Battery State of Health Monitoring, Combining Conductance Technology with Other Measurement Parameters for Real -Time Battery Performance Analysis

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Abstract: Managers responsible for stationary battery systems may need to consider this question, "What monitoring option(s) can be used to effectively evaluate the relative state of health of installed batteries?" This is no small issue given the proliferation of site designs and the sheer number of locations equipped with stationary batteries. Further, there seems to be no consensus among battery users or battery manufacturers regarding what to monitor. Detailing which battery operating parameter(s) will provide the appropriate technical information associated with identifying weak or failing battery strings/cells while in service is the challenge.

To help clarify one of several new technical options, this paper will introduce new battery monitoring models that illustrate how multiple measurement inputs can be configured to guarantee finding potential service-affecting battery faults. Once detected, this information can be sent through embedded alarm communications systems to a designated maintenance response authority.

1. Core Issues

Many sources have documented the low performance issues affecting a significant number of stationary battery installations, especially those with Valve Regulated Lead Acid (VRLA) designs. This is true in virtually every operating environment and across multiple applications and uses. This information should not be a revelation to persons who have worked in the battery industry over the past ten or more years. What may be less apparent is the fact that so few of these sites with the potential for low battery performance seem to be equipped with an effective monitoring system. These monitoring systems would logically need to identify potential battery problems as part of a package of system information and would need to do so on a continual basis.

Battery problems are often brought to light only after there has been an actual system failure. There may even be more situations when batteries are on a pace to become fully discharged, long before they would have delivered >80% (typical acceptable minimum) of their rated capacities. This failure potential seems unconscionable at a time when the stakes are so high and remedies exist that can assist in identifying these problems. The demand for highly reliable and consistent power performance has become a significant component of many modern service providers' business plan. This is based in large part on the reality of today's increasingly competitive communications marketplace.

2. Industry In The Midst Of Change

The forces of change started in earnest with the Divestiture of AT&T in January of 1984. That was when the regulated Regional Bell Operating Companies (RBOC's) were first created with the organizational re-alignment. That nucleus of RBOC's, along with several major existing independent communication companies, formed the model for what might be called the "incumbent United States Wire-line service architecture". Note that we did not refer to any of these companies as "telephone companies". This is based on knowing the only thing these providers have in common is the fact that they all provide communication links to their customers. The exact content of the communication could be voice, data, Internet access, or anything else. Exactly what information is being sent and over whatever transmission medium is in fact, irrelevant. This realization, combined with the emergence of the radio/mobile signal communications has forced a metamorphosis in the communications industry.

The ever-increasing demand for communications services has propelled this industry into a phenomenal growth cycle. Coupled with that, the total number communications sites equipped with batteries has skyrocketed in these years since Divestiture. Simultaneously, as the number of equipment sites has been expanding, a business climate has mandated a proportionate reduction of the number of people in the work force. That means the number of qualified technicians available to install, service and maintain these new distributed sites has been reduced. There lies the paradox, more work and fewer resources available to maintain the physical plant.
The need for a system management program has never more justifiable than it is now. **Table 1** includes a list of some typical operating parameters for batteries and their

environments that are commonly being monitored. It is possible to have these values reported from one or more system providers. This list is not comprehensive by any measure, but has been compiled for reference and abbreviated for simplicity. The specifics at this point are not important, only to state that these options and others can provide some form of information for use in a remote, battery monitoring scheme. We want to be clear that the options mentioned are merely representative of some possible "remote monitoring parameters". We do not suggest these are the only options to consider and they are not being ranked according to their relative technical merit.

CAUTION

Deployment of remote battery monitoring options does not replace the need for actual site maintenance activity. Human observation and documentation on some logical schedule is required to confirm proper system operation. What the appropriate battery monitoring values can do however, is help streamline the maintenance schedules by giving guidance when trying to prioritize maintenance activity based on remote monitoring devices. Any monitor should be capable of reporting the existence of any unacceptable field operating condition. Monitoring every possible battery room variable at every location could tend to be as complicated as it is costly. The key is to decide which options can be introduced in a cost-justifiable package for the sites where battery performance is considered most critical.

Automation

Automation and remote monitoring would seem to be the logical solution. Technology is available to remotely monitor dozens of battery and other plant operating parameters. It is even technically possible to remotely manipulate battery parameters such as float voltage or float current. Although the technology is available, its commercial success has been limited, perhaps in part due to its relative cost and complexity.

Now comes the challenge for each end user. When asked to do everything possible to secure the survival of the network, users would logically try to base decisions around the state of art technology, not just the state of the industry. These are sample questions that might be appropriate to investigate when developing a network management plan:

1. Which battery sites will require monitoring protection?
2. What available parameters will satisfy system needs?
3. How will the deployment be carried out?
4. Where do we start to implement a plan?
5. How do the results get documented?
6. Who is responsible for future battery maintenance?

Monitored Parameter	Invasive	Technical Value	Technical Weakness
Battery Conductance	No	Passively finds weak cells/batteries	No need for battery discharge to indicate relative state of health
Temperature Differential	No	Clearly shows high battery temperature	Problem is occurring – combined with other data to verify battery fault
Float Current	No	Indicates high resistance battery/current path	Requires each parallel string to be monitored individually for best results
High/Low Battery Temperature	No	Can signal thermal stress problem	Locations of sensors is critical plus battery temperature variation from ambient
High/Low string voltage	No	May indicate rectifier problem	Indicates state of charge, cannot predict capacity
High/Low Cell Volts	Yes	True value only when measured at the cell level	Needs battery discharge of sufficient length to point out weaker cells
Battery Discharge	Yes	Only indicates discharge is in progress	Capacity prediction is based on history. Only reports what has happened
Projected Life (Run Time)	Yes	Requires battery discharges and history	Complex & variable calculations needing time, temperature, DC current, and history
Offline Battery Alarm	Yes	Safety feature - detects battery availability	No capacity prediction – only indicates battery is connect to system
Discharge Cycle Counter	Yes	Manufacturer may require for warranty data	Only documents activity, not battery performance or expected capacity

TABLE one Some Common Battery Monitoring Parameters

None of these issues seems to be particularly difficult independently. However, when challenged to develop a cohesive plan on behalf of the service providers and their customers, these decisions take on a significant new dimension.

It is impossible to consider battery performance monitoring alone without considering other site monitoring needs. One recent Request for Proposal (RFP) was received from an end user detailing a list of not less than 40 distinct values to be monitored. Only nine of these values were directly associated with the battery plant. Are nine values sufficient for their intended objectives? Furthermore, are they accurate, do they have technical merit, or do they simply report some form of data? Secondarily, are these items able to predict battery capacity or not? These are complex questions, and a single YES or NO answer will not fit each question.

What Can Change?

When changes occur that will affect performance of the battery system or the related power plant, there are several critical analysis problems to address. All of the measurements that describe the operating conditions of the battery installation must be considered. The number of design variables from location to location must also be factored in. Site electrical load, charger capacity, battery rated capacity, power cable length, battery temperature variations, multiple battery strings in parallel, batteries not matched by manufacturer, date code or by their rated performance [1], are all part of the equation. There may be other factors to consider as well, but these variables alone can make the work of the battery maintenance staff very complex.

Remotely trying to identify and understand what changes may be taking place in battery plants at multiple locations is increasingly important. The most difficult part of the problem may be deciding which site(s) and which value(s) to monitor that can provide the margin of security required for each system, and what will happen when a site problem is identified? Immediate dispatch of a technician may be needed to verify a site is both operational and safe, based upon the data being reported.

Comparing Functions

Remote battery monitoring techniques will generally fall into one of two basic categories, invasive or non-invasive. We have commented in Table 1, indicating where we believe each of these listed options should be categorized. One of the problems associated with battery monitoring simply includes the potential for a large number of power system variables.

If there is one variable that has the potential for significant fluctuations in a relatively short period of time, it is battery temperature. Changes in the battery temperature alone can make the predictions of a discharge run time algorithms very difficult to rely on. Battery monitoring programs based exclusively around discharge algorithms tend to work incredibly well in the battery laboratory when all the operating variables can be confirmed. Without a stable battery temperature, consistent discharge rates for successive activity, good historical data from previous discharges and sufficient duration discharge, the battery run time predictions are much like the weather. "If there had only been more data, the prediction could have been more accurate." Not to compare battery monitoring to predicting the weather, but everyone understands when there has been a rainstorm. Customers expecting seamless service are less likely to understand the problems of a service provider when they have experienced communication down time due to an incorrect run time algorithm prediction.

Additional complexity is brought in when site designers can stack three, four, five or more battery strings in parallel. This is usually done to increase site capacity, but this makes it nearly impossible to "predict" the battery run time or health of each individual string. Very weak cells may be masked by the relative good health of adjacent battery strings so their problems would not be evident. This is especially true with a calculation based on a short duration run times. The comparative accuracy of predictive run-time algorithms should improve as the length of a discharge event is extended beyond 50% Depth of Discharge (DOD). It is also most effective when calculated on a single battery string. Each of those discharge events then needs to be counted as a battery cycle and is taken from its life expectancy.

Remote Monitoring Options

In a practical sense, what can be done? When considering the installation or improvement of a battery monitoring system, the operator must choose from a variety of optional measurement parameters. Each measurable value has some utility in determining what might be happening to the battery at each site. Remote battery monitoring problems become more difficult with the total number of batteries being used and the increasing number of parallel battery strings. The total number of strings included in any system will make a huge difference in what can be monitored and how effective the chosen parameters will be in forecasting battery health and performance.

Information has been presented at previous Intelec and other power related conferences [2] [3] that report the relative value of various battery measurement parameters. There are no definitive rules, however, that conclusively guarantee which battery (system) monitoring variable(s) [4] will be the most effective in identifying battery problems in given situations. What may work well for small batteries in an uncontrolled environment, may not work successfully for large flooded cells in a controlled environment. Many users have responsibility for batteries in each of these two categories, with even more battery profiles existing in between those two extremes.

Field Experience

Developments have been underway for some time that will combine three discreet monitoring elements into an enhanced site analysis system. These three values include battery conductance measurement, temperature measurement(s) and a float current measurement. Each of these parameters has been shown to have some significance independently. The motive for adding these values together was in this case, to facilitate improvements to imbedded site monitoring systems. As the list of options monitored expands, so do both the cost and complexity of each system. The bottom line is dependent upon how many details the end users believes they can economically address. Here is where a clear corporate agenda and overall action plan need to be very specific.

To that end, there has been a cooperative engineering effort between these authors and several major North America communications infrastructure providers and equipment vendors. The synergy of this cooperative effort has created a strategic advantage by adapting newly developed technology into their embedded systems. The project focus has been to satisfy the cost/benefit relationship needed by the end users. The following will introduce the details of these system configurations and why the flexibility was key to accomplishing the intended monitoring goals.

Measured Values

At previous Intelec conferences, multiple authors have documented the successful use of Conductance monitoring devices and their ability to identify changes in a battery string that indicate a capacity loss [5] [6]. Earlier product designs have only used the "Mid or Half String Conductance" (differential) technique to evaluate battery health. That product will perpetually scan any single 24- or 48- volt DC battery string (within its specified operating range) looking for changes in either the side A or side B conductance. By comparing the battery to itself in two half-string segments, both conductance balance (differential) and conductance change (loss) over time can be observed. Conductance balance and conductance loss were the only two conditions the original product was created to observe. This singular measurement technique provides a minimum amount of protection at a relatively low monitoring cost.

It is obvious that new product development cannot take place in a vacuum. Technology by itself is useless without the involvement of an end user that has a clear idea of what specific goals they intend to accomplish. There also needs to be a business plan to support achieving those goals. With input and involvement of multiple end users, additional features have been incorporated into the original mid-point conductance monitoring architecture. Along with the conductance data, temperature and float current information are now available with the Monitron™ platform from Midtronics. New monitoring data will include options for reporting float current, (battery) temperature, battery/ambient temperature differential, and either battery string equivalent conductance or Side A/Side B equivalent conductance values. As it exists today, users have selected from combinations of these available features to obtain what they believe will be the best way to analyze batteries under their field conditions.

Complex Problems, Simple Solutions - -

The following examples detail the efforts of two end users that have been working to improve their battery system readiness. These companies each operate large network of distributed sites across North America. In one instance, they are using a single battery string, while the second company uses multiple strings. In each case, all of the sites operate in strictly controlled environments. Each company provided a specific set of monitoring requirements. We then worked to incorporate the new measurement data into an embedded transport system, or as part of a total site-improvement project focusing on building control. Although these end users have requested anonymity at this time for internal reasons, these application scenarios may have something in common with the readers application responsibilities. Here is a detailed look at the measurements from the Monitron™ platform. This will show how the values of conductance, current and temperature are expected to produce meaningful information about the batteries.

Battery Conductance Information

With the first application, the need was to provide two half-string conductance values per battery string at each subject site. An output signal representing battery temperature was also included as part of the site specification that needed to be addressed. The combination of these three values were communicated via discrete zero to 5-Volt output terminals intended to mesh with other parallel site improvements.

In the second specification, similar information was needed, but with a very different output for each reported value. In this case, the subject locations already had an embedded alarm system for monitoring building and equipment status. Our objective was to provide additional battery information via that existing communications link. These facts made the engineering portion of these problems relatively simple.

Battery Temperature/Differential Information

Circuitry was designed to allow one of two temperature monitoring options to be used. The first design which, was the MCT-148T uses a single sensor to report a representative battery temperature to a host system with a zero to 5-Volt output signal. This temperature reporting range has been scaled from –15°C to + 85°C and was designed to match the unique input requirements of the embedded reporting system.

A second temperature option appears on the MCT-148TC. This design is intended exclusively for use in controlled environments, where battery/ambient temperature differences are expected to be minimal. The temperature differential issue took a little more discussion with the user who had to define exactly what would signal a battery temperature fault condition. Again, the temperature differential comparison was not uniquely to identify battery-operating temperatures. Rather, it was designed to indicate when a measured battery temperature was significantly different (defined as >10°C) from the ambient temperature. There was some initial concern over the possibility of receiving false "Temperature Alarm" indications based on poor placement choices for the sensor or ventilation problems. The programming was adjusted to allow Monitron™ a one-hour alarm delay to prevent false positives based on non-threatening battery events. This could include something as simple as the door to the site opening and closing in colder locations. The output for this unacceptable temperature differential is provided via one “Temperature Fault”, form C contact.

Excessive Float Current

Temperature and conductance are accounted for and float current is the next critical item to consider. These three values are all inter-related and none of them can change significantly without having some peripheral affect. Float current behavior can be closely related to the internal resistance of the battery elements in the string, the connection resistance of their cabling and current path. Differences in the condition of the battery or the current path will cause changes in the float current, but exactly how much current is too much current?

To gain the full benefit of float current information, it needs to be considered in context with all the following. Battery temperature, battery size, and relative battery age are critical. Other important questions can include: has there been recent discharge, a charge equalize or even discharge cycle activity? Any or all of these issues will radically impact what the float current is doing at any moment in time. Measurement techniques are also subject to some debate regarding what method is most accurate. Historically, it seems that most power personnel were only interested in looking at the DC float current. Now, some attention is being given to AC (ripple) current, as another indication of what may be happening with the battery. Using a calibrated shunt or a high quality hall-effect current sensing device under field conditions can tend to be both expensive and may not provide the accuracy a laboratory researcher would expect. We were asked to measure the float current, but rather than reporting incremental changes on the mili-Amp level, we were only to report a “problem” based on what the user described as excessive float current in their application.

To accurately measure float current down to the mili-Amp level requires a significant technical effort. We were instructed to only consider float current conditions that would undeniably be associated with either a significant battery fault or the possibility of a current path to ground problem. The end user defined excessive float current to be any DC battery current in excess of 2 Amps for more than 24 hours. Since it is possible to see short-term increases in float current after a battery discharge, the delay feature was specified. The two amps for more than twenty four hours would clearly signal the presence of a battery fault if in fact there were no other significant outages which would have caused the increase in float current.

The user also understood that while the battery is undergoing a thermal stress condition leading up to thermal run-away, the float current must increase. This does not happen in minutes but over several hours. With that realization, the user was interested in having a second way to confirm that a thermal stress event was taking place. The battery temperature should rise along with the float current and both faults would confirm that a thermal stress battery fault condition exists.

Recap/Summary

Commercial pressure today requires system operators to consider every possible option for protecting their sites from unplanned power outages. This is in response to the huge potential costs associated with the failure of any of the communications links their batteries are intended to support. Batteries are one of the most difficult elements of the system to gain control over without a dedicated effort. These facts are part of life in the communications industry today:

- End users do have options when choosing their level of service and which service provider they use
- Battery monitoring is a fundamental need to guarantee seamless power system performance for those end users
- Non invasive testing will eliminate the potential for low battery capacity going undetected

Deciding what to look at to identify the relative state of health of the battery can present a formidable challenge. Every attempt to gain insight into battery operating condition holds some potentially difficult decision. What is undeniable is that batteries will show certain characteristics under a variety of operating conditions as they age and eventually fail. The conductance signature of a lead acid battery will decline as it ages. Battery float current will increase as the conductance declines. Battery temperature will increase if there is significant excess float current in the battery. Excessive float current does have a deteriorating affect on the batteries because of the excess heat generated by overcharging. Any of these failure mechanisms can be underway without any change in system voltage

Although no system has proven to be fool proof yet, the combination of these three measurement values will identify the electrical signature representative of a failing battery. By incorporating the three elements of conductance, temperature and float current into a single hardware component, we believe it represents the most complete stand-alone system for passively identifying failed batteries without invasive activity. The information can then be communicated by analog or binary outputs over a host system for remote analysis and action where needed.

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