A Method of Conductance/Impedance Testing in Remote Application of Battery Monitoring Systems.

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Abstract

Conductance is one of the most often recommended indicators of the battery State of Health, yet it is one of the most difficult to test in remote applications. There are number of methods and test apparatus offered by different suppliers, however, there is no simple and inexpensive device which allows users to do this test in remote locations without actually traveling to the site. This paper will discuss a solution using a combination of a remote monitoring system along with a simple device which allows for injection into the battery of a low frequency current transient with precisely controlled current. This transient condition will then allow calculation of battery conductance and Coup De Fouet, which then will be automatically stored in the system's log. The paper will describe methodology of the testing as well as equipment used, and will provide the test results of such systems installed on selected beta-sites.

1. Ohmic measurements – market availability

It is general consensus that Ohmic parameters of the battery (impedance, resistance, and conductance) are key indicators of battery current and near term expected performance of the battery[1][4][10][11]. In response to this trend, the number of diagnostic tools have emerged. However, this in turn has caused an endless discussion about the relation of the measured parameters to the battery actual State of Health (SOH), State of Charge (SOC), life expectation, etc. One thing that has emerged from this discussion is the growing consensus that analyzing the trending of these parameters rather than precise actual value can be a useful tool to determine "whether the system might be within a failure zone" [1]. The Author will use this fact and concentrate on providing the battery user with a simple and inexpensive tool to perform this task.

The study presented in [1] indicates that progression in Ohmic value change is indicative of different scenarios of battery failure. An excellent illustration of this scenario is the graph presented in this study and shown here on Fig. 1.

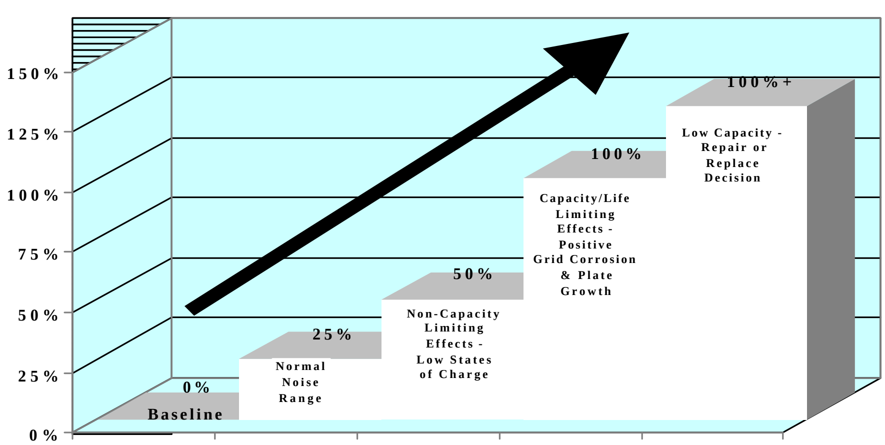

Fig. 1. Ohmic Value Changes and Ramifications

The Ohmic test is performed by a number of suppliers, however, only a few of them are doing remote, on-line testing. Examples of equipment available on the market are given in Table 1.

Table 1.

Manufacturer	Model/Series	Application	Approx.price
Midtronics	Celltron series	Portable	
Megger Biddle	Biddle Bite	Portable	$5.8K – $6.9K
Alber	Cellcorder series BDS-40, 256 MPM-100	Portable On line On line	
NDSL Cellwatch	BMU and iBMU	Online	

One can see that this equipment demands a relatively high price, which practically makes low end, small system applications economically prohibitive. Portable equipment, although expensive, still can be used for such applications; however, the human cost factor has to be added when considering use for multiple sites.

There is no on-line, yet inexpensive equipment on the market which can be easily justified for small, remote battery systems such as CEV, Outside Plant or Customer promises Telecommunications applications. Although such applications represent relatively small hardware costs, in many cases a lot of revenue is dependent on system uptime, and reliable battery backup might be essential [8]. The method and apparatus presented below will try to fill this market gap.

2. *Ohmic measurements basics*

Comparison of methods and hardware used to perform Ohmic measurements indicates one common feature: obtaining reasonably accurate results of the Ohmic measurements requires costly equipment, and in the case of conductance measurements, no reasonably priced remote equipment can be found on the market. Before our proposed method is presented in detail, we will discuss some basic information about battery Ohmic parameters and their behavior as an aspect of the measurement circuit design features.

An overview of applicable publications [2][6][7][9][10] reveals a number of battery models which can be used to provide an electrical equivalent circuit. Although this author does not intend to discuss these models in this paper, there is a consensus that some of the simplified models can be used to perform battery Ohmic parameters trending if the test conditions are properly selected. One such generally accepted basic model is, the Rohner/Willihnganz electrical equivalent circuit (1959), shown in Fig.2.

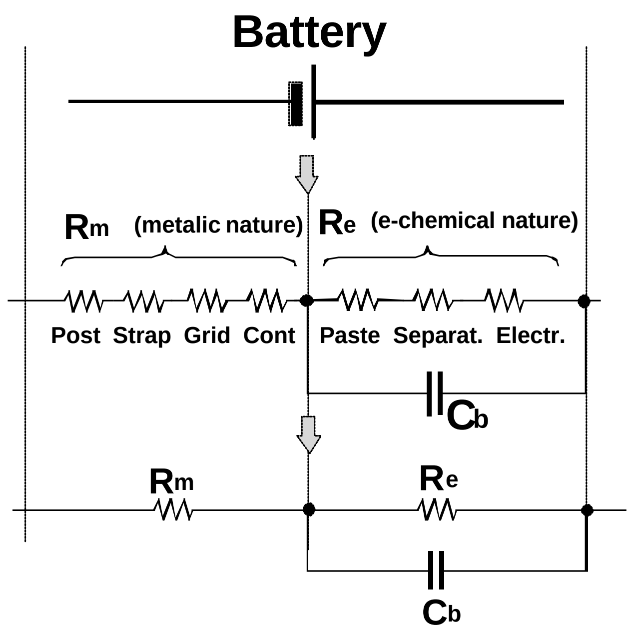

Fig.2. Electrical equivalent circuit of a VRLA battery.

The model consists of resistance R_m being the results of factors such as resistance of the posts, straps, grid and grid to paste layer connected in series with $R_{e,}$ being the results of resistance of paste, separator and electrolyte. R_m is generally metallic in nature, while $R_{e,}$ considered as non-linear is electrochemical in nature. Each of these parameters participate in various degrees in the overall resistance of the battery; however, the ratio between them is roughly 55% of the battery's overall resistance [2][5].

Since the resistance of the plates is paralleled by the battery capacity, this part of the resistance (representing a significant portion of the impedance) will depend heavily on the frequency of the AC current used to perform this test, as proven by the results of the following simplified analysis.

The overall impedance of the battery can be presented as follow [ ]:

$$Z_B = R_m + \frac{(R_e *1/j? C_b)}{R_e + 1/j? C_B} = R_m + \frac{R_e}{1 + j? C_B R_e} = R_m + \frac{R_e}{1 + (? C_B R_e)^2} - j \frac{? C_B (R_e)^2}{1 + (? C_B R_e)^2} \quad \textbf{(1)}$$

One can calculate that for the frequencies = 20Hz, the factor $(? C_B R_e)^2$ meets the criteria

$$1 << (? C_B R_e)^2 \quad \textbf{(2)}$$

therefore, (1) can now be presented as

$$Z_B = R_m + R_e - j ? C_B (R_e)^2 \quad \textbf{(3)}$$

What is the expected value of $? CB(R_e)^2$ for a typical battery and for different frequencies? Assuming that the battery capacitance is approx. 1.7 Farad per each 100Ah [3] and R_e is approx. 40% of overall battery resistance [2][5], the calculated data are presented in Table 2.

Table 2.

Frequency	[Hz]	5	10	15	20	60
Capacity [Ah]	Imp. [Ohms]					
50	0.0060	0.0002	0.0004	0.0006	0.0008	0.0023
80	0.0040	0.0001	0.0003	0.0004	0.0006	0.0017
100	0.0030	0.0001	0.0002	0.0003	0.0004	0.0012
200	0.0015	0.0000	0.0001	0.0001	0.0002	0.0006
800	0.0003	0.0000	0.0000	0.0000	0.0000	0.0001
1500	0.0002	0.0000	0.0000	0.0000	0.0000	0.0001

The calculated data from Table 2 indicates that the imaginary part of the battery impedance becomes significant at frequencies = 60Hz. At frequencies less than 20Hz, this imaginary part is in the range of 10% and less of battery resistance. The graphical presentation of this relationship and associated error is presented in Fig.3.

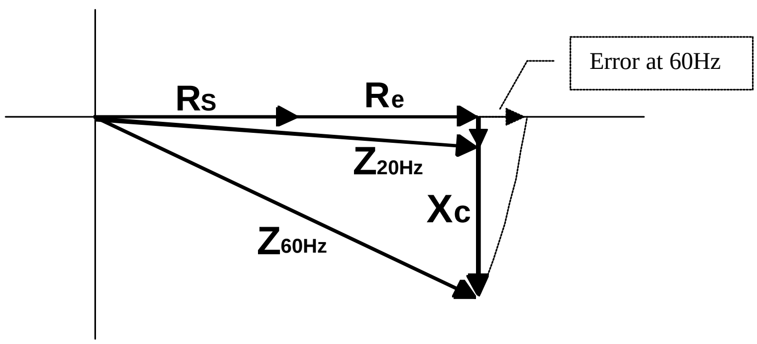

Fig. 3. Resistance/conductance test error at different frequencies.

Calculations can be made to prove that while the resistance test error is in the range of 10% at 60Hz, the same error will be less than at 1% for the frequencies = 20Hz. The battery conductance (as an inverse of impedance) can be calculated from the equation:

$$|Z_B| \sim R_B \quad \text{and} \quad G = 1/|Z_B| \qquad (4)$$

The above analysis supports a similar analysis done in [2] where the author proved that the AC voltage test used for impedance/resistance test is associated with significant error when using test frequencies above 60Hz. Furthermore, it could be stated that the “AC voltage” test method provides reasonable results of resistance/conductance testing when using frequency below 20Hz. The proposed practical equipment solution will use this approach (single frequency below 20Hz) as an equipment feature.

3. Measurements and equipment concepts

While the test principle is similar to that used by a number of manufacturers (and discussed above), the practical realization is different. The proposed concepts feature the following:

- The AC current in the battery string is caused by superimposing of the AC component on the battery float voltage. The amplitude of such voltage is smaller than the difference between battery float and OCV (Open Cell Voltage); thus the battery response is linear, depending only on battery internal resistance (Fig. 4).

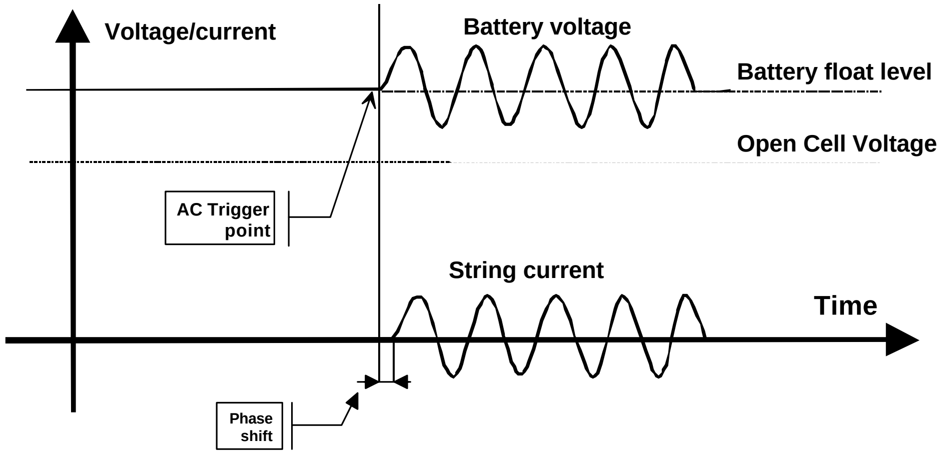

Fig. 4. AC current generation.

- The AC Current Source (ACCS) is a very simple unit consisting of an AC voltage divider, an isolating capacitor and a relay. An additional component of this unit is an RF receiver, which provides a communications means for triggering of the AC.

- The AC component causes the AC current flow thru the battery, which is charging the battery during the positive half of the sine wave and discharging during the negative half of the sine wave. The AC current is measured by either a clamp or shunt type of device.

- Each battery voltage within the string is measured by the local device, which provides signal conditioning and ATD (Analog to Digital) conversion.

- The local device receives the value of the AC current, so the impedance (or resistance) and conductance can be calculated and stored locally, thus allowing for data trends to be captured.

- Since the measuring device for both current and voltage are within the same device and AC signals are well filtered, the eventual noise and other fluctuations of the AC signal should have minimal impact on the measurements results.

3.1 System block diagram

To simplify design and consequently reduce costs for small battery systems, the monitor will serve only 4 batteries, a typical telecommunications string for remote application. Larger battery systems (with multiple strings or with more than four batteries per string) have to be monitored by multiples of the core 4 battery system.

The AC current generating device is a separate piece of hardware which can service either a single string or multiple strings, depending on the application. The AC current is triggered by the Master Monitor Unit (MMU). An MMU unit is created by software configuring one of the string monitors.

A block diagram of the above described configuration is shown in Fig. 5.

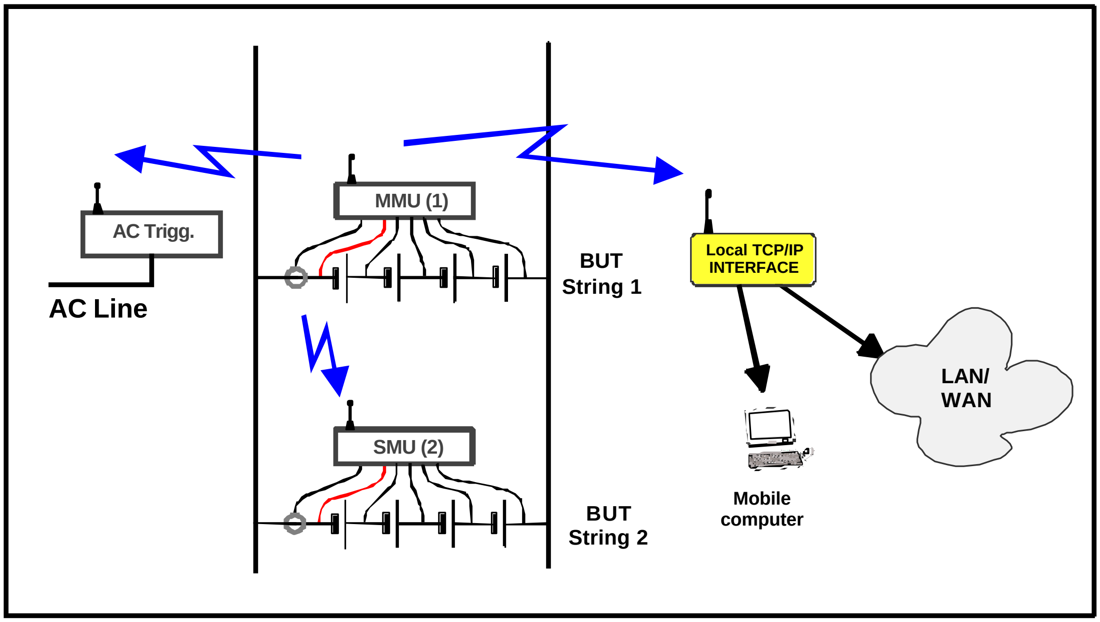

Fig. 5. Monitoring system block diagram

To perform battery resistance/conductance test, each battery requires the AC current flow thru the string. The unit shown in Fig.4 as an AC trigger generates AC voltage with the frequency of 20Hz, which is then superimposed on the battery float voltage. The AC voltage component causes the AC current flow thru the battery, which is charging the battery during the positive half of the sine wave and discharging during the negative half of the sine wave (Fig. 4).

3.2 Master/Slave Monitoring unit

The Master Monitoring Unit (MMS) and Slave Monitoring Units (SMU) are identical as far as the unit design is concerned. The unit performs analog signal front end conditioning, signal ATD conversion and signal processing. The following signals are monitored:

- ? Individual Battery DC Voltage (4 inputs).
- ? Individual battery AC voltage drop (4 inputs).
- ? Individual battery temperature (4 inputs).
- ? System Voltage (voltage for 4 battery connected in series, 1 input).
- ? Ambient Temperature (1 input).
- ? String DC current (1 input).
- ? String AC Current (1 input).

Each monitoring unit thus measures 16 analog inputs. Since they are converted into digital form within the unit, there is no problem with electrical noise caused by long analog connections. The digital signals are processed and stored within the unit in the form of end results. The following signal processing is performed:

DC Voltage/temperature.

- Battery DC voltages compared against preset threshold and alarm logging.
- Individual battery temperature compared with ambient and high unit temperature detection and logging.
- Individual battery high temperature cumulative time detection and logging.
- System (4 battery units) DC voltages compared against preset threshold and system alarm logging.
- Ambient Temperature alarm detection and logging.

Current.

- String DC current and charge/discharge detection.
- Float current (only if a shunt current sensor is used).
- AC component of string current.

Multiple signal processing.

- Based on AC signals measured, calculation of individual battery impedance and/or conductance using equation (4).
- Storing of individual battery reference impedance and creating trending information of battery impedance progressing over the time.
- Calculation of cumulative number of Ah removed from the battery during discharge and added during battery re-charge.

As mentioned before, there is no difference in the basic design of the MMU and SMU other than software: the master unit governs local network and test processes, the slave unit just receives commands in order to perform certain processing of the data. More about this part of the operation will be provided in Section 3.4, dealing with communications.

3.4. System communication and networking

The system components are communicating using RF media. Each system component is equipped with a low range, 2.4GHz Transceiver which allows for two-way communications. The system networking is kept very simple in order to eliminate the possibility of noise impact on RF communications. As an example, the ACCS communication module is set in the receiving mode in order to receive the “Trigger ON/OFF” signal broadcasted by the MMU. The communication modules in the SMU’s are also operating in receiving mode in order to pick up commands to perform the AC Test and impedance calculations.

In normal mode, all components of the system, including the MMU, are operating in the Receiving mode. The change into Transmitting mode is performed in the following cases:

- In the MMU, when the AC test trigger command is generated.
- In the SMU, when the unit detects new alarms in order to acknowledge this situation to the MMU.
- In the MMU, when data transmission is requested by the external interface.

3.5. *Hardware design*

The hardware consists of three major mofules:

1. A string monitor for a single battery string (1-4 batteries). The function of this unit has been described in section 3.3. The communication function of the monitor is software defined as Master (which governs the entire system in the case of multiple strings), or Slave, which is controlled by the Master as far as system level functions are concerned.

   The unit's electronics are enclosed in a small plastic enclosure measuring 3"W x 1.5"H x 0.8"D. Each battery terminal is connected to the unit by a single wire. Separate wires connect an external shunt used for string current measurements. The monitor also has to the capability of connecting a clamp type sensor. In this case, the string float current is not measured. The Monitor unit is shown in Fig.6.

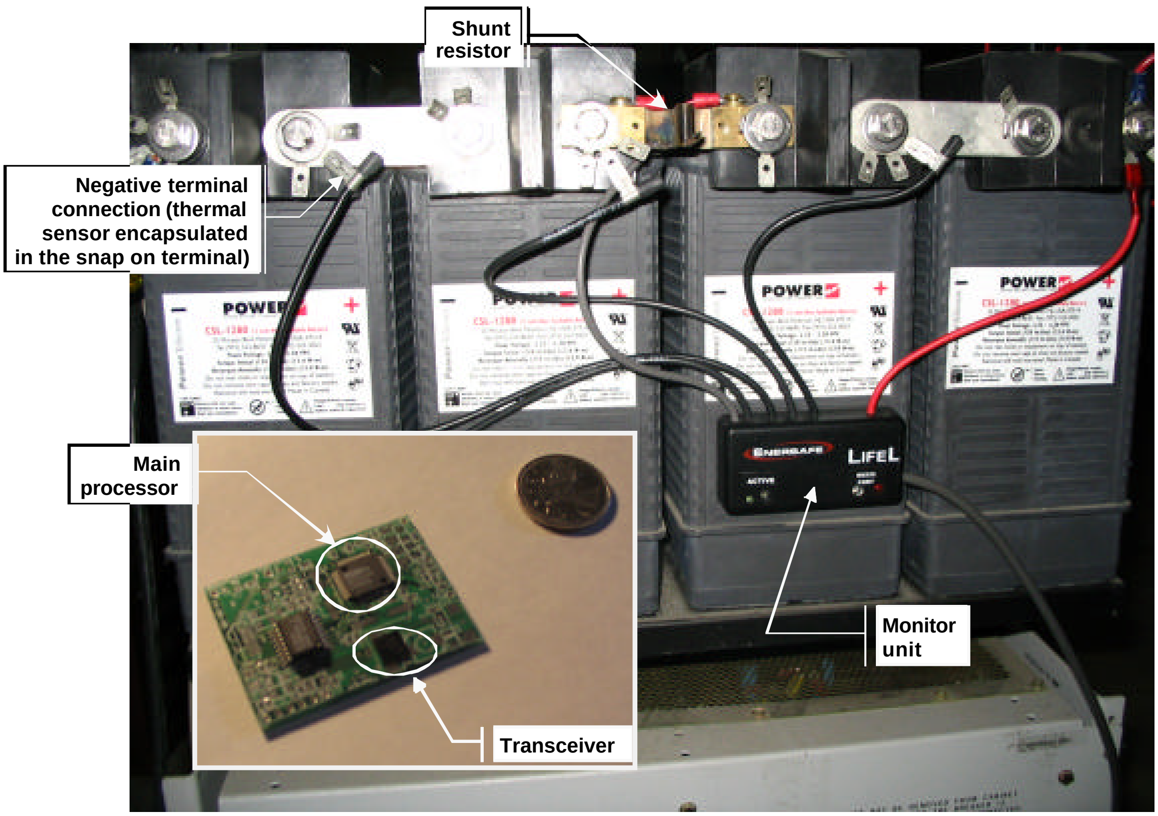

Fig. 6. Single string monitor.

2. AC Current source (ACCS). This unit is controlled by the MMU in terms of triggering of the AC current. The unit consists of a transformer, frequency divider, low pass filter, relay and simple control board. The control board receives an RF command to trigger on and trigger off an AC current when the impedance test is requested. The unit can be built for a single string or for multiple strings. AC power is provided by the local line source.

3. RF Interface unit. This unit provides a communication means for a local connection between a serviceperson's laptop and the monitor, or as an interface for an application on a LAN or the TCP/IP network to retrieve data from the monitor.

4. Conclusion

The presented monitor features the following.

- Small size, mult ifunction unit capable of monitoring different configurations of remote battery systems (anywhere between 1 to 4 batteries). The technology used will allow a very low cost per string. The volume pricing below $450 per string is entirely possible.

- The unit can be further scaled down to perform monitoring of just one battery. The sample of the PCB for such application is presented in insert on Fig. 6, and compared to a 25 Cents coin. In such case, the monitor cost can be brought down another order of magnitude, thus allowing it to be embedded in the battery plastic, or attached to single batteries for applications such as generator starting or some motive applications.

- Installation of the monitoring unit is very simple. no calibration has to be performed, and the entire set up is essentially software initialization. Such a design guarantees low installation cost,

5. References

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