Midpoint Conductance Technology Used in Telecommunication Stationary Standby Battery Applications.

Part VI. Considerations for Deployment of Midpoint Conductance in Telecommunications Power Applications.

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Abstract:

This paper discusses the effectiveness of midpoint conductance monitoring on 48-volt battery strings using a **M**idpoint **C**onductance **T**ransducer (MCT). Data from laboratory and MCT field installations is presented. The MCT accuracy in a stand-alone application, as well as with a remote monitoring system application is examined. Results indicate that in each configuration tested, midpoint conductance monitoring was effective in identifying capacity string failures.

Introduction:

Improving reserve battery power reliability in today's distributed telecommunications networks has received significant attention in recent years. Conductance technology has been shown to be an effective and useful tool to assess many of the failure conditions of VRLA technology. Conductance technology has gained widespread acceptance in standards organizations worldwide, and with battery test equipment users. From the user's perspective, VRLA technology has fallen short of 20 or 10 year service life expectations, and in many cases, life is lessened more significantly when applied in high temperature uncontrolled environments.

Over the years the general consensus of VRLA users has indicated that a 5 year life is the rule rather than the exception, independent of the particular manufacturer involved. In a recent paper presented at INTELEC one of the authors presented data on the performance of 25,000 cells which clearly quantified the user community experience [1].

Because of this experience the majority of time spent in recent INTELEC battery workshops was used to vent user concerns. As a result, what is clear is that the users of VRLA technology have a common problem best described as **P**remature **C**apacity **F**ailure **O**n **F**loat (PCFOF). With heightened awareness of PCFOF more test programs were initiated and pressure placed upon the battery manufacturers to provide a solution to PCFOF. Recent publications attempt to describe PCFOF as it relates to compression loss due to the inability of the mat fibers to maintain shape over time. Battery manufacturers have undertaken water addition field adjustment programs commonly known as "field adjustment repairs" to thousands of cells, which is costly to both the users and to the manufacturer [2]. The value of these field repairs will only become obvious as a significant population is tracked over several years and their performance recovery is quantified.

Recently, independent research [3] on VRLA PCFOF was published from a two-year study of VRLA batteries. The results of this study present significant insight and possible explanations for VRLA PCFOF. The first is that VRLA cells examined in that study had gas emission rates greater than expected (>20mL per 100AH) to achieve 20 year life; thus PCFOF could result from premature dry-out. Of more significance, the negative plates of many of the test cells appeared to be discharging as indicated by the decay of conductance over time. The results were further quantified when the test cells did not meet their capacity performance ratings (<80% capacity) and were negative limited. The proposed solution presented by the authors of that study suggests the adaptation of a catalyst to recombine excess oxygen and hydrogen to keep the cell balanced over the life of the cell [4].

Despite these weaknesses of VRLA batteries, the fact still remains that the user has to rely on VRLA technology in the event of an AC power failure. Discussions with several users indicate that a cost-effective approach to monitoring the "State of Health" of the battery system is needed. However, much confusion exists due to the influx of battery monitoring devices and algorithms, which have little published data to support claims and/or are very costly. While IEEE 1188 suggests quarterly maintenance be performed on VRLA cells, discussions with many telecom users indicate that quarterly maintenance of VRLA cells is not cost effective, especially for the distributed network where the cost of the battery ranges from $1,500.00 to $3,000.00 U.S. dollars (two to four parallel strings of < 50 ampere-hour batteries). In addition, telecommunications companies have limited resources available to initiate and or maintain a continuous battery maintenance program. The result is that many telecommunications companies are considering or have adopted out-sourcing power and/or battery maintenance.

Companies which have implemented battery monitoring have experienced problems in the management of the data and spurious alarm conditions. In addition, the cost of implementation and or justification has been a source of continuing difficulty. Thus the telecommunications industry seeks a justifiable "low cost" battery monitoring approach which provides a solution to many of these problems.

This paper will describe how many of these problems can be addressed with a new low cost Midpoint Conductance Transducer (MCT). We will address how the Midtronics Monitron® MCT interfaces to common monitoring architectures. We will show results from deployment of the MCT transducer on new 24 cell (48-volt) configurations. We will add to previously published midpoint results on aged battery plants while observing the conductance and performance behavior as a string.

1.0 The User's Perspective.

1.1 Southwestern Bell Perspective

A significant number of valve regulated lead acid batteries are in use in outside plant cabinets. Battery monitoring and management for this application will ideally include these objectives:

- Temperature compensated charging for improved battery life.
- An alarm indication when the battery is nearing the end of its useful life.
- An alarm indication that the battery is in thermal runaway condition.
- Require very little mounting space in the cabinet.
- Be easy to install and operate, and require no preventive maintenance.
- Be very inexpensive.

As to the last objective, capital and expense budget limitations drive the consideration of first cost. If adding a battery monitor adds substantially to first cost, we are inclined to rely on periodic passive testing rather than invest in battery monitoring equipment. As a company, we at Southwestern Bell have developed a lot of confidence in battery conductance testing based on usage of portable test sets. Applying this same technology with an on-site monitoring device reduces the dependence on periodic testing by field technicians. It also provides the added benefit of improved service reliability if we can get to a bad battery before it contributes to a service outage[*].

1.2 Bell Canada Perspective

Four years ago Bell Canada became aware of the anomalies of VRLA batteries i.e. PCFOF, which resulted in shorter than anticipated life expectancy.

Given the above, Bell Canada immediately replaced 100 plus strings of VRLA batteries to ensure network survivability and initiated an extensive program of testing and analysis. To determine a "best method" of managing VRLA technology, we concluded that cell voltage was in general meaningless, as many strings with less than 40% capacity still indicated all cells with acceptable float voltage. At this point, Bell Canada opted for conductance measurement techniques as a standard to determine VRLA battery condition.

We deployed fifty portable conductance test sets to network maintenance sections and began accumulating annual conductance data on several thousand strings of VRLA batteries. This method has proven to be effective, although it is difficult to manage with the huge amount of data obtained to analyze and reach the desired objective.

We are now deploying a low cost, small size device to monitor battery string condition. The Midtronics Monitron® MCT was selected and is configured to alarm or indicate a change in internal ohmic condition when detected. We are presently deploying an MCT, which alarms if the mid-point shifts. In addition, we are continuously monitoring the conductance of both halves of the string using the MCT analog outputs and interfacing those outputs to already deployed remote power monitors. This gives us the additional ability to trend relative deterioration for each half of the string, which could occur without affecting the mid-point balance[**].

2.0 Interface to Common Architectures.

One of the most challenging parts of maintaining a modern communication system is the analysis and reporting of alarms in equipment nodes or critical system locations. If there is a component failure in any system, it is usually a fairly routine task to detect. Loss of commercial power, rectifier failure and circuit card failures are some of the events easily detected as yes or no problem. The most difficult problem perhaps is the accurate analysis of a battery system and its expected discharge capacity.

Increased demand for remote system monitoring has been proportionate with the explosion in the total number of remote telecommunication sites housing electronics. Based on this proliferation of distributed system electronics, the documented PCFOF results plus the extensive reports of thermal runaway, the scope of the monitoring problem becomes rather obvious. Some

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[*] Information prepared by Bill Popp of Southwestern Bell.

[**] Information prepared by Jim Dunn of Bell Canada.

companies are currently adding sites containing electronics at the rate of 1,000 or more per year. These sites include CEV's, huts, cabinets and customer premise installations with a variety of components. All are likely places to use VRLA batteries.

Because batteries tend to lose capacity over time, it has been difficult to determine exactly when they need replacement without relatively expensive site testing. Statistical formulas can be applied to the battery reaction to a discharge (voltage change over time) at a known rate and specific duration to indicate what capacity is expected. However, these system formulas require as much as 60 minutes of run time to make a prediction. If the battery has serious problems, it may already be in serious trouble before an alarm is indicated based on voltage change [5].

Although the equipment vendors and the nomenclature used to describe their equipment may vary, the operating company's objective is always the same. System managers want the capability to continually monitor, analyze and have status of critical network components reported. When a plant condition occurs that falls outside of acceptable operating limits, this information must be reported to an alarm-monitoring center. The alarm center is then required to direct the appropriate response activity or corrective action as stipulated by local procedure.

An alarm reporting function within a common language modeled around Bellcore defined NMA or Network Management Architecture is commonly used today. Even though this is widely used in the United States, the system details and description are far from uniform. There are vendors who have approached this remote alarm monitoring and reporting with a variety of hardware, software and communication protocols. Virtually all alarm systems accept analog inputs from a variety of transducers and report via a dedicated communication link assigned to each site.

3.0 MCT Operation and Calculations.

The Midtronics Monitron® Midpoint Conductance Transducer (MCT) uses patented conductance technology. It is intended to be used in a maintenance program in conjunction with portable test set measurements for new battery installations. The unit is made from non-corrosive ABS plastic material and is designed to operate in temperature extremes from –40°C to 70°C. The MCT unit dimensions are 8.5"x 5"x 1.5" (21.59cm x 12.7cm x 3.81cm) and weighs only 1.10lb (0.5kg). The MCT is powered from the battery under test and normally draws <30 mA. The unit can measure battery strings from 250 Mhos (Siemens) to 3500 Mhos (Siemens), roughly 10 ampere-hour to 1000 ampere-hour in size. The unit has green and red alarm indicator LED's used to indicate normal and alarm conditions. The LED's for each MCT are a helpful aid to the technician especially when parallel battery strings are involved. In this case the normally open (NO) contacts would be tied in parallel to the plant alarm structure and the particular battery string having trouble could easily be identified by the technician when he or she arrived at the site.

The MCT uses an 8 wire (color-coded and jacketed 4 pair) cable assembly which is pre-terminated on the module end. The MCT also uses 8 fusible links at the battery connections to protect the system in the event of a short circuit condition. The MCT unit and cable assembly was utilized in both the field and laboratory tests, which will be described in the next sections.

When installing the MCT on aged batteries, the portable conductance equipment should be used to detect any significant variance within the string and remedial action should be taken prior to installation of the MCT. The MCT is designed to report a potential "battery failure" condition when detected on either half (cells 1-12 or 13-24) of the string. The unit reports battery problems with one normally open alarm contact when the **M**id**P**oint **C**onductance **D**ifference percent (MPCD%) exceeds a preset threshold. This threshold is selectable by 2 dip switches on the front panel. The midpoint conductance difference percent (MPCD%) is calculated by the equation:

$$MPCD\ \% = \left(1 - \frac{G_{lo}}{G_{hi}}\right) * 100 \qquad (1)$$

Where G_{lo} and G_{hi} are the respective low and high conductance readings for either string (1-12) or (13-24).

The MCT has additional capability to provide two analog 0 to 50 mV outputs. These outputs when monitored by a host monitoring system, can give representative conductance data for each half (12 cells) of a single 48-volt string to provide relative conductance alarming capability. Equation (2) can be applied to calculate the conductance for cells 1-12 or 13-24, where k is a constant representing the nominal conductance as programmed by a front panel switch on the MCT unit.

$$G = \frac{mV_{out}}{25}(k) \qquad (2)$$

4.0 Expectations for MCT Midpoint Values on New Batteries.

More published conductance information exists today than ever before. Several battery manufacturers are beginning to provide typical "nominal" conductance values as part of their product information. In May of 1997 experimental trials were conducted with the MCT transducer. The goal was to understand midpoint conductance values for new battery installations and the effect of manufacturers' tolerances on midpoint conductance readings. A random selection of three representative 48-volt battery strings was selected for the experiments. Each battery string consisted of four 12-volt monobloc units and was placed on charge at 54.5 volts. The MCT was installed and set to alarm if the conductance exceeded 10% MPCD%. Table 1 shows the MPCD% calculated for cells 1-12 and 13-24. Note no special charge or discharge conditioning was performed prior to the experiments.

Battery String	**Ampere-Hour Rating**	**MCT MPCD%**
1	60	0.4%
2	100	0.8%
3	40	2.17%

Table 1: New Battery MPCD% Results

In no case did the values exceed the 10% MPCD% alarm threshold used in this experiment**.** These results and other observations show new 48-volt battery installations tested with MPCD% values fall generally below 4% and well within the manufacturers' tolerances.

5.0 Gross Battery Failure Detection Using MCT.

One of the most catastrophic problems associated with any battery system failure is the loss of metallic conduction path or group bar corrosion. If this occurs the battery reserve is no longer available to provide energy. For VRLA technology the following causes for this problem have been reported [6]:

1. Differences between strap and lug negative group bar alloy
2. Abnormal sulfation of the negative plate to strap when not submerged in sulfuric acid
3. Lack of cathodic protection
4. Highly Porous lead

Irrespective of which failure mechanisms may be impacting battery capacity, when placed on load, the battery will usually fail early in its discharge cycle. One-time measurements of conductance or quarterly measurements have been useful to examine the high resistance open circuits but may not detect changes that predicted the onset of strap failure. Therefore, full time midpoint conductance monitoring should be able to identify the strap corrosion changes prior to failure.

The first test was performed by simulating a loose connection between two batteries on one side of the 48-volt battery while monitoring with the MCT. Upon doing this we immediately observed the MCT fault LED indicator while measuring the MCT analog channel output with a digital voltage meter. The milli-volt output values from the MCT used to calculate the MPCD% show the expected difference between the two halves of the string. Next, we measured the dry contact output of the MCT. As expected the normally open contact was closed indicating a fault condition. We performed an additional test by inserting a battery with a suspected internal metallic conduction path problem into one side of the string and performed the same test sequence. The results in Table 2 show an even greater impact on the MCT analog measured values and the calculated MPCD%. The simple experiments performed with the MCT demonstrate the impact of continuously monitoring the battery string condition and alarming when Ohmic changes are present. The MCT could be a valuable asset for detection of potential internal battery metallic path deterioration and/or poor connections, or any failure mechanism which will cause an imbalance when any one cell first starts to fail.

Test Condition	**MCT (VA) Cells 1-12**	**MCT (VB) Cells 13-24**	**MPCD %**	**MCT Alarm**
Initial Conditions	25.6mV	26.7mV	4.1%	No
Loose connection 1-12 side	20.2mV	26.7mV	24.3%	Yes
Insert bad battery 1-12 side	5.8mV	26.7mV	78.3%	Yes

Table 2: Gross Battery Failure Detection

6.0 Using MPCD% For Alarm Detection of New and Aged Monoblocs.

The MCT has the capability to measure the 12 cell equivalent conductance of each half of a 48-volt battery string and report this information in the form of milli-volt signal levels to an existing host monitoring system at the site. If the host monitoring system has intelligence, it can trend the data and provide alarms based on user selected set points. While this represents ideal use of the product, not all installations have a remote monitoring system. To address those situations the MCT unit can also be used as a stand alone unit and provide battery failure alarms based on the difference in measured conductance of side A (cells 1-12) of the string and side B (cells 13-24). For now we will discuss the experimental procedure and results obtained from capacity testing along with MCT results measured prior to the discharge test.

The battery samples used in our experiments were VRLA, 12-volt, lead calcium, AGM technology. The age of the battery string when removed from the field was approximately 4 to 5 years old. Additionally, another new set of the same VRLA battery type was purchased from the manufacturer and received at the Midtronics laboratory. Capacity testing for each battery was performed at the 1 hour rate or 60 Amps to 10.5 volts per battery. Table 3 shows the performance results for both the aged and new batteries and the calculated conductance for each side of the string.

Battery ID	Age Years.	mV (MCT)	G Mhos	Percent Capacity
A	4-5			63.0%
B	4-5			86.7%
C	4-5			55.0%
D	4-5	19.2	1536	48.3%
E	New			123.3%
F	New			125.0%
G	New	27.8	2225	118.0%
H	New			118.0%

Table 3: Battery Performance and MCT Conductance Values

After each of the batteries was discharged, they were recharged individually using 10 amp automotive taper chargers. For our experiment we wanted to simulate conditions representative of what would happen to the capacity performance, relative conductance and MPCD% value when a single bad monobloc was placed on one side of the 48-volt string. To accomplish this objective, we started with a good string containing batteries E, F, G and H. Next, we replaced the best performing battery F (125.0% capacity) with the worst performing aged battery D (48.3% capacity). The string now contained E&D (MCT side A) and G&H (MCT side B). The battery string was then placed on float for 72 hours at 54.5 volts. The MCT was attached and representative MCT analog values were obtained on float. Using equation (2) the conductance was calculated for each half of the string. Please note that for our experiments we set the k value in equation (2) to 2000. A conductance value of 1536 Mhos was obtained for MCT side A (batteries E&D) and 2225 Mhos for the good string MCT side B (batteries G&H).

The MPCD% for this battery configuration was also calculated using equation (1) at 30.9%. Next, we performed a capacity test on this configuration. Figure 1 shows the discharge characteristics for the individual 12-volt monoblocs. Note discharge curves for batteries G&H are very similar and difficult to see in the graph. Shown in Figure 2 are the discharge curves for each half of the string and the full string.

Figure 2 shows the overall string discharge curve (33 minutes @ 42 VDC or 55% capacity). The two lower curves show the half string capacity of batteries E&D (30 minutes @ 21 VDC or 50% capacity) and batteries G&H which exceed the 56 minute end of discharge criteria of 21.0 volts. It is clear that the half string capacity of E&D is limited by battery D (25 minutes @10.5 VDC or 42% capacity) on side A of the string.

As expected the MPCD% midpoint conductance calculation of 30.9% detected the performance difficulty, by exceeding the nominal MPCD% set point of 10%. Under this condition, the MCT provides an alarm output correctly indicating this battery fault. This simulated imbalance represents the fault condition that would occur during the actual loss of an individual cell or monobloc occurring in real-time as the imbalance takes place.

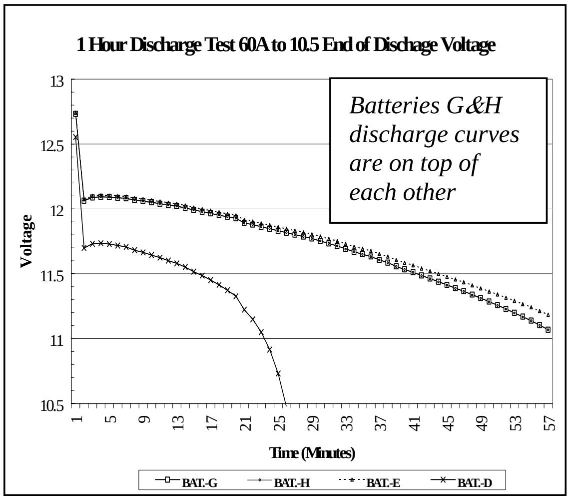

Figure 1: Discharge curves with bad battery insertion on one side of the string

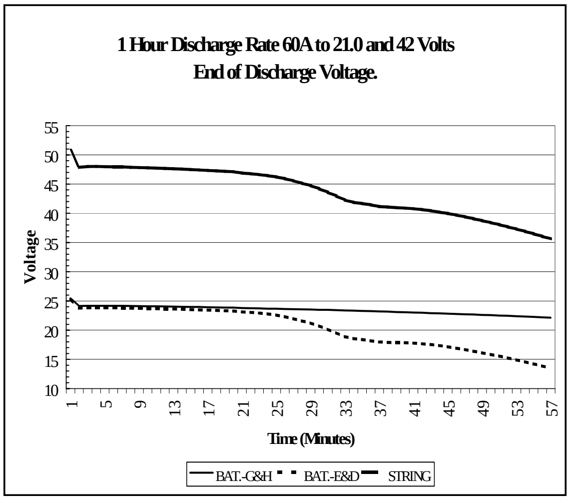

Figure 2: Half String and Full String Discharge Curves.

7.0 Relative Conductance Alarming with MCT.

In the previous section, data was presented on the MCT used in a stand-alone application configured to alarm on MPCD% thresholds. This section presents data on the MCT used in conjunction with a monitoring system. In this application, the analog output channels of the MCT are connected to a remote monitoring system that provides additional alarming capability

In order to demonstrate the relative conductance capability of the MCT, we performed an experiment while placing a single bad battery on each side of the string. Next, we obtained MCT values for each side as shown in Table 4.

Battery ID	Age Years.	MV (MCT)	G Mhos	Percent Capacity
A	4-5	20.7	1657	63.0%
E	New			123.3%
C	4-5	20.9	1674	55.0%
H	New			118.0%

Table 4: Data Set for bad battery placement on each side of the string.

Figure 3 shows the individual monobloc discharge curves. It is interesting to note the capacity of monobloc C is much lower than the results obtained previously as shown in Table 4. This particular monobloc appears to be degrading rapidly as it is cycled. Figure 4 shows the half string discharge curve characteristics, as well as the full string discharge curves.

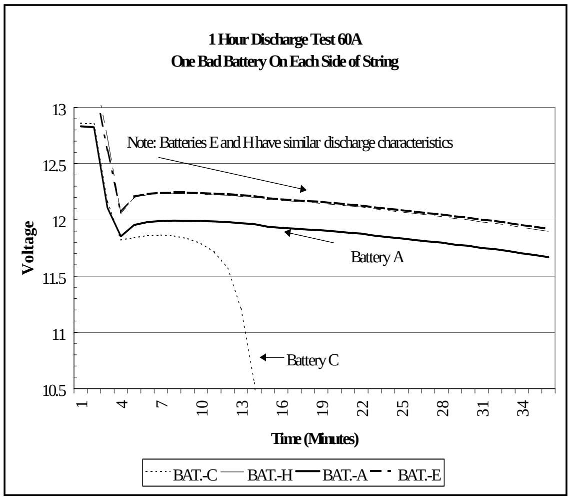

Figure 3: Individual monobloc discharge curves.

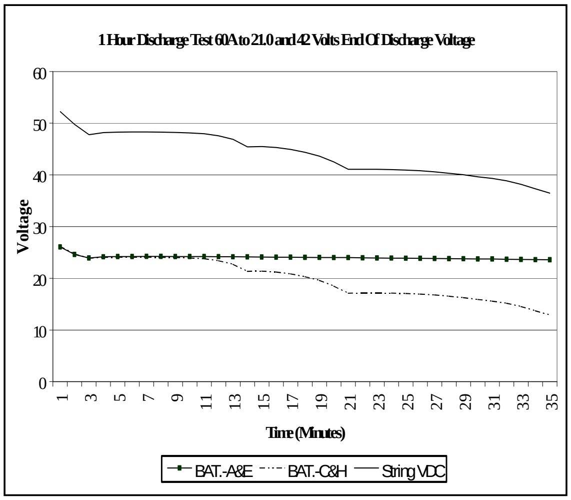

Figure 4: Half string and full string discharge curves.

The measured string capacity for this configuration was 30.8%. The half string capacity for batteries A&E was greater than 33 minutes at which point the test was concluded. For batteries C&H, the capacity was calculated at 18%. Clearly, placing such poor performing batteries on each half of the string significantly influences the discharge characteristics. The MPCD% would likely have detected such a problem early on, as one side of the string or the other would have declined first. If we consider the application of relative or trending conductance, we can see an additional benefit of the MCT monitor. To do this we utilized information obtained from the previous experiment.

Since we already established the 2225 Mho value from the good battery pair G&H used in the first experiment, a calculation of the relative conductance for batteries A&E (Cells 1-12) and batteries C&H (cells 13-24) sides of the string could be determined. The calculations show 1657/2225*100 or 74.5% and 1674/2225*100 or 75.2% for each side respectively. Using the IEEE 1188 [7] recommended practice for battery diagnosis, the alarm threshold of 80% for the analog channels would be used on the host monitoring system to bring in the alarm. This is important to note in the unlikely event that both sides of the battery string degrade at the same rate over time. The MPCD% in conjunction with the dual analog outputs, are the most effective way to identify capacity loss in a string.

The MCT provides two analog output channels which provide an analog representation of the measured conductance of each half of a 48-volt string. This output is between 0-50 mV for each side of the string which is connected directly to the remote monitoring system. At installation, the remote monitoring system reads the initial conductance of the good string and can provide additional alarming capability if either side of the string falls below 80% of the original value. This alarming capability is in addition to the MCT MPCD% alarming function. Conductance testing and screening prior to MCT installation would have detected all of the defective batteries below 80% capacity.

For our purpose, we looked at 29 battery strings ranging in size from 650 Ah to 975 Ah. The data was collected from field installations in the United States and Canada. The string data presented contains both good and bad strings based on their capacity. The data is supplied in Table 5. The table compares the measured string conductance (based on individual cell conductance values) and the calculated MCT mV outputs from each half of the string. Reference conductance values were obtained by measuring new batteries of the same type. Next, the relative conductance of each side of the string was determined. Using an 80% relative conductance threshold and an 80% capacity threshold, correlation was determined.

String #	Calculated G: 1-12	Calculated G: 13-24	MCT Analog mV 1-12	MCT Analog mV 13-24	Reference G	% Ref G side A	% Ref G side B	% Capacity	Correlation
1	2110	1931	26.4	24.1	2800	75%	69%	43%	YES
2	2068	2092	25.9	26.2	2800	74%	75%	43%	YES
3	3569	3596	44.6	45.0	3680	97%	98%	112%	YES
4	2662	2723	33.3	34.0	3680	72%	74%	78%	YES
5	3491	3599	43.6	45.0	3680	95%	98%	107%	YES
6	2182	2024	27.3	25.3	2800	78%	72%	42%	YES
7	2089	2077	26.1	26.0	2800	75%	74%	36%	YES
8	1755	2341	21.9	29.3	2800	63%	84%	30%	YES
9	2115	2095	26.4	26.2	2800	76%	75%	48%	YES
10	2592	2474	32.4	30.9	2800	93%	88%	74%	NO
11	2189	2059	27.4	25.7	2800	78%	74%	5%	YES
12	2095	2170	26.2	27.1	2800	75%	78%	42%	YES
13	2145	2243	26.8	28.0	2800	77%	80%	78%	YES
14	2901	2495	36.3	31.2	3750	77%	67%	61%	YES
15	2373	2165	29.7	27.1	3750	63%	58%	0%	YES
16	2866	2260	35.8	28.3	3750	76%	60%	86%	NO
17	2874	2870	35.9	35.9	3750	77%	77%	74%	YES
18	3027	3135	37.8	39.2	3750	81%	84%	109%	YES
19	2856	2403	35.7	30.0	3750	76%	64%	60%	YES
20	3037	3032	38.0	37.9	3750	81%	81%	59%	NO
21	2842	3239	35.5	40.5	3750	76%	86%	79%	YES
22	2618	2921	32.7	36.5	3750	70%	78%	57%	YES
23	2047	1969	25.6	24.6	1950	105%	101%	115%	YES
24	1813	1735	22.7	21.7	1950	93%	89%	97%	YES
25	1741	1716	21.8	21.5	1950	89%	88%	99%	YES
26	2277	2367	28.5	29.6	2475	92%	96%	90%	YES
27	2103	2054	26.3	25.7	2475	85%	83%	93%	YES
28	1905	2153	23.8	26.9	2475	77%	87%	84%	NO
29	2178	2252	27.2	28.2	2475	88%	91%	100%	YES

Table 5: Battery String Field Data

The results show a correlation of 86%(25/29) between the MCT relative conductance output and actual string capacity. It is clearly demonstrated that the MCT is effective in identifying both bad battery strings, as well as not alarming on strings with good discharge capacity.

8.0 MCT Detection of Thermal Runaway Conditions.

In addition to generating an alarm for a battery due to gross failure or loss of capacity, the Monitron® MCT will generate an alarm for a MPCD% created by one side of the string increasing in conductance. As shown in previously published results, measurements during a thermal event indicate that there is a measurable increase in conductance during the event which can be used to alarm the user before damage or the event takes place[8].

Using the analog outputs of the Monitron® MCT while connected to a host system provides the best information of a potential event condition and could provide the system with the necessary information to change the rectifier output to minimize damage and/or prevent the occurrence.

Conclusions:

1. Midtronics Monitron® MCT can interface to common architectures with a simple contact closure or analog channels showing relative conductance, which can be used for trending, and detection of failures as they occur.

2. Simple MPCD% can identify and provide alarms when detecting gross metallic path problems and gross faults or conductance imbalances in real time, caused by PCFOF or thermal events.

3. Continuous trending of relative conductance accompanied with MPCD% provides best overall information of battery condition prior to AC failure events.

4. The combination of the MCT and portable conductance testing provides for full time monitoring and alarming capability with a proven testing technology to isolate failed cells and monoblocs as required.

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