LOW COST, CONVENIENT BATTERY HEALTH ASSESSMENT: WHO NEEDS IT?

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INTRODUCTION

Why are small, low cost battery sites generally a poor match for highly capable ohmic battery monitoring products? The answer isn't just cost. This paper draws a contrast between the differing performance expectations and resource environments of two categories of stationary battery system user. It proposes some simple requirements for battery monitoring at cost-constrained sites with modest sized stationary battery systems and proposes a solution to providing battery health assessment at such sites.

Operators of high profile mission-critical systems spending large sums on batteries and power electronics justifiably want assurance that their standby batteries will perform per specification. Many of these high budget users employ sophisticated battery health assessment equipment that gives early warning of degradation in one or more battery cells, and notifies the user so he can take appropriate action.

In contrast, small, low-cost battery sites (e.g. 24, 48 and 120-volt systems with batteries up to, say, 250 AH) are typically devoid of automated battery health assessment. This is despite greater risk of catastrophic battery failure than exists at high-end sites. Small battery systems are often sold on the basis of price and on the purported benefits of "maintenance-free" VRLA technology. They are frequently installed in out-of-the-way places without air conditioning and many times forgotten until a power failure one day reveals the battery is dead. Down goes the system.

Sophisticated battery monitoring solutions are ill suited for low-end users. Although offering high performance, they cost more than low-end users are willing to pay and require skilled labor to install and use that typically is not available at small sites. Small battery system users would enjoy increased application reliability if a low cost, easy to install and convenient battery assessment solution were available. It is worth the effort to find such a solution because the low price of lead-acid battery technology means it is not likely to go away soon.

HIGH PERFORMANCE SOLUTIONS SUIT SOPHISTICATED USERS

The battery monitoring industry has made a strong case that today's ohmic battery monitoring systems are effective at discovering battery weakness well in advance of complete failure. Such systems are employed to increase a user's certainty that stationary batteries will deliver their rated output when needed, thus preventing application downtime. The need for uptime at a credit card processing site, for instance, suggest that near-perfect prediction of battery condition is worth the required capital investment and related qualified support staff. Compared with downtime that can exceed six figures per minute[1], investments in battery monitoring are trivial – "no-brainer" added pieces of insurance. For example, a battery monitor with capital cost of $10,000 is an insignificant 1% additional capital cost to batteries and electronics costing $1 million. This is excellent "bang for the buck".

For every "high value" site, however, there are hundreds of small battery-backed sites, supporting communications equipment, utility substations, petrochemical and pipeline operations, power generation plants, shipboard systems and industrial complexes of all types. The very presence of a battery at these sites defines them as *mission-critical* to someone. These small systems are subject to the same types of battery failures as large ones, so users would benefit if battery health assessment means were available. Deploying ohmic battery monitoring systems to low cost sites might be an option but there are formidable barriers to success:

1. *Capital cost.* Assume a site with combined battery and power electronics investment of between $1,000 and $25,000. For this to enjoy the same "no-brainer" return on battery monitoring investment as the large site (defined as 1% of battery and power electronics cost) the monitoring capability can cost no more than $10 to $250. That is indeed a stretch goal.

2. *Lack of trained personnel*. It took our company's experienced chief engineer and a capable electronics technician over 20 man-hours to connect, troubleshoot and receive useful data from an ohmic battery monitor on a 120-cell battery. One major telephone company estimated that only 10% of the full-featured battery monitors it bought was ever installed and operated correctly.[2] These difficulties suggest that today's products might be too complex to be useful to other than specialist users.

3. *Organizational resistance to change*. Implementing any a new method of doing things, including how battery health is assessed, requires a motivated individual to (a) justify new expenses, (b) change or develop procedures to take advantage of the new capability, (c) enlist cooperation to implement the new technology while, (d) minimizing the influence of naysayers. This is hard work! A single individual can often accomplish a lot at a small site, but even he will find change easier if a new technology is easy to use and inexpensive, rather than difficult and costly.

   Although not a *good* reason, organizational resistance to change helps explain why some battery monitors sit dark and disconnected from the battery: The company made a logical purchase commitment, but failed to execute the needed organizational changes to insure success. Unfortunately, resistance to change to even the most logical of innovations is an all-too-common fact of life.

USERS *DO* MAKE LOGICAL DECISIONS!

Although it is tempting (particularly for suppliers) to criticize users for making technology choices that may seem inappropriate, users do in fact make rational decisions. Compared with an equipment vendor, the user is more likely to understand his company's priorities, the limits of his budget, and what his people can and cannot accomplish. If he makes a purchase decision he will logically choose the *lowest cost solution* that *meets his quality expectations* and is *about as sophisticated as his organization*. Sophisticated solutions are suited to complex, demanding organizations, and vice-versa.

The following description distills down several months of discussions with a major corporation that operates a gas pipeline system covering several western states. It may provide useful insight into some of the challenges facing operators of small battery systems in even well endowed corporations.

> Battery Performance Verification at Distributed Sites
>
> Pipeline safety and status are monitored by a SCADA system. A 24-volt charger in parallel with a VRLA battery powers each of the widely distributed sites. Maintenance crews are periodically dispatched (sometimes requiring several hours' drive) to make preventive maintenance inspections of chargers and batteries. After several site outages the user inquired into load testing his batteries in order to verify operation. Unfortunately, this approach increases safety risk to the service person and risk of dropping the load because there is no easy provision to isolate the battery from the charger and load. Service techs decide whether the battery (and other equipment to which they attend) is good or bad in a subjective manner – sometimes even by ear. Chargers in this system are 15+ years old and are reported not to regulate properly. There is no common battery size or type. The user feels that battery life is too short. The user's budget includes replacement of batteries and chargers as they fail, plus travel to and from sites. The "battery" budget includes no other items, such as battery monitoring systems. The user expects that next year's maintenance budget will be cut, but has been given the task of increasing system availability.

This user would benefit from tools to make objective assessment of his batteries. It is unlikely, however, that this organization has the financial, technical and organization resources needed to put a complicated battery monitor to good use. A supplier looking to solve battery uptime problems in this environment is challenged to provide solutions that will make the site manager's job simpler and more predictable, without adding a need for training that he does not have time to take. A successful outcome would result in fewer wasted service calls, more systematic decisions, less downtime and cost savings.

Defined in terms of quality, in this instance a low cost, simple and convenient battery assessment tool would give *higher quality results* than highly sophisticated equipment that, even if purchased, might never work right.

Summary of Battery Assessment Needs at Smaller, Cost-Constrained Sites

Let us assume that the above user is reasonably typical of small stationary battery users. If so, requirements for success of a battery health assessment tool in his application look like this:

Parameter	**Requirement**	**Likely general characteristics of the successful solution**
Low capital cost	$10 to $250	Cost target likely dictates integrating battery assessment function with other familiar hardware.
Simplicity and convenience	Simple to install. Gives easy to read, unambiguous results.	Can be installed and activated by an electrician. Needs no software to load or setup. Short installation time. No need for special parts, tools, instruments or training. Information output is easily understood GO/ NO GO indicator. System provides remote indication using already established means for other equipment.
Adapts to user's environment	Demands no new budget or procedure to buy or use	Make it easy to specify and buy. The solution should be integrated into hardware with which he is already familiar (e.g. battery charger). The user decides whether, and how, to employ the new function.
Delivers useful predictive function	Reduce probability of simultaneous AC outage and battery failure	Use a credible battery assessment technique requiring least reasonable marginal cost. Comply with guidance in IEEE Standard 1491

IMPLEMENTING A USEFUL ASSESSMENT SYSTEM AT LOW COST

My employer provides charger and battery systems to smaller mission-critical applications such as the one described above. For some years it has been clear that reducing the impact of battery failure is the best way to increase the user's overall system reliability. In contrast to power electronics that can achieve MTBF in the range of 1 million hours, *all* VRLA batteries will fail between "now" and perhaps a little more than a decade.[3] Giving users advance warning of an event of this certainty ought to be standard procedure.

We perceived a shortage of battery assessment solutions for the types of products our customers use. We believed we could remedy some of these shortcomings by embedding a battery assessment function in a microprocessor controlled battery charger for these reasons:

1. At AC powered sites a charger (or UPS rectifier) is always supplied with the battery.
2. Chargers contain the right sort of electronic hardware (e.g. power handling capability, accurate voltage and current metering) to implement a battery monitor.
3. Chargers typically contain alarms. Adding one more (battery failure) alarm makes no demand on the user to change his existing remote monitoring procedures.
4. The battery charger controls DC bus voltage. This is significant because the charger's output can be changed when desired to cause a change in behavior of the battery.

Choice of Battery Assessment Method

Two INTELEC papers from the '90s discuss the battery failure predictive capability, and limitations, of a technique called "battery middle point voltage comparison".[4] This technique continuously compares the voltage of each half of the battery to the other, and sets an alarm if the deviation exceeds a pre-determined value. The principle of operation is that voltage drop in healthy cells tracks the others during discharge. In contrast, weak cells show early, and faster voltage decay. A weak cell would create an imbalance between strings, activating the failure alarm.

Glad, Waltari and Suntio determined that demonstrating a battery can deliver *some useful capacity* by detecting catastrophic failures is a lower cost, but still useful alternative to attempting to prove the battery can deliver its full rated run time.[5] The ability to detect catastrophic failure gives users the ability to avoid system downtime if they act before their next AC outage. Although not perfect, this function is an enormous advancement for users with no former battery assessment capability!

Our design team determined that *demonstrating the battery can deliver useful capacity* was a reasonable performance target for a charger-based battery heath assessor. For the sake of simplicity and cost we chose to ignore the question of whether the battery could deliver its full rated capacity. Although the middle point comparison scheme has limitations (i.e. useful information is generally available only during discharge) we chose to implement it for the following reasons:

- The technique's performance characteristics and shortcomings are documented.
- It is inexpensive to implement: The charger already includes voltage and current measuring instruments of the accuracy required for battery assessment.
- The charger control system can be easily programmed to cause discharges from time to time while remaining at a high enough voltage to safely power the load should the battery fail. This eliminates risk of dropped loads during testing.
- Middle point voltage measurement detects bad cells earlier than could a simple gross load test without middle point voltage measurement.

System Operation

During normal operation, function of the battery assessment system is totally invisible to the user, except for a green LED showing the battery passed its last check.

At user programmable intervals, and for user programmable durations, the charger automatically executes a battery test cycle. During this cycle the charger reduces its output to approximately system nominal voltage. A healthy battery will deliver current to the load. A failed battery will drop below the charger's backstop voltage setting, causing the charger to resume delivering load current and activating the "battery failed" alarm. The midpoint measurement system is active at all times. Should the battery successfully power the load during the test, but fail the midpoint test threshold, the "battery failed" alarm is activated.

A button on the front of the charger allows users to manually start or stop a battery check cycle.

Failure of the battery during a check cycle is conveyed in all of the following ways:
1. Locally, by charger front panel red "battery status" LED
2. Locally, by plain language message on the charger's LCD
3. Remotely, by activation of the charger's summary alarm relay contact
4. Remotely, depending on the remote alarm configuration specified, activation of a "battery fail" Form C relay contact or communication via RS 485 port or other network connection

If the battery passes its check cycle the charger's battery status LED stays green.

The fact of a successful test and data recorded during the test are automatically written to an electronic log after each test.

Getting Better Results Without Spending More

We felt that improved test accuracy would become available if the test method were modified. With increasing string length each cell becomes a smaller portion of the total string, increasing the detection time and required precision in the detection system. The system was therefore designed to support up to four "middle points" allowing, for example, comparison of five strings of 12 cells each in a 60-cell battery. This will yield a more accurate result than comparing two strings of 30 cells.

History Information and On-Board Data Analysis

Data collection and analysis offers the potential to speed resolution of field service problems and to help the user better understand the battery's condition. At regular intervals and when triggered by abnormal events, such as AC outage, the charger writes relevant data to a permanent log. Data from this log is useful in augmenting the assessment capability already discussed. For example:

- A record of battery temperature over time since installation helps understand when excessive temperature over time has affected the battery's life.[6] [7]
- Comparing battery float current to values from a history file can reveal when the string float current increases to unacceptable levels – indicating a need for battery replacement.
- Understanding the number and depth of discharge cycles can give insight into whether the cyclic duty is wearing out the battery sooner than might be expected.
- The record of charging voltages with temperature indicates whether the battery was properly charged during its lifetime.
- A record of user adjustment changes (e.g. float and equalize values, disabling of temperature compensation) will help isolate human factor problems such as need for training or other measures.
- A record of discharge length and depth could be used to indicate a reduction in the battery's life.

Did We Meet The Goal?

Here is a comparison of development outcomes to the requirements table generated earlier:

Parameter	**Requirement**	**Outcome**
Low capital cost	$10 to $250	*Does not yet meet goal.* $250 can be reached, but $10 is not possible today because, although simple, the required battery data acquisition module is hardware that needs a housing and circuit card.
Simplicity and convenience	Simple to install. Gives easy to read, unambiguous results.	*Achieves goal.* 30 to 45 minute installation time seems reasonable, and it is less than that required for more capable monitors. User interface with GOOD / FAILED indications is easy to use and understand.
Adapts to user's environment	Demands no new budget or procedure to buy or use	*Achieves goal.* System can be sold as a "charger" or as a more capable product. The user can elect to use, or not use, the battery assessment function.

Delivers useful predictive function	Reduces probability of simultaneous AC outage and battery failure	*Achieves goal.* The system can detect catastrophic battery failure and issue alarms. History log delivered more value than anticipated. With regard to IEEE 1491, the embedded battery assessor:
		• DOES measure float voltage
		• DOES measure equalize voltage
		• DOES measure recharge voltage
		• DOES measure open-circuit voltage
		• DOES measure discharge voltage
		• DOES measure midpoint voltage
		• DOES measure battery current
		  • DOES NOT measure ripple voltage (charger is well filtered)
		  • DOES NOT measure ripple current (charger is well filtered)
		• DOES measure cell temperature (one)
		• DOES measure ambient temperature
		• DOES measure cycles
		  • DOES NOT perform ohmic measurements
		  • DOES NOT measure specific gravity
		  • DOES NOT measure electrolyte level
		  • DOES NOT measure connection resistance
		• DOES provide ground fault detection

SUMMARY

1. Ohmic battery monitoring systems, while well suited for sophisticated sites, may be a poor match for application at cost-constrained smaller battery sites where users are likely to find the products overly complex.

2. Automated battery monitoring at small battery sites is not likely to become widespread until the availability of modest performance that is very low cost, simple and convenient.

3. Simple and convenient battery monitoring solutions will be less thorough in detecting battery problems than ohmic technology. Simple monitoring schemes, however, will deliver higher quality results than ohmic monitors if the latter are not connected, used and interpreted properly.

4. There is an interesting opportunity to mine data from the charger's permanent log to create more accurate prediction of the battery's state.

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