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WHITE PAPER

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Why Monitor Your Standby Battery?

Why monitor your battery?

- To ensure that it will function immediately and reliably when it is required.
- To obtain the maximum service life possible from the battery.
- To save on time, cost and resource
- To comply with statutory regulations and recommendations

✓ Continuous battery monitoring can help the user achieve all these things

Note

In standby battery systems the terms 'cell', 'monobloc' ('bloc) and 'unit' refer to an individual unit within a 'battery', which may be made up of anything from 4 x 12 volt blocs to several hundred 2 volt cells. For the purpose of this paper these terms are interchangeable.

Examples

Although UPS systems are used as an example, this paper applies to all standby battery systems that support critical loads: utilities, telecom, fire & safety systems and generator start batteries are some other example applications.

Mean Time Between Failures (MTBF)

Perhaps 35 years ago the MTBF (Mean Time Between Failures) of electronic UPS (Uninterruptible Power Supply) systems was estimated using a long and complex calculation involving the failure rates of all the system components, including every chip, resistor and capacitor. This calculation would hopefully come out in tens of years and was at best a 'guesstimate'. Even then, when complex electronics were a lot younger and less predictable than they are now, the standby battery was recognised to be the weakest part of the system, particularly if the battery was of the (then) new VRLA type.

Today historical data of the electronic sections of the UPS and chargers have, over many years, proven MTBF calculations to be mainly true, apart from the odd failure, and the failure rate of the electronics is even lower today than it was then. This can't be said of the battery; while VRLA failure rates have gone down slightly, the battery is still the most common failure in the UPS, and always will be so. In fact in the 2013 Ponemon Institute survey of over 584 managers who have responsibility for one or more data centers, 85% had at least one power outage per year in the previous two years and of those 91% had an unplanned outage to the load.

There is only one guaranteed circumstance in standby battery systems: the battery ***will*** fail. All batteries fail at some stage; the trick is to know when ahead of time and do something about it, so that your plant or commercial systems aren't affected.

All standby batteries are composed of battery cells in series or series/parallel to achieve the necessary voltage and power for the system. Some batteries achieve their planned end-of-life without a single cell or monobloc (bloc) failure; most batteries have a few individual cell failures on the way. This can mean that if one cell fails open-circuit (or very high resistance) the whole battery will fail. If, on the other hand, a cell fails by shorting, the battery will have a much shorter hold-up time and a very much reduced service life than the battery was designed for.

The battery is the primary cause of UPS failure

The Ponemon survey showed that despite electronic infrastructure having become much more complicated than a few years ago, the single major cause (an average of 60% per year over two years) of power outages affecting the critical load was the failure of the UPS battery.

A recognised problem

The above statements are recognised throughout the battery industry, so it makes complete sense to monitor the battery to ensure it is in good condition and will respond when needed doesn't it? Nobody wants the disruption, data and financial losses, and the sometimes life-threatening problems of a supply failure to the critical load do they? Not to mention the high cost, confusion and loss of business during disaster recovery?

Well no, no-one does want these things, so the number of UPS users who don't pro-actively monitor their standby batteries is constantly surprising.

The Ponemon survey showed that every outage (one or more a year for the majority of the companies polled) averaged a loss of over $200,000 USD, which makes the investment in a monitoring system look pretty small by comparison.

It is the proud boast of more than one battery monitoring company that there has never been a supply failure to the critical load of a battery monitored by their systems. Providing that intelligent attention is paid to the data collected, this is believable.

Why then do the majority of critical system users not monitor their battery systems as a matter of course?

Why aren't all standby batteries monitored?

There are several reasons for not monitoring standby batteries, but the primary reason is cost. A premier battery monitoring system can cost maybe 60-70 percent of the cost of the battery; added to that is the cost of the installation, perhaps another 20-50% of the battery cost. This makes it prohibitive for many users, quite a few of whom decide to change-out the battery earlier than would otherwise be indicated.

Changing-out batteries more often than necessary is very short-sighted; it not only means that over time the system is far more expensive than it needs to be, but there are often burn-in failures of new cells which put the critical load in even more danger than normal, and the user still doesn't know when his battery will fail.

Given all the problems that can arise if the battery fails it would seem that it is very short-sighted not to monitor your battery due to cost. Everyone takes out driver's insurance on their car, even though it's expensive and there are only a low percentage of accidents per number of drivers annually. You *may* have an accident in your driving life; many people don't. On the other hand your standby battery <u>will</u> fail; it's a fact of life. Batteries are <u>guaranteed</u> to fail at some time, you just don't know when…

In the UPS industry a second major cause of not monitoring the battery is that the battery in a UPS system is normally supplied by the UPS manufacturer, and UPS sales people are always bidding against each other. To suggest that the battery they are supplying may not be totally reliable, and propose an additional cost, is something that none of the UPS (or charger) companies want to do. In fact most of the time they will only quote a battery monitoring system if the customer (or his consultant) requires it.

In this they do their customer a disservice and, if the battery fails, often cost them a great deal of money. If there was a history of heart disease in your family and your doctor said checking for heart disease it wasn't important, you wouldn't be very impressed, would you? Don't forget, 60% of data centre UPS failures are caused by the battery…..

Monthly, Quarterly and Annual maintenance

Quite simply, a lot of maintenance just doesn't get done. The IEEE considers it is essential that monthly inspections of the individual cells of standby batteries are carried out, and as a minimum quarterly measurements of parameters, such as temperature and resistance or impedance are measured and recorded. The battery should also be discharge tested once per year or, as a minimum, at least once every two years.

US NERC PRC-005 requires that the battery and, if VLA cell, cell electrolyte levels, are monitored and the data analysed for security of supply. This is very labour intensive.

It often happens that, due to commercial pressures, trained technical personnel are not available, or too pressed to carry out inspections and measurements. Resource cutbacks mean that the maintenance is outsourced, however this doesn't mean that all is necessarily well. A major UPS manufacturer recently admitted privately that only 70% of its contracted maintenance visits are carried out because, due to staff reductions, they can't get round to them all in time.

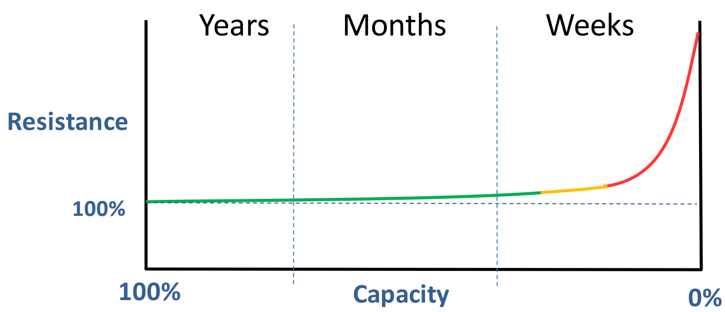
Another major point against reliance on purely maintenance visits is that it is quite possible that the battery can fail between one maintenance visit and the next. Battery systems can fail within weeks of a fault developing, so quarterly maintenance is only really reliable if the battery has a redundant string.

Although maintenance initially appears less expensive than a full continuous monitoring system, this doesn't hold true over the service life of the battery. Many companies have cut back their technical staff and have to out-source technical tasks. This can mean the cost-effective (and technically more effective) option is to install a continuous monitoring system.

Last, but not least, the best indicator of incipient failure for standby batteries is the 'Ohmic' test, the measurement of the DC resistance or AC impedance of the cell (conductance, advocated by at least one major instrument manufacturer, is defined electrically as 1 divided by resistance, so it is resistance which is measured).

Ohmic testing as part of annual maintenance

Ohmic testing is undoubtedly the best non-intrusive indicator of cell condition available at this time; however the maximum change in the resistance, whether it is from old age or from a failure mode, such as corrosion, sulphation or dry-out, comes at the last stage of cell failure. It is difficult to detect small rises, so this doesn't leave a great deal of time to change out the cell before it fails, and failures can occur between one maintenance visit and the next.



Much the optimum solution in Ohmic testing therefore is continuous monitoring and trending of measured parameters to detect small changes before larger ones.

Autonomy (discharge) testing

"**Capacity testing** is still the only way to be sure the battery has the capability to hold up the critical load for the time specified." This is an absolute in the battery industry.

That said there are some problems with discharge testing:

- It is expensive & disruptive
- To be safe you have to take the battery off line to do it
- With the subsequent recharge the battery may be off-line for more than 24 hours
- In some cases the recharge exacerbates undetected problems, so that the next time the battery is required, it fails
- The test is only valid for the day of testing; a couple of weeks later the battery could fail

Continuous Battery Monitoring

Battery monitoring types

Monitoring can take various forms but basically all seek to provide continuous information about the battery, with the intention of preventing unexpected outages and prolonging its service life. Battery monitoring systems however are much the same as anything else; you more or less get what you pay for.

Choosing the right system for your needs is therefore important, to avoid wasting money by buying a sophisticated system when all you want is to comply with regulations, or buying a simple, inexpensive system when your battery makes a critical contribution to the continuity of supply to your critical systems.

Examples of the various types of battery monitoring systems could be:

- **A simple overall voltage and ambient temperature monitor**
  Monitors and records the total voltage of the battery and the ambient room temperature. This is not of any great value in indicating the condition of the battery, but may satisfy some regulations and be of some small use when discharge testing.

- **A split battery monitor, dual or quad**
  Monitors the battery in two halves or four quadrants, comparing each section against the other(s). A simple dual system monitors two voltages and an ambient temperature plus perhaps a specimen cell temperature. A more sophisticated quad may also measure current (for discharges), four section voltages, section resistance and two or three specimen cell temperatures. Better systems may use sophisticated algorithms to estimate the condition of a quadrant and may even be able to measure and record float current (see 'float current' below). Such systems can be cost-effective and useful in detecting battery problems down to quadrant level.

- **A cell level monitoring system**
  This system is approaching the more effective end of the spectrum and can be quite successful in detecting incipient battery faults. It should monitor individual cell terminal voltage, internal resistance/conductance (or impedance) and cell temperature, plus string current.

- **A comprehensive cell level system**
  This system is state of the art and the best type of system for critical batteries. It will monitor all the previous system parameters, (individual cell terminal voltage, internal resistance/impedance and cell temperature) plus intercell connection resistance and float current, and should employ sophisticated algorithms to determine the day by day condition of the cells in the system and the battery risk of failure.

Monitoring parameters (detail)

IEEE recommendations for the maintenance of the battery by continuous monitoring identify several parameters which should be measured and stored.

These include, but are not limited to: cell voltages, cell temperatures, cell resistances/impedances

Battery discharges

All battery monitors should detect and store discharge performance; the optimum is a log of how each cell functions as the battery discharges.

Terminal voltage

Not very useful on its own (the terminal voltage is fixed by the charger and often doesn't change until the battery has completely failed), but essential to be measured and recorded during a discharge test.

Ambient temperature

Useful for detecting adverse temperature conditions and for determination of the required charger voltage. The service life of a VRLA battery reduces by 50% for every rise or fall of 10°C from specified temperature (75°F in the USA, 20°C RoW) however the effects of adverse temperature can largely be offset by dynamic adjustment of float voltage at the charger.

Cell resistance or impedance

Ohmic testing is a critical component in the detection of incipient failure battery and is now recognised throughout the industry as the most effective method to date for the non-invasive identification of poor cells.

State of Health (SoH)

The most desired parameter is day to day state of health, together with a reliable prediction of remaining life. This is not possible with Ohmic (resistance, impedance and conductance) measurements alone.
At least one BMS company has spent several years on the project with a leading university, and is now offering a comprehensive battery management system with analysis, cell state of health and battery at risk factor.

Cell temperature

Monitoring the temperature of every cell is essential for the detection of thermal runaway conditions. In thermal runaway as the resistance of a cell increases the temperature increases, and so on, until the temperature rises in an exponential fashion, ending in an explosive situation.

However, individual cells can be in the early and mid-stages of the exothermic reaction spiral without affecting their neighbours, and the explosive last stage can take place very quickly. It is therefore not sensible to rely on an ambient temperature measurement of the battery room, or a pilot temperature measurement of, say, cell number 3, when the cell in thermal runaway condition is number 17, perhaps even on a different rack!

US IFC608.3; 2010 requires that any battery with a substantial amount of acid electrolyte must be protected against fire and explosion. This means that thermal runaway conditions must be detected before the critical temperature is reached, and this means monitoring the temperature of individual cells.

System noise & ripple

UPS system noise and ripple currents can be very destructive to battery systems, particularly VRLA types. All batteries have a resistance to electrical current and, if a significant amount of noise and ripple current is passed through the batteries it will cause the cells to heat up more than normal, shortening the life of the battery.

Additionally, system noise and ripple currents higher than normal can indicate problems in the UPS system.

Float current

What we should measure, but with standard technology most systems can't yet, is float current. Float current is dictated by the battery electrochemistry and the condition of the cell; it is usually 0.5 to 1.0 milliamp per battery ampere-hour. This will rise significantly with fault conditions and is an important parameter to measure and trend, however this is not possible commercially with currently available Hall-effect technology. Hall effect sensors that are sensitive enough to measure float current of a few tens of milliamps (say a 0-3 amp transducer) are badly affected by the relatively high battery discharge and subsequent recharge currents.

High currents will saturate the transducer core, leaving an unpredictable offset of several Amps remaining after a discharge event, which destroys the trending pattern. In addition, Hall-effect sensors are affected by temperature, which is particularly significant in the milliamp range.

Beware of suppliers who claim to measure float current with standard Hall-effect sensors. A sensor rated to measure currents of 10 Amps or over cannot achieve this. If a sensor rated to measure say 50A at 1% accuracy it will only be accurate to 0.5 amps, or 500 milliamps. A battery composed of 100 A/h cells will only have a float current of 50-100 milliamps. The 50A current transducer therefore cannot measure the battery float current.

How does a battery monitoring system help to prevent unexpected failure?

The primary aim of a monitoring system is to assist in preventing any of the problems laid out in this paper. If attention is paid to what the monitor is telling you, faults can be identified before the battery can fail, the service life can be extended by detecting and changing out faulty cells and the costs of manual maintenance can be virtually eliminated.

Even the costs of capacity testing can be reduced; the monitor will record the voltages of the individual cells and the string currents, saving time and resource. Additionally, in any discharge and subsequent recharge the behaviour of the string currents in a multi-string battery is an important. Many failure modes can be detected by observing how closely the individual string currents track each other, and this is a basic function of a monitoring system.

Choose your system carefully

There are many battery monitoring systems available, some have large wiring requirements from the cell or jar back to the system that make them vulnerable to system noise, and some measure more than one cell or jar per sensor module. If, for example, one sensor measures four cells, the power requirements of this type of system means that 4 cells are required to power the sensor. So, if the string of cells does not divide perfectly by 4 then some cells have to double up to supply two modules; this makes them 'sacrificial cells' with a shorter service life than the others.

In addition, systems that employ a sensor module for one or more cells will say that, as the sensors are in series with the charger, the power for the sensor comes from the charger.

This is true as far as it goes, however, if the sensor's power requirements are different for each sensor (a power supply can be accurate to 10% for example, thus two sensors in the same circuit can be 20% different to each other) then the difference must be taken from the cell itself, which is not a good situation for the battery.

To be accurate in measuring resistance/conductance or impedance an individual sensor must use what is called a 'Kelvin' connection to the cell/jar.

This is a four-wire connection, two carry the test and supply current and two sense the cell's response at the cell terminals. In this way the sense circuits do not sense the volts drop in the power wires and connections caused by the test current.

A Kelvin connection is the *only* connection that should be used in an accurate measurement system. The four wires must connect to the battery terminals separately.

Safety

Finally, a continuous monitoring system contributes significantly to the safety of technical personnel. It is a statutory requirement that two persons must be present in a higher voltage battery room at all times. In decreasing the requirement for manual maintenance intervention, a battery monitor reduces resource costs and also reduces the chance of accidents.