintenance services which do not include ohmic testing and a lack of real time data from the DC Plant.

- Approximately 3-5% of new batteries will fail during the warranty period
- The typical error rate inherent in manual battery inspections is 3-5%
- Batteries in normal use can actually deteriorate (go bad) in a 2-week timeframe
- Just one bad battery can cause the entire string to fail

Reasons for the inherent unreliability of batteries span a very wide range of possible causes such as design flaws, manufacturing defects, poor quality control, lack of care in storage and transportation, environmental factors and application stresses. In some cases, scheduled battery changes actually introduced problems due to shoddy workmanship or mechanical connectivity failures.

Additionally, load tests and in service battery tests stress batteries and only guarantee that the battery system worked the day of the test and give customers a false sense of security. Once installed, many unnoticed factors such as power grid issues, environmental conditions and charging stresses caused by demanding DC applications all contribute to create a high risk of battery failure. To give some insight:

- A temperature increase of 18° F reduces battery life by 50%
- A 20% reduction in storage capacity puts a battery at great risk of failure if asked to perform, and according to IEEE standards, it should be replaced immediately.

Reasons Batteries Fail

When it comes to battery systems there is one undeniable truth, as a battery system ages it will lose capacity, and eventually the battery system will reach end of life. The battery industry has spent a great deal of time and effort defining the metrics that determine end of life. Why then do battery systems fail prematurely or fail to perform to publish expectations?

There are a variety of factors

Improper Testing

Proper testing and benchmarking a new battery system is key to ensuring a battery system is going to operate as designed, this is commonly referred to as acceptance or commissioning testing. These types of tests usually involve "load banking" the system at full load for the engineered run time. For more information on the details involved in performing these tests please refer to I.E.E.E 1188 and 450. It is strongly recommended that any test include data logging at the unit or cell level. Many times a system can meet or exceed the design run time but the system has underperforming units that should be replaced before the system is accepted. If these units are left in service they will adversely affect the units around them, causing the system to underperform and fail prematurely. Diagram 1 compares the theoretical performance expected by the battery manufacturer compared to the actual performance, the reason why the systems underperformed is because the battery systems were not properly tested and benchmarked at acceptance.

Early Detection Is the Key to Improving Reliability

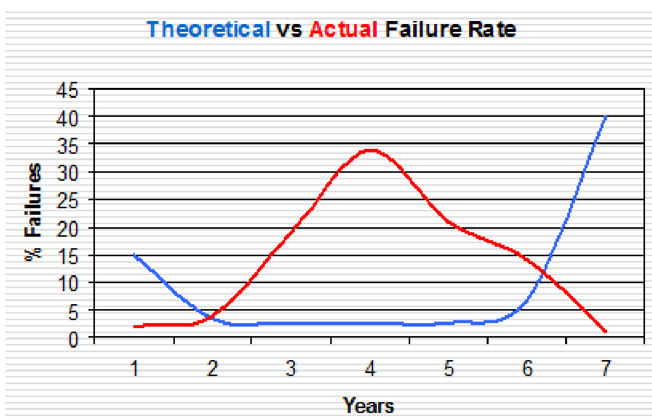


Diagram 1

Additional Factors That Affect Aging

All batteries are not the same each manufacturer incorporates different design and manufacturing standards. The design life, inherent ruggedness, quality of materials, plate formation and manufacturing process all combine to determine how long a system will last. Sometimes the batteries are abused during handling, shipping and storage. The way the system was installed may affect the battery.

In-service factors

The ambient temperature, charging quality, duty cycles and maintenance activities all effect battery health, some of these factors may be unavoidable (outdoor enclosures). The quality and competency of in serve maintenance activities also affect battery system health.

Natural Aging

Lead-Acid Battery is a sacrificial design with unavoidable degradation over time; the battery is a highly chemically active environment. Corrosion of positive plate grid structure is a common aging factor even under ideal conditions and is unavoidable

Failure Modes Associated with Aging

As the batteries age a permanent loss of capacity occurs and the internal resistance increases. The reason for this increase in resistance can be traced to several factors.

- Obstruction of active material in discharge reaction
- Internal short circuit.
- Loss of physical strength
- Failure of conduction path
- Plate Sulfation

Other failure modes include

- Post seal leakage
- Cracked container
- Plate warping
- Crazing

Temperature Effects

All battery manufacturers base their design and performance standards on the 77°F (25°C) ambient temperature. Deviation from the ideal operating temperature has varying effects.

- Increased ambient temperature improves performance but accelerates positive plate corrosion; generally battery life is halved for every 15° – 18°F (10°C) above 77°F (25°C)
- Operating a battery system below the 77°F (25°C) benchmark reduces performance but can extend the battery system life

Charging Abuses

Overcharging and undercharging is one of the central reason battery systems fail prematurely and operate correctly.

Overcharging causes:

- Cell Dry Out (VRLA)
- Accelerated aging
- Excessive polarization of the positive plate = accelerated corrosion.
- Generates more free oxygen = accelerated corrosion.
- Excessive Gassing
- Shedding of active material
- Increased water consumption
- Increase in heat generation

Undercharging causes:

- Undercharging means that the battery is not operated at a full SOC (State of Charge)
- Plate Sulfation.
    - Sulfation is a build-up of lead-sulfate crystals on plates and causes a loss of capacity that could be permanent Equalize or boost charge may fully or partially recover the unit...
- Plate deformation.

Additional charging problems can be caused by an unsuitable charger with high ripple current which causes increased positive plate corrosion, increased temperature and shorter cycle life. Unsuitable chargers generally have poor regulation which can cause undercharge or overcharge conditions.

Lastly using the wrong battery for the wrong application can cause problems. This combined with Inadequate or improper maintenance, high cycling and/or repeated deep discharges all effect battery life.

Answers to Your Questions

Why should I monitor my batteries? I already have a quarterly maintenance contract with my UPS or Battery Service Provider

The quarterly maintenance services utilized to inspect DC power plants cannot adequately assure the reliability of your mission critical battery systems. The DC power plant(s) and the cells or jars they are made up of are inherently unpredictable. This unpredictability means that battery systems can fail at any time in their life cycle without warning and have been known to fail in as little as two weeks. BTECH's battery monitoring system provides up to date information ensuring the DC plant(s) will perform to the designed specifications. Additionally when a battery monitoring system is engaged it reduces unnecessary maintenance and testing costs. BTECH'S superior information gathering techniques provide not only timely information that will improve the overall the health of your DC plant but will protect and extend the life of the DC Plant Asset.

How does Battery Monitoring help me?

BTECH battery monitoring offers several distinctive advantages over traditional maintenance programs. BTECH's products include a very unique and distinctive predictive analytical capability that enables an operator to receive up to the minute notification that a particular unit (cell or jar) has the potential to fail well before it does. A traditional maintenance program cannot provide the type of automatic analysis a battery monitoring system can. BTECH's systems allow for a combination of Real-Time notifications on critical battery system changes (thermal runaway, discharges, charge failures etc.) and long term tracking and trending analysis of key battery systems parameters. Postmortem maintenance cannot provide any Real-Time benefits. The BTECH battery monitoring system is designed to use a repeatable test that is very accurate; the way the data is reported is simple, clear and very reliable. On line stationary battery monitoring eliminates operator errors and inaccuracy inherent in manual maintenance. By utilizing the data collected by a battery monitor a user can detect and manage impending battery failures long before their backup system are affected!

Doesn't my UPS or battery charger already monitor my batteries?

The UPS or Charger only measures the DC Buss voltage and the UPS/Charger systems will not go into low battery alarm until many units have lost the ability to hold the proper voltage. The UPS/Charger does not have the capability to look at each unit in the battery system. One of the major technical advantages of the battery monitor is the ability to monitor *each slice in the loaf of bread*.

Doesn't your system just add to my costs?

Any operator looking to utilize battery monitoring to ensure DC power plant performance will need to make the investment necessary to gain the benefits of stationary battery monitoring. The battery monitoring system will reduce costs and save money, the typical ROI is two to three years which is more than reasonable given the twenty year life span of the product. In most applications the BTECH battery monitor system will long out live the batteries which are monitored. If the BTECH system eliminates just one battery system failure; you will save many thousands of dollars in potential lost revenue, data and productivity. The BTECH system will also allow you to increase system availability, shorten maintenance outage windows, prevent or reduce un-planned emergency visits, unnecessary testing (disruptive load bank testing etc.) and extra maintenance visits.

Why should I install a Monitoring System if we can buy new batteries for just a small amount more?

It has been proven that replacing the battery system does not ensure reliability; you need to do a little more. This is due to several factors, industry statistics indicate that up to 5% of new batteries fail in the first year due to infant mortality. Odds are if you install a new battery system a couple of units will be defective right out of the factory and if these units are not identified and replaced the integrity of the DC circuit is compromised. The battery monitor can detect and identify the weak units before you accept the battery system. Some units will not fail until they are in service for a while and a battery monitor can identify these units before they affect your new system, which is usually during the warranty period. Installing a new battery system does not reduce the risk of battery failure and a warranty is not the same as a performance guarantee.

Is it true that you can only install a battery monitor on a new battery system?

BTECH systems can be installed on a new application or as an aftermarket product; the system is designed to make it relatively easy in either situation. BTECH utilizes some unique techniques to calibrate the monitoring system to a battery system that has been in place for several years.

Why should I rely on impedance to determine battery health?

In the early days of BTECH's product development, our engineering team searched for tools (other than unit voltage) to determine the relative health of a cell or jar and impedance testing was invented. It became evident that as the battery aged over time the impedance of a battery (i.e. the ability of the unit to conduct and produce electricity) changed, thus causing the impedance to rise. Over the past 22 years we have proven that impedance is a very reliable tool in predicting battery failure. Subsequently IEEE, various industry associations and the battery manufacturers have all recognized the value of trending impedance. Many technical papers have been written about impedance being a leading indicator of battery health.

Please see this web page (www.cdtechno.com/custserv/pdf/7271.pdf) for a general discussion of battery impedance vs. capacity and VRLA maintenance requirements.

At what point should we replace a battery with high impedance?

The assumption is made that the behavior of any battery that has a high impedance value is unpredictable and that as the impedance value rises, the capability of a battery to hold a charge is decreased. BTECH uses a 30% rise in impedance to trigger a critical alarm on 12 Volt VRLA batteries and a 50% rise on 2 Volt Cells. If you look at the graphs in the "Complete Guide" you can see that once a battery's impedance starts to rise, it continues to rise until the point at which the battery could fail open. Because batteries have many failure modes and their failure points are not easily determined by the load placed on them, it is impossible to state exactly at which point the battery has "gone dead". By looking at rising impedance values, the BTECH software sends out an alarm recommending to the customer that they should remove a failing battery from a string before it is can affect a system's reliability.

I have been told that if bad batteries are identified the entire battery string should be replaced!

Replacing weak units as they are identified is a crucial component to ensuring long term battery system health and performance. This practice is endorsed throughout the battery industry as long as it is done in a timely manner and is performed correctly. To make this practice work, operations managers should adhere to the following principles; new cells that are identified as defective for any reason during the commissioning of a system should be replaced and those identified in the first year of service of the battery system should also be replaced as soon as possible. After this period (usually after the first year of operation) if units fail due to in-service conditions they should also be replaced, generally this should not be more that than 5% of the units in the battery system. If managers are seeing failure rates of up to 15% or 20% then something else is going on and that should be investigated as to the cause.

If we don't have initial impedance data of the batteries (often, manufacturers do not release the initial impedance), is there any means to calculate or test the initial impedance data?

Yes, regardless of whether the battery system is new or if the system has been in service for a while BTECH's technology is designed to measure and establish a baseline impedance value as a starting point for trending. The BTECH monitor is set to perform a series of impedance measurements, these measurements are analyzed and a baseline for (initial) impedance is established. The initial impedance will then be stored in memory and this measurement will be used as the baseline measurement from which the system will track and trend each battery in the system.

I have a portable battery test device, why should I buy your system?

One of the biggest benefits of stationary battery monitoring is that it happens automatically, portable impedance testers are great but you are still relying on a maintenance schedule to ensure battery performance. This takes time and scheduling, in today's budget conscience world owner/operators are now responsible for performing more tasks than usual and sometimes there is not enough time left over for some important maintenance issues. By installing a BTECH system you can collect the measurements automatically and eliminate any possible human error.

How long should it take me to review the data?

BTECH's software solutions automate the data collection and analysis process; the data is automatically collected and routed to the data-base. The data is collated and analyzed for changes immediately and the system watches for abnormalities that could affect battery system performance. The software automatically sends out analysis, notifications and real-time alarms to the facility management team.

Can the Battery Monitoring System fix bad batteries?

No, it will only indicate units that may need to be replaced in advance of them failing.

How often should the Battery Monitoring System be programmed to collect data?

The BTECH Battery Monitoring System is set to continuously collect all battery data except for impedance. The standard default program for the impedance test is usually once a week, but can be re-programmed to a customer desired schedule. Unit voltage, temperature, bus voltage, discharge current and power supply to BVS® are all monitored 24/7 and are also programmed at start-up.

Can't we solve this problem another way? For example, can't I simply buy better batteries?

Actually no, installing new batteries simply starts the process all over. Most battery manufacturers turn out the best quality product possible. With BTECH's Technology, your best strategy is to replace only the identified failed units and keep the good units that are reliable.

We have not had a problem yet so why do I really need battery monitoring?

The simple answer is that you are rolling the dice, and since batteries are extremely unpredictable you run a risk every day that your systems could fail. In all good contingency planning, your critical applications and the support technology needed to keep those systems operating are identified especially under adverse conditions, so why not monitor one of the most critical failure points, the battery system. The last thing you want is for that support technology to fail when needed or worse, be the cause of a system crash during normal operating conditions or at any time for that matter!

New Developments

Thermal runaway and the International Fire Code

In the last few years the International Fire Code has inserted recommendations regarding Thermal Runaway Management, in this standard approximately two pages are reserved for this subject. The following is an extracted from Section 608.3

Section 608.3 Change to read as shown: (F53-06/07)

608.3 Thermal runaway. VRLA and lithium metal polymer battery systems shall be provided with a listed device or other approved method to preclude, detect, and control thermal runaway.

Section 608.1, Table 608.1 Change to read as shown: (F53-06/07)

608.1 Scope. Stationary storage battery systems having an electrolyte capacity of more than 50 gallons (189L) for flooded lead acid, Nickel Cadmium, and VRLA, or 1000 pounds for Lithium-Ion and Lithium Metal Polymer, used for facility standby power, emergency power, or uninterrupted power supplies shall comply with this section and with Table 608.1.

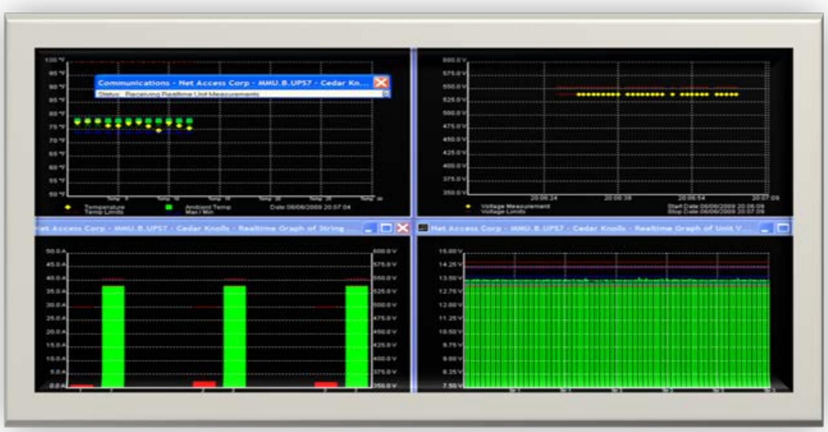
TABLE 608.1
BATTERY REQUIREMENTS

Requirement	Nonrecombinant Batteries		Recombinant Batteries		Other
	Flooded Lead Acid Batteries	Flooded Nickel Cadmium (Ni-Cd) Batteries	Valve Regulated Lead Acid (VRLA) Batteries	Lithium-Ion	Lithium Metal Polymer
Safety Caps	Venting caps (608.2.1)	Venting caps (608.2.1)	Self-resealing flame-arresting caps (608.2.2)	No caps	No caps
Thermal runaway Management	Not required	Not required	Required (608.3)	Not required	Required 608.3
Spill Control	Required (608.5)	Required (608.5)	Not required	Not required	Not Required
Neutralization	Required (608.5.1)	Required (608.5.1)	Required (608.5.2)	Not required	Not Required
Ventilation	Required (608.6.1; 608.6.2)	Required (608.6.1; 608.6.2)	Required (608.6.1; 608.6.2)	Not Required	Not Required
Signage	Required (608.7)	Required (608.7)	Required (608.7)	Required (608.7)	Required (608.7)
Seismic Protection	Required (608.8)	Required (608.8)	Required (608.8)	Required 608.8	Required 608.8
Smoke Detection	Required (608.9)	Required (608.9)	Required (608.9)	Required 608.9	Required 608.9

Generally this code is enforced by the local fire marshal; practical application has been haphazard at best. The following parameters are generally regarded as acceptable parameters for detecting *thermal runaway*.

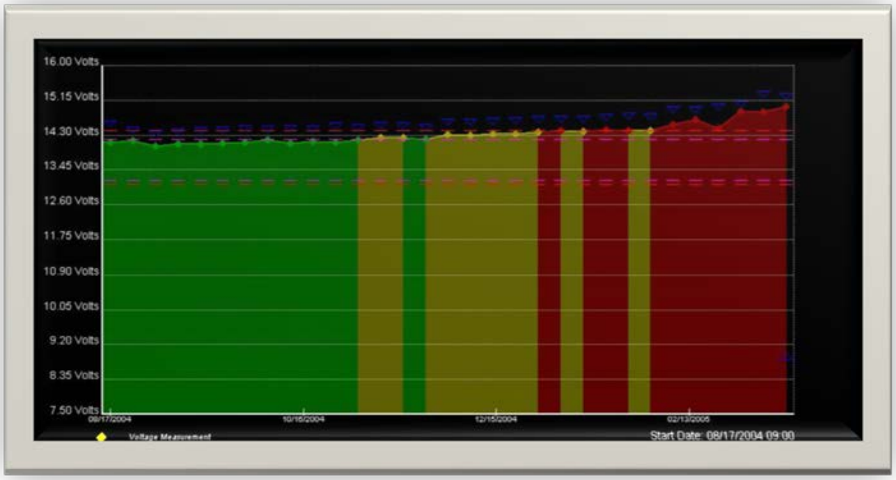
- Elevated Unit voltages
- Elevated Unit Temperatures
  - Delta Temperature
- Elevated float current
- Elevated Battery compartment temperature
- Battery Compartment Smoke
- Ground Fault

From a battery monitoring perspective a system needs to be real-time to detect thermal runaway

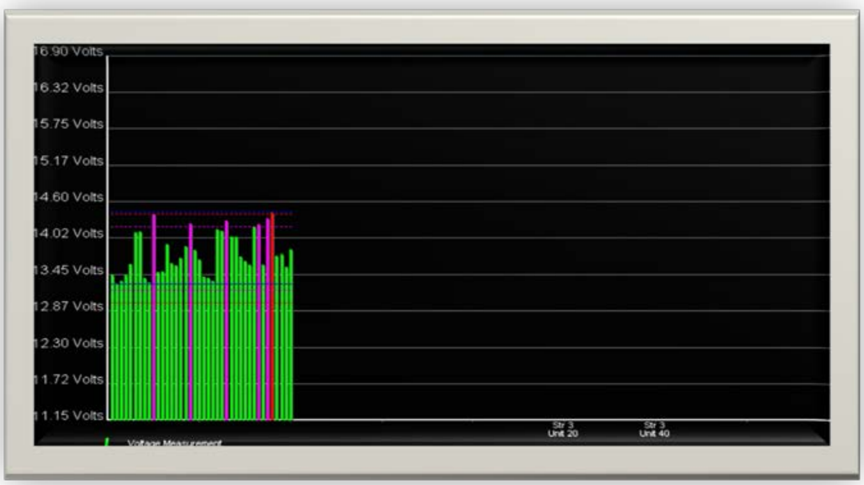


Real Time-Voltage-Temperature-Current, Smoke- Ground Fault

Elevated Unit Voltage – If the case or post seal of a cell or jar has been compromised and is leaking enough active materials to create a path to ground current will leak from the battery system through this path. The charging system will compensate by applying additional ”float current” to the battery system to make up for the current loss, eventually this will lead to elevated unit voltages. Elevated unit voltages can also be driven by shorted jars with lower float voltages, the effect is the same, the units with elevated units voltages will begin to overheat and deteriorate.

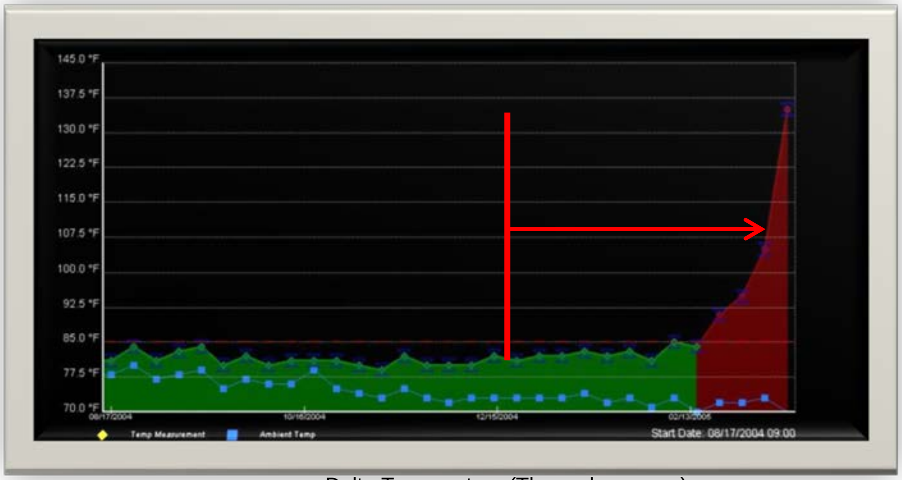


Elevated Unit Voltages



Low Voltage Units Causing Elevated Unit Voltages

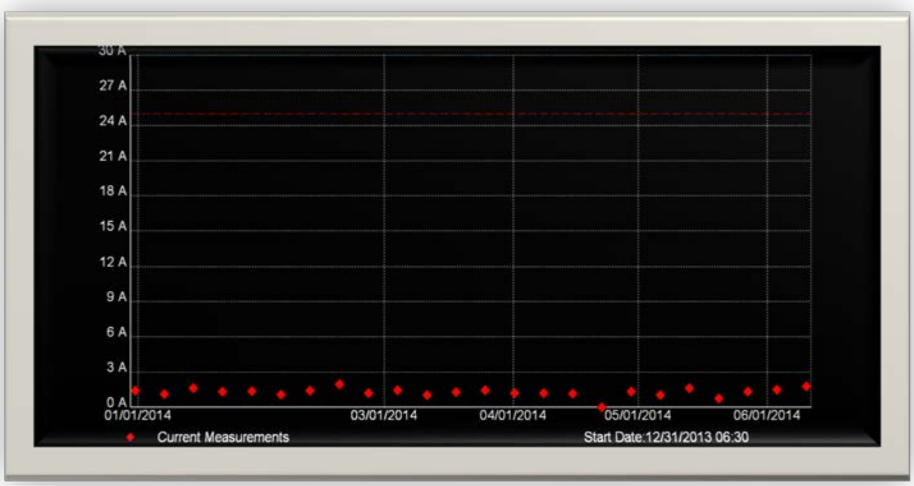
Elevated Unit Temperatures – As the unit voltages and the float current goes up the battery temperatures will rise, this can also be identified and the ability to alarm on *Delta Temperature* (the difference between the ambient temperatures and the battery temperatures) is a key metric in identifying *Thermal Runaway*



Delta Temperature (Thermal runaway)

Elevated Float Current – elevated float current is a little more difficult to rely on, this due to several reasons

a. Most manufacture measure current with a Hall Effect current transducer, depending on the manufacturer these devices can vary in accuracy from 1% – 10 % (BTECH uses a 1% device), on a 540 Volt UPS for example it may be difficult to get accurate float current data.
b. Hysteresis may affect the data
c. As battery systems age the float current naturally rises as it takes more current to keep the system at the proper float voltage. There is very little data on how much additional current indicates thermal runaway, thus accurate alarming becomes difficult.



Float Current over Time

Elevated Battery compartment temperature – Due to conditions in the battery compartment (usually a battery cabinet) some specifications call for additional Temperature sensors, these are relatively simple devices that will alarm on high temp via a Dry Contact.

Battery Compartment Smoke– Another spec driven requirement Smoke detectors can alert an operator to a sever condition Dry Contact.

Ground Fault– Specialized ground Fault devices (such as BTECH BGM-600) are designed to identify units with external short, these devices can prevent a very dangerous condition that can lead to Thermal runaway and bodily harm.

The international fire code simply recommends a "listed Device" or other *approved method to preclude, detect and prevent therma runuaway*. The IFC does very little to explain how this should actually be done, solutions range from a simple notification to the management team, automatically shutting down the battery charger and sending and alarm via the building management system to automatically opening the battery btreaker, each facility needs to make an operation decision on the methodology best suited to their needs.

Examples of Thermal Runaway

What is an Ohmic Test?

Ohmic Measurement is the terminology used by the IEEE to describe the measurement of a cell's Internal Resistance.

- Resistance
- Conductance
- Impedance

Typical Lead Acid Model (2)

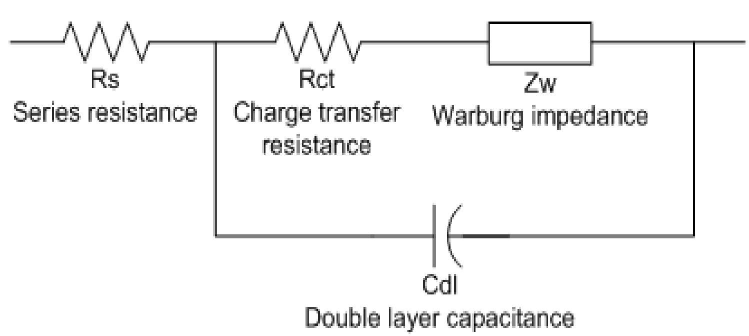


Figure J.1—Cell Equivalent Circuit Model *

Rs Series resistance (metallic), posts, straps, plate to strap, and Intercell welds. Acts as a simple resistor so does not change with frequency.

Rct - Charge transfer resistance (electrochemical)

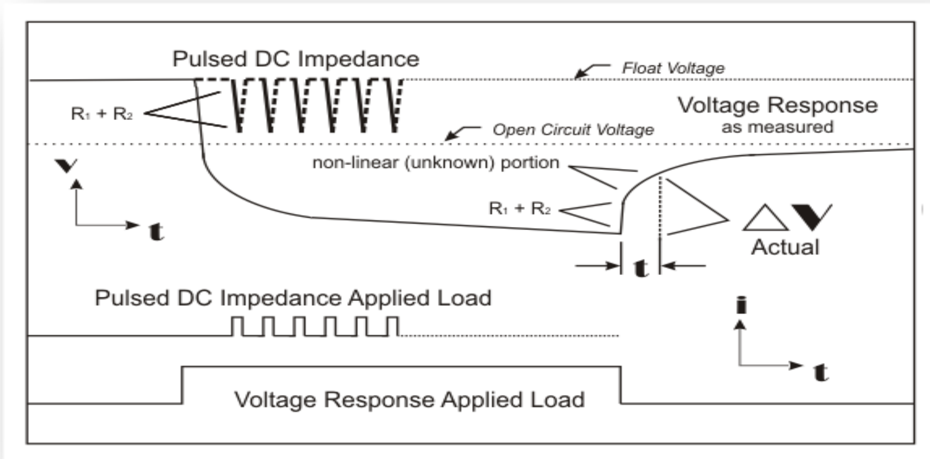
Cdl - Double layer capacitance (electrochemical), charge separation near the surface of the electrodes from ions close to the plate surface.

Zw - Warburg (Diffusional) impedance (electrochemical), non linear diffusion of ions in the electrolyte.

Internal ohmic testing is based on measuring the response of the cell to a voltage or current stimulus, and relating the response to an ohmic value. The values of the components of the model (Rs, Cdl, and Rct) correlate to the ohmic value calculated by the instrument.

- A high frequency test signal will tend toward Rs, the Metallic Resistor
- A low frequency test signal will tend towards Rs + Rct + Zw, the entire battery, at high frequency Z ≈ Rs, at low frequency Z ≈ Rs + Rct + Zw tests at no frequency tend toward RS
- A DC resistance test only measures Rs and Rct and ignores Zw and Cdl Impedance testing uses an AC signal to include the capacitor in the measurement

BTECH 215 Ω, Impedance Technology, the reference standard for Ohmic testing



BTECH's patented impedance technology is designed for any battery type, technology and amp hour rating, without discharging the unit and detects all failure modes

BATTERY MONITORING TECHNOLOGIES

Battery Monitoring is a technology that enables both real-time notifications of changes in battery conditions that can impact (DC) plant reliability and long term proactive tracking and trending of battery health.

The benefits of battery monitoring:

- Real time condition reporting
- Predictive Analysis
- Ability to integrate DC plant status into the facility
- Improved safety
- Improved testing
- Improved availability
- Excellent data storage, archiving and accessibility
- Reduction of unnecessary maintenance
- Risk and revenue lost due to downtime are virtually eliminated
- Extended battery life
- Improved continuity
- Better warranty support

There are basically three levels of battery monitoring:

- Low end data collectors
- PC/server based systems
- Autonomous systems

<u>Low End Collectors</u>

Low end data collectors are defined by the amount of data the units collect, generally the units are limited to current or temperature and their main functions are to support warranty claims. Most units lack software and require the operator to interrogate the unit locally by collecting data via a log file (.csv) or some other method. Some manufacturers may add buss voltage. In all instances such systems provide limited trending, the systems do not have any predicative capability and do not take measurements at the cell or jar level.

Typical data points included and featured in low end collectors:

- System voltage
- System current
- Ambient temperature
- Quantity and duration of discharges

Purpose and Capability

- Designed for warrantee compliance
- Limited system capability
- Lack of software
- No support
- Little or no integration capability
- No real-time capability

<u>PC/server based systems</u>

These types of systems are defined by the addition of looking at units or groups of cells, some systems are voltage only systems. Software may or may not be available, it depends on the manufacturer. Most of these systems are not real time and have limited predicative capability.

Typical Data points available from Mid-Range battery monitor (PC/Server based systems):

- Unit level measurements added
    - Unit voltage
    - Unit ohmic measurements
    - Unit temperatures (jar or cell temperatures some systems record the temperatures of all the units some pilot cell temperatures
- High component count
- Modules powered from the battery

- Parasitic battery loads can lead to premature aging of the cell or jar
- Proprietary software or limited software
- Difficult to integrate
- Ineffective on many battery types

Many systems cannot collect ohmic data on all battery types; these systems are usually modular and are characterized by a module on each cell or jar. Systems like this have a limited ability to collect data on the largest battery types because the modules apply a single low amperage test load to the unit. Additional consideration includes the fact that the modules are powered from the unit and place a parasitic draw on the unit.

  - Monitoring Module
- Some systems can only collect data at the jar level
- Cell masking
  - Cell masking is found in technologies that can only monitor groups of jars or cells, this is very undesirable because a unit in the group can fail but the data is “masked” by the system monitoring it.
- Single point of failure
  - Some system architectures manage several independent battery systems with a single master controller or server. This Master is essentially a single point of failure; if the master fails connectivity to the battery systems connected to it is lost. Robust system design provides for a single self-contained system for each independent battery string.
- No real-time capability

Autonomous Systems

Autonomous systems are not limited by battery technology, integration issues and produce predictable reliable data. These systems are defined by robust software, multiple communications options and the companies that produce the systems are full service organizations with tech support and direct services

Typical Performance Parameters

- Real-time systems
- All parameters measured at system, string and unit levels
- System functions as IEEE compliant discharge data recorder
- Intelligent front ends operate without the need for a dedicated computer or server
- Robust ohmic measurements
- Ability to collect data on the largest amp hour cells
- Easy integration into the building management systems
- Communicate via Modbus
- SNMP (simple network management protocol)
- Input and output dry contacts
- Easy to use interpretive software
- Direct support
  - Field Services
    - ✓ Installation
    - ✓ Startup
    - ✓ Commissioning
    - ✓ Training
    - ✓ Preventative maintenance services
  - Maintenance agreements available
  - Remote monitoring services
  - Training available
  - Tech support readily available
- The only technologies that can support the International Fire Code Requirements

BTECH Monitoring Center Background

When BTECH developed the first stationary battery monitoring system based on trend analysis, the importance of assisting the customer in learning about their batteries and battery problems was understood from the beginning. BTECH keeps an extensive reference database of battery measurement data for customers and helps them in recognizing problem batteries. Our collection of battery failure data is unique and allows us to claim an understanding of battery failure that is unmatched in the industry.

Today, BTECH actively monitors many thousands of battery units. Many Fortune 50 customers place their trust in the ability of our battery monitoring systems and our staff of trained battery experts to assure their systems will work when needed. The failure analysis published here is the result of over ten years of collecting and analyzing battery failure data.

How to Read the Graphs

The monitoring of individual battery voltage, impedance and temperature gives a wealth of data to analyze. Let us go over each of the data types and their significance to battery health. Case studies that illustrate the relationships between these measurements will follow afterwards – and will show you how to analyze the data from your BTECH monitoring system yourself!

Impedance – BTECH pioneered the on-line measurement of impedance to determine battery health, in the early 1990s – the early days of the company – we needed to convince the technical community that this was a valid argument. Fast forward to 2016 – today impedance is accepted after being proven in practical use by our customers and in the large number of technical papers verified by the engineering community. Generally, one can state that when the impedance rises 50% or more above the baseline or initial impedance (values given by the battery manufacturers and defined by battery type and size) that the battery is at risk and is on a path to failure. Moreover, a rapid impedance rise is more common in the sealed VRLA or “maintenance-free” batteries that short open, larger 2 volt VRLA and VLA applications (VLA cells short closed) experience longer impedance rise indicative of the inherent design life.

Voltage – Voltage has traditionally been the way battery service personnel would detect bad batteries. In general, when the individual cell or unit voltage has declined significantly, the battery has been at risk for considerable time – especially with VRLA batteries. Most often – but not always - voltage change lags impedance. On larger (1000 AH+) wet cell batteries, voltage can change before impedance. The monitoring system will detect these changes and make you aware of them.

Temperature – One of the most overlooked measurements is temperature. The ambient temperature of the batteries significantly affects service life. For every 18° above the standard reference of 77ºF, your service life decreases by 50% our monitoring systems have detected several cases where customers have switched off air conditioning systems to save money on weekends and then wondered why their batteries were failing early! We have also detected failed air conditioning systems at remote sites this way.

Graph Types: The Complete Guide shows battery data in a variety of formats:

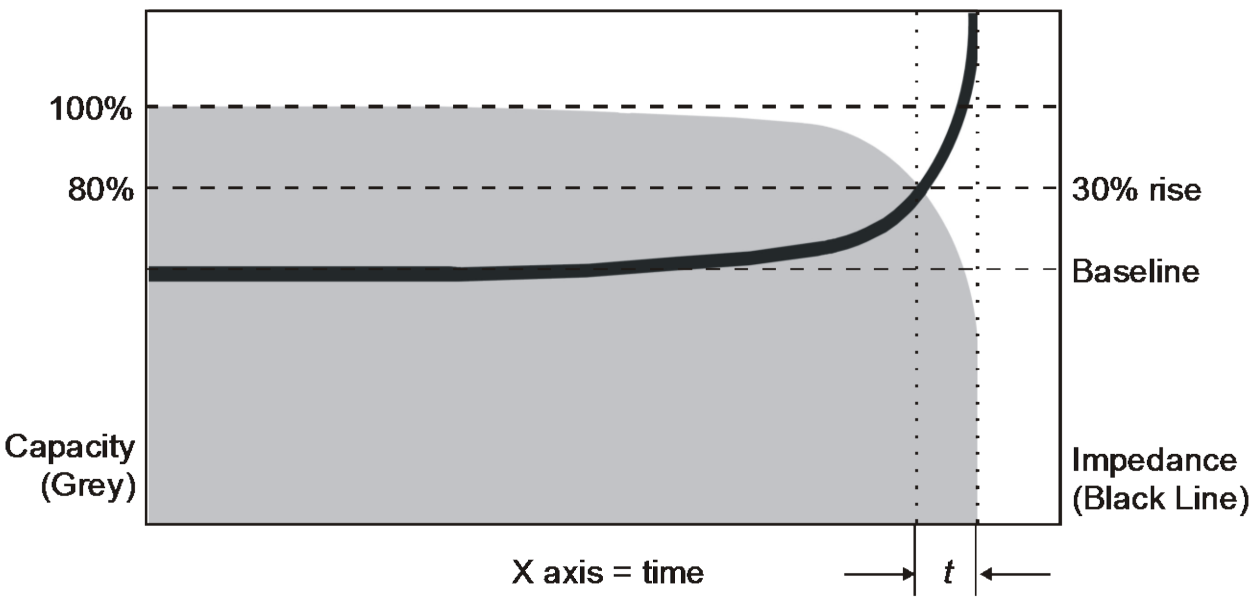
System/Unit Snapshot: Voltage, Impedance and Temperature measurements made at one specific time are shown for all of the units in the battery system

System/Unit Trend: Trended Voltage, Impedance and Temperature measurements are shown vs. time. Each data point represents a weekly measurement, which is typically all that is needed to detect problems in advance.

Discharge Voltage vs. Time: During a discharge, a data log is created with saved voltage vs. time data with the time in seconds. This is used to display battery performance during the discharge.

Battery Lifecycle Explained: VRLA Batteries

BTECH's Battery Life Cycle Graph



BTECH's battery lifecycle graph displays important relationships between impedance and capacity for VRLA batteries. Some important points that stand out:

- The baseline impedance, which is measured for each battery in the string by the BTECH monitoring system after the system has passed the initial discharge test, equates to 100% capacity when the battery is new.
- A 30% rise in impedance above the baseline roughly equates to 80% battery capacity, which is the point at which the IEEE recommends immediate replacement. Based on recommendations of a number of battery manufacturers, BTECH has adopted the 30% value as the critical impedance alarm point – the time for the user to schedule a service visit to possibly replace the battery.
- The behavior of the battery after the 80% capacity point is reached is unpredictable, making the time from the 80% point to outright failure, as displayed on the graph as "t", indefinable.
- Because the behavior of VRLA batteries has been demonstrated by BTECH to be unpredictable, capacity remaining or time remaining functions built into current UPS systems or competitive monitoring systems are inherently inaccurate. BTECH believes it is technically impossible to provide accurate time-remaining data.
- The only way to ensure the integrity of your VRLA battery system is to replace the failing battery in the string when the impedance rises 30%, when the data from BTECH's monitoring system tells you.

Battery Lifecycle Explained: Early Detection is the key

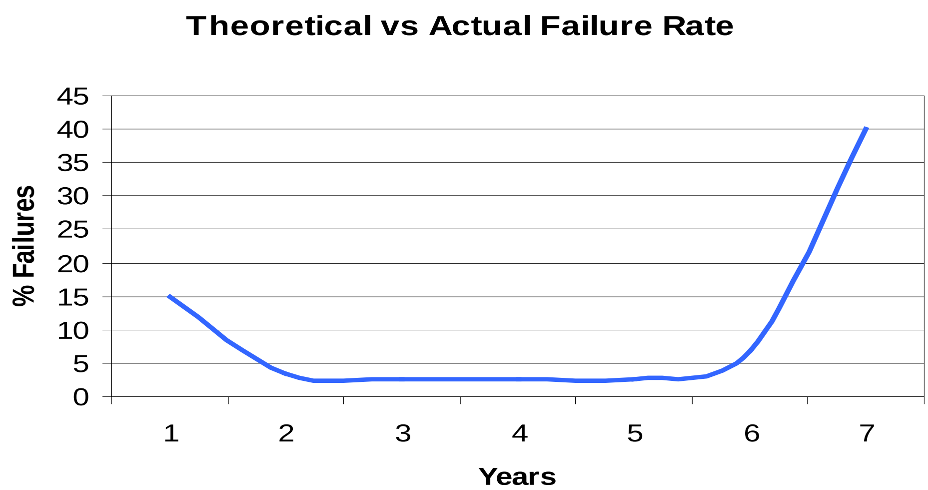


Diagram I

Battery manufacturer's studies expect unit failures to manifest themselves in the pattern displayed in Diagram 1. Industry studies indicate 3% – 5% unit failure rate in the first 18 months of use is normal, than a long period of reliability during the useful life of the battery system. As the batteries age and loose capacity a rapid increase in the failure rate is expected as the graph indicates.

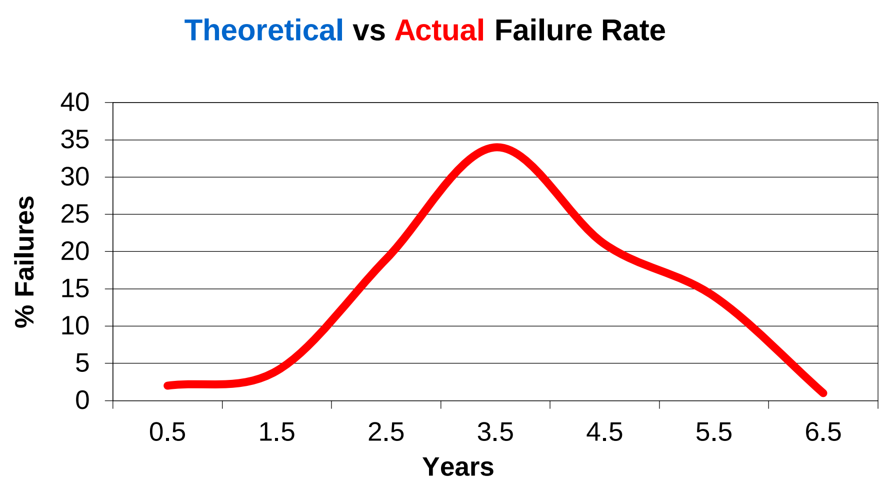


Diagram 2

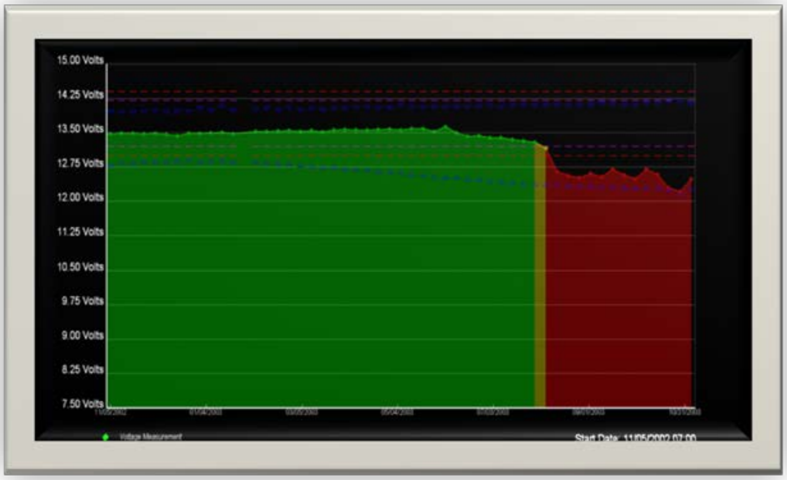
What the industry actually experiences is something totally different; Diagram 2 identifies the highest failure rate 3.5 years into the operation of the battery system.
Why, there are several reasons

A. Improper or non-existing acceptance testing of the battery when installed
B. Improper or insufficient maintenance routines
C. Failure to identify weak units that ultimately ruin the battery system.

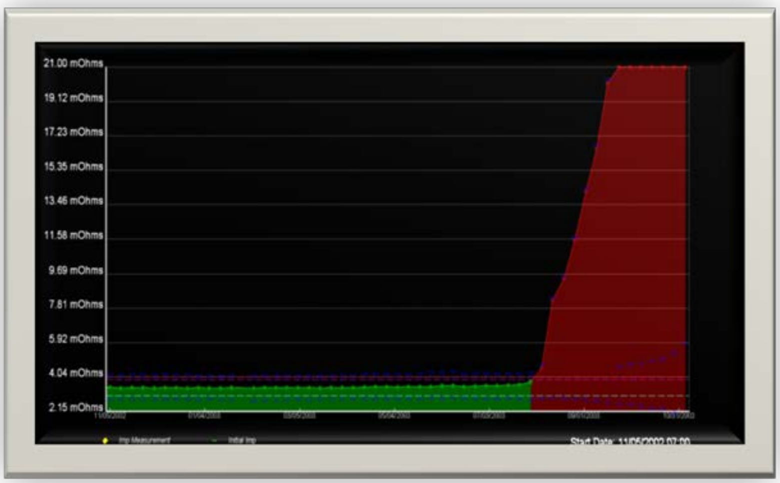
Conclusion: If a battery system has weak or shorted units that are not holding a charge the charging system compensates by adding more current to the system to maintain the proper float voltage. In constant voltage applications the charging system must do this to hold the system at the preset Float Voltage. When this happens the units surrounding the weak units become overcharged, resulting in excess gassing, corrosion and cell dry out (VRLA) systems.

Remedy: Battery monitoring eliminates this scenario

Example #1 –Ignoring the Warning: A 2-Week Failure



Unit #13 Voltage vs. Time



Unit #13 Impedance vs. Time

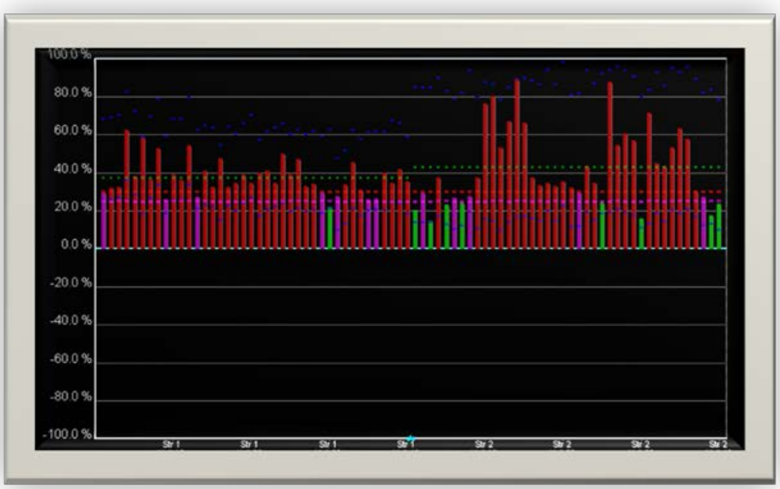
Background: Unit #13 illustrates a classic impedance and voltage trend observed at the BTECH Monitoring Center. The graph finds impedance rising rapidly within a 2-week period, showing the importance of weekly monitoring. The 300% rise in impedance corresponds with a 1.5 volt drop in the unit voltage. That data proves why impedance is a key factor in determining battery health, the BTECH system created a critical high impedance alarm (9) nine weeks before a critical voltage alarm was generated, this confirms what we have learned that Impedance is the leading indicator of battery health not voltage. With VRLA technologies impedance *leads* voltage as key metric in battery system data.

Conclusion: The UPS that this unit supports is at risk of failure, and depending on where the customer is in their battery maintenance schedule; this failed unit may go undetected for several months. Using BTECH's system, the user replaced the bad unit before it posed a risk.

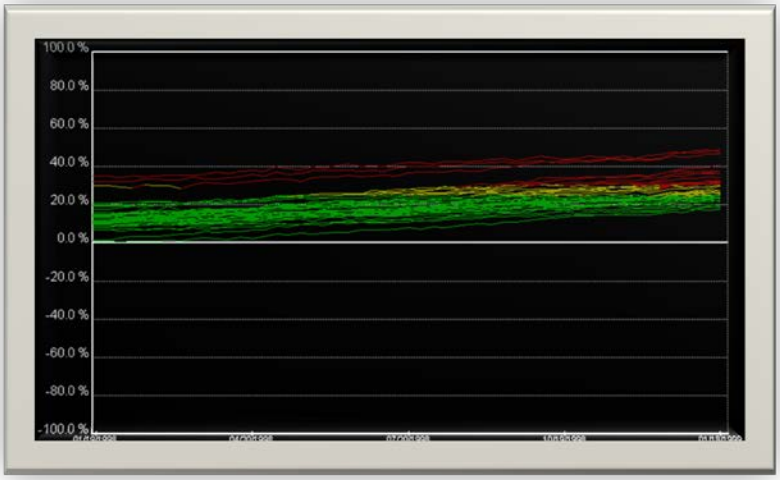
Example #2 – Impedance Vs. voltage

Snapshot of Unit Voltage

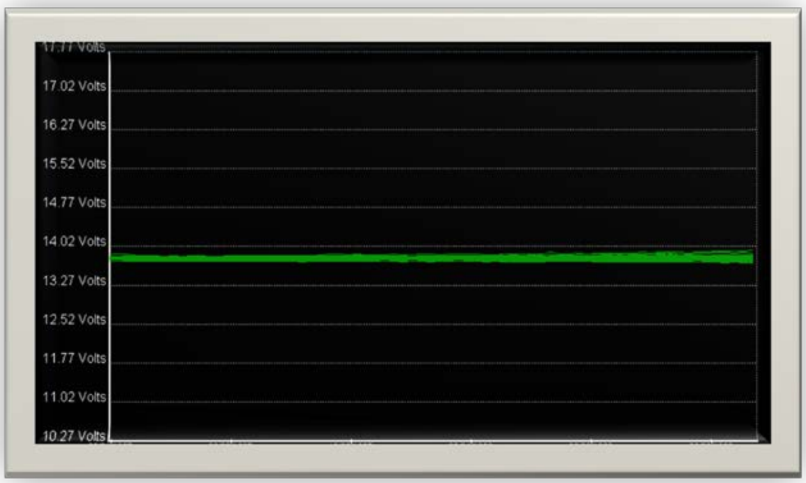
Snapshot of Unit Impedance



Differential Impedance Graph



Differential Impedance Graph – All Units



Unit Voltage – All Units

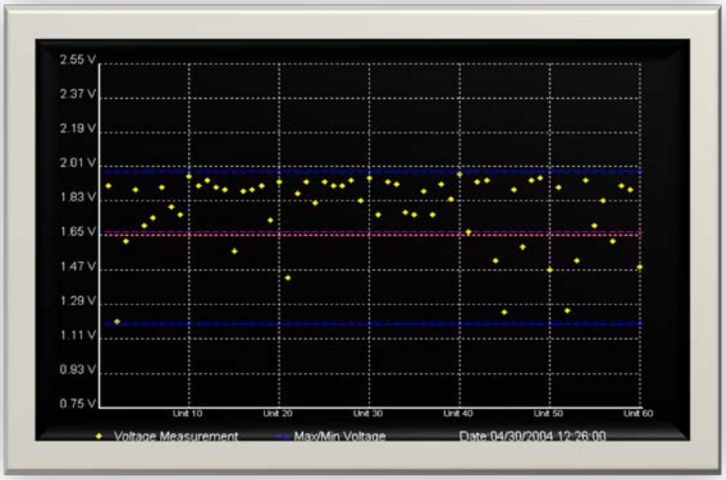
Background: These graphs illustrate why comparing impedance to voltage is critical. This data is from a two string (80) jar system with (40) jars per string. The data is displayed is in the form of both snap shot and trends.

The voltage graphs have critical high and low parameters defined by the Red Lines if a unit was above or below the red line an alarm would be generated, there are maintenance parameters defined by purple lines, an alarm can be generated if the unit is above or below these lines. From a voltage perspective there is really not much to be concerned with.

The Impedance graphs tell a much different story, impedance alarms are generated by a percentage change from the baseline (indicated by the green + signs), this system is set up to provide a maintenance alarm (purple)at a 20 % rise and critical alarm (red) 30% voltage trend observed at the BTECH Monitoring Center. Many of the batteries in this system are well above the 30% critical threshold; the average impedance rise for all the batteries is 29%

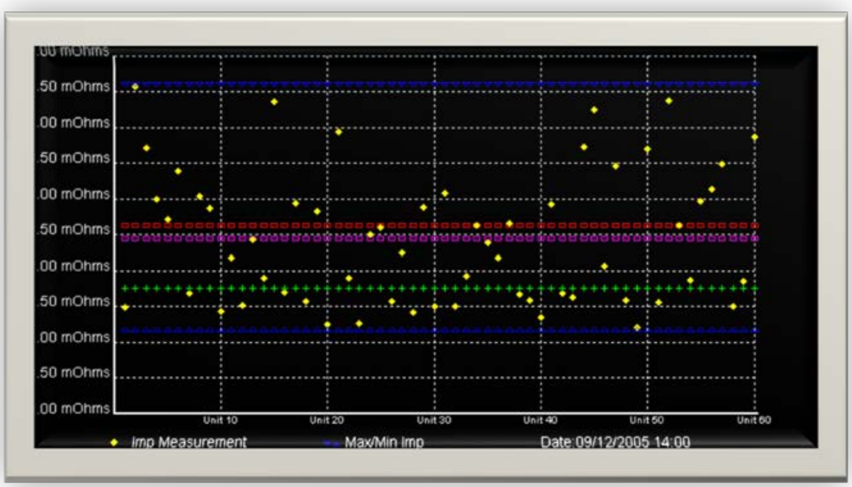
Conclusion: The UPS that this battery system supports is at risk of failure, as the data shows relying on only voltage data can provide a false sense of security. While voltage data is critical in identifying shorted cells impedance data tells us about the internal conditions of the unit and the unit's ability to conduct and produce electricity. If a load was placed on this system the worst case scenario is the UPS failed outright, the best case scenario is the UPS failed to make the deigned run time.

Example #3 – Discharge Analysis

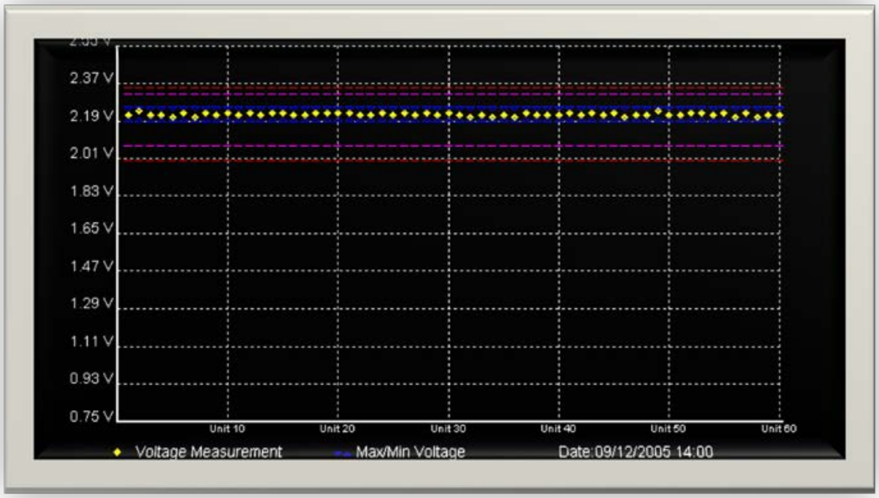


Snap shot of unit voltages under discharge

Snap shot of unit voltages at Low Voltage Cut off



High impedance cell after discharge

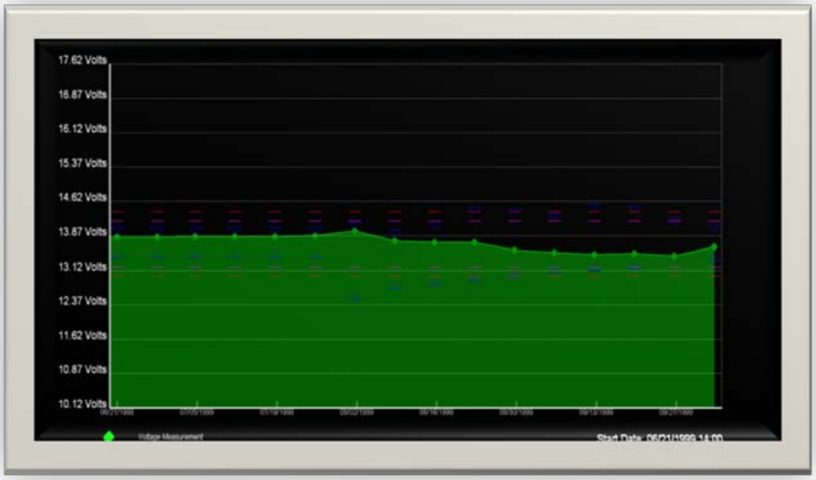


Voltage readings indicate the battery is "ok"

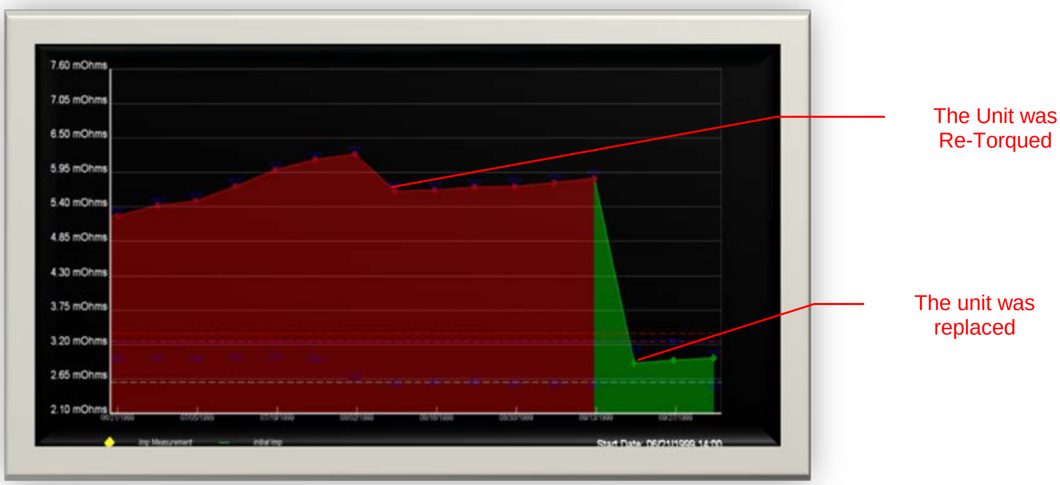
Background: This data demonstrates the value of the battery monitor functioning as a data logger. The 60 cell system in this case was run past the cut off voltage and many of the cells went below the battery manufactures recommended cut of point. When this happens the useful life of the battery system is reduced dramatically. Subsequent tracking and analysis of the impedance data proves this out, as the cells aged after the discharge the impedances rose rapidly and the data identified that the cells which were discharged the deepest had the greatest rise in impedance.

Conclusion: The automatic data logging by the battery monitor and regular trending after a discharge event is a valuable tool in ensuring battery system reliability. Any discharged planned or not can tell you how a battery system performed compared to the design parameters, only a battery monitoring can tell you how the system will perform tomorrow.

Example #4 – Effects of Re-Torqueing – Unnecessary Maintenance



Unit #67 Voltage vs. Time

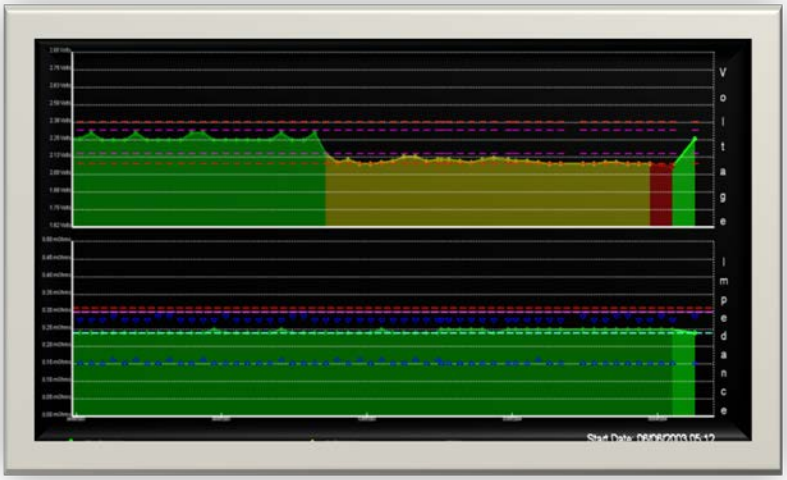


Unit #67 Impedance vs. Time

Background: Unit #67 shows impedance starting at 80% and finishing at 120% above the baseline. In this case, the customer had battery maintenance performed in the beginning of August, hoping to cure the failing unit. Although re-torqueing the connections lowered the impedance, the unit continued to exist in a failed state. The customer replaced the unit in the middle of September during a second service call.

Conclusion: The customer would have saved the cost of the second service call if the customer had replaced the failed battery by looking at the data in mid-June, and the time UPS was at risk could have been shortened by three months!

Example #5 – A Short Forms in a Flooded (Wet) Cell

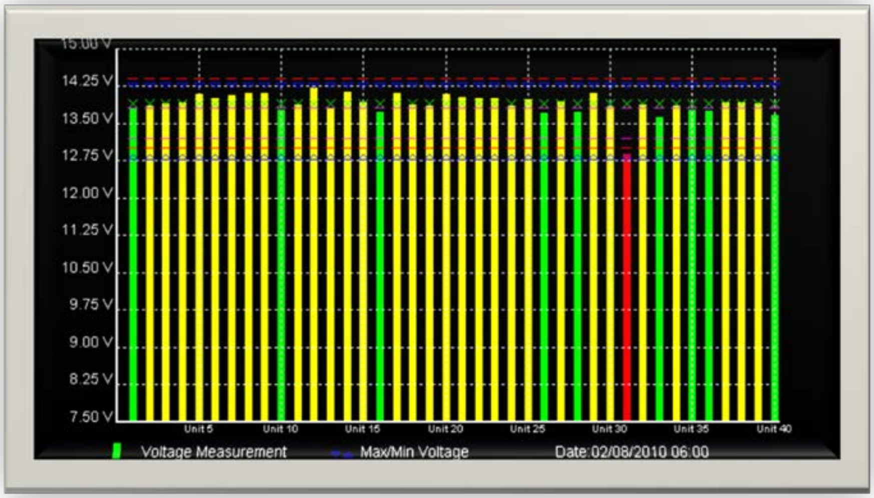


Unit #213 Voltage and Impedance vs. Time

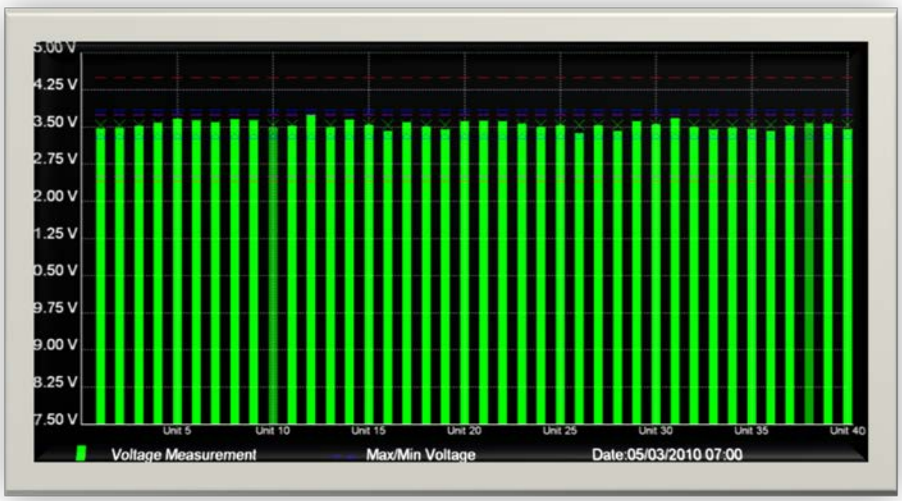
Background: Here is an interesting case on a large flooded (wet) cell string where the voltage change of one unit actually occurred before impedance. Voltages declined 10% quickly over a two-week period. From the graph, we were able to deduce that this battery had a small dendritic short, causing the voltage change. This customer needed to replace the unit immediately.

Conclusion: This is a great example where the monitoring system can provide measurement data good enough to understand what is happening with your batteries. Particularly with large flooded cells rated above 1000 Amp Hr, the change in impedance can actually lag the voltage.

Example #6 – Effects of Failed Batteries on Others



One String of 40 Batteries – Voltage vs. Unit Number
Unit 32 is defective



One String of 40 Jars – Voltage vs. Unit number
The unit has been replaced

Background: These graphs show the impact of a faulty jar on the surrounding batteries, in a float application the battery charge will hold the batteries at a predetermined voltage (540 volts in this case), if a unit is damaged and cannot support the voltage the surrounding units present a higher voltage, over time this condition would shorten both the reliability and life of the battery system.

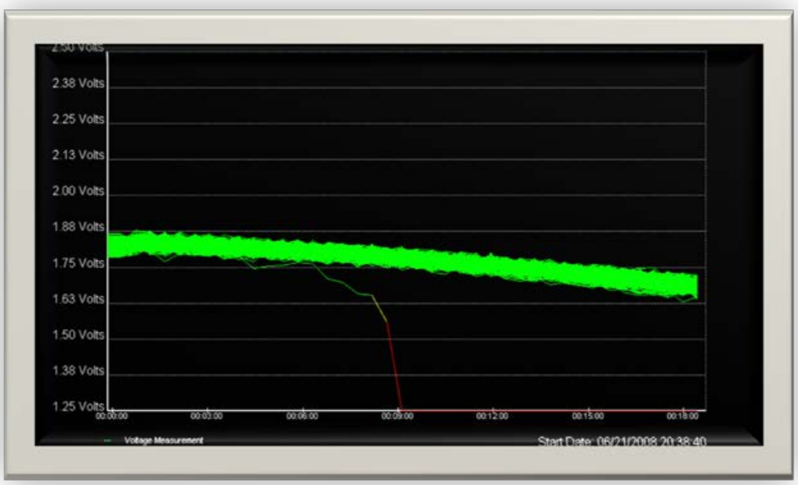
Conclusion: A great example to show how bad batteries affect others in the string – the lowered voltages of the failed units have driven up the float voltages of those remaining, possibly overcharging them. Changing the faulty unit will improve the reliability of the system and extend the life of the system eliminating several potential problems.

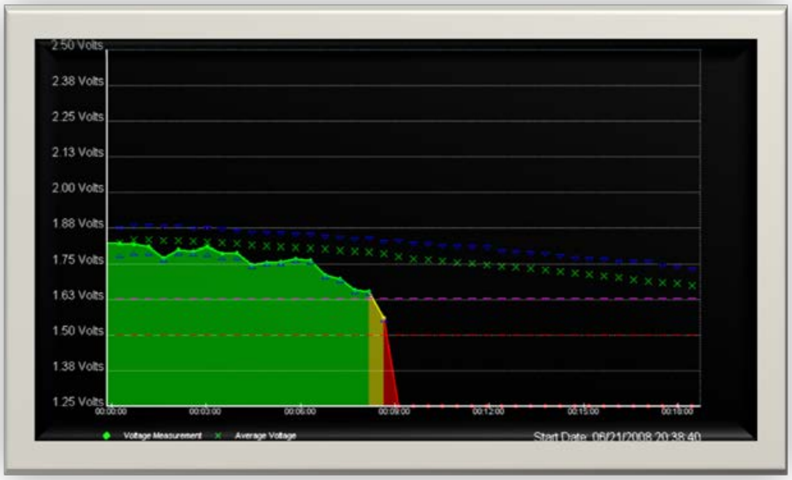
Example #7 – The Importance of Analysis

Unit 53 in String 1 (10/31/2008)	1.198 mOhms	At the present trend, the rising impedance will exceed the maintenance limit within 14 days.

Background: This graph is an example of rising impedance, most battery monitors are *set limit* products, if a specific value crosses a threshold than an alarm is triggered, the key to best utilizing the battery monitor is to choose a product that predicts a battery fails before it actually does. This will enable the user to proactively manage the battery system.

Conclusion: Notice how the yellow line extends past the last measurement date, this line extrapolates out how the battery is deteriorating past the last time data was recorded. This is extremely valuable in predicting battery failures and enable real time battery management.





BTECH Commissioning discharge test
Discharge Durations

Date and Time	Duration	6/21/2008 20:38	0:18:35

Notes Unit 234 died @~9 minutes in

Unit 233	Within Limits
Unit 234	This unit exhibited significantly lower performance during discharge than most other units in the same string.

Background: This graph is an example of a cell that underperformed during an acceptance test; the analysis provided by the battery monitor enabled the commissioning team to proactively replace the cells under warranty before the battery was accepted.

Conclusion: An acceptance test and Data Logging are essential to ensuring a new battery system is reliable; additionally proper analysis is key anytime the battery system is discharged

Background: This graph is an comparative example of impedance rise over time, the graph trends all of the unit impedances over time, the impedance rise is presented as a percentage change from the initial impedances were recorded. Utilizing this type of analysis makes it very easy to identify which units are critical and require replacement.

Conclusion: Comparing new data to existing data with Automatic and Automated analysis creates a dynamic real-time examination of the battery, pending failures can be identified and remediated well before the situation becomes critical

Conclusion: A Call for Action

We've presented a plan here for you to implement in your facility, changing the way you are managing your batteries by using trend data. The trend data obtained from BTECH's battery monitoring products show how critical the DC plant is to your operation - especially since just one rogue battery is able to cause a complete system failure. BTECH's data proves mission critical battery systems stand at risk of failure because of hidden battery problems, problems only a battery monitor can solve.

BTECH recommends a shift in the way batteries are monitored and maintained. The current IEEE battery management recommendations cannot guarantee the batteries will function when needed. Only by moving to a battery management program based on real-time, data-based, continuous impedance measurement, can risk due to battery failure be virtually eliminated.

We will be happy to assist your implementation of this new recommendation by choosing the right battery monitoring system for your application and recommending a battery service provider who will use the data from our systems. To find out more about our products and services, visit http://www.btechinc.com, or call us at the number below!

About BTECH’s NEVERFAIL Battery Monitoring Partnership

BTECH’s NEVERFAIL service is a partnership between you and BTECH... and a comprehensive program to ensure the integrity of your backup batteries.

The back bone of this service is BTECH’s Monitoring Service Center, the MSC manages data worldwide 24/7 and provides automatic distribution and analysis of the critical battery data, real-time. The monitoring team is in constant contact with our customers and proactively ensures industry best DC plant reliability. Whether you depend on 2, 20 or 20,000 units the NEVERFAIL program is the solution for your organization, the program includes three critical elements:

1. BTECH’s benchmark battery monitoring products, designed and configured for your unique applications

2. Remote "around-the-clock" data collection, analysis and alarm reporting by BTECH’s staff of trained experts

3. Regular on-site inspections and preventative maintenance of the monitoring hardware, – the vital human link –to observe and correct all risk factors.

NEVERFAIL is the result of BTECH's 25 years' experience and more than 7,000 installations worldwide. We hold patents to key battery monitoring technologies that produce consistent, reliable data from virtually every battery type and manufacturer.

You'll find our systems where critical backup power is needed most, including:

- Government agencies;
- Military installations;
- Public utilities;
- Fortune 500 multinationals;
- Business enterprises in every industry and on every continent, including Antarctica!

Contact BTECH, Inc. at 973-983-1120 or visit *www.btechinc.com*