INTERCONNECTION RESISTANCE MEASUREMENT AND DATA ANALYSIS: MANAGING THE TASK

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INTRODUCTION

All stationary battery maintenance regimes require a number of tasks that must be completed on a regularly scheduled basis to meet in-house requirements as well as the maintenance requirements of the battery makers. Among those tasks is the measurement and analysis of interconnection resistance values to verify electro-mechanical connection integrity. While gathering the data is relatively easy by a technician versed in the use of the instrument, what to do with the data once it has been collected can be somewhat confusing to some involved in the management of continuing maintenance of large stationary batteries. The purpose of this paper is two fold. First, to educate and enlighten the reader regarding the fundamental theory and techniques in the measurement process. Second, to discuss the analysis methodology of data analysis. Once completed, the latter provides indicators as to the condition of the connections and points to those that are in need to corrective action. IEEE standards are discussed (Refs 1, 2, 3, 4). The paper will also examine a number of misconceptions and pitfalls the author has seen in more than fifteen years experience working with stationary batteries in UPS and telecommunications applications.

FUNDAMENTALS

In an effort to deliver the maximum transfer of energy from the battery to the connected load, the interconnection resistance must be as low as practical. In an effort to determine that the resistance value is maintained in good condition, periodic measurements of the cell-to-cell detail resistances throughout the battery are made, recorded, changes, if any tracked and analyzed.

How Does it Work?

The instrument used to make connection resistance measurements is called a micro ohmmeter. This instrument is very sensitive with typical accuracy to 2% and .1 micro ohm of resolution in some instruments. The instrument works on the premise that all conductors have *some* resistance. The key with measuring the DC resistance of what essentially amounts to large bolted bus work on a battery, is to accurately and consistently measure very low values. Standard hand held multi meters with ohmic functions used in every day application will not do.

One method of deriving a resistance value is to inject a measured current through the specimen resistance. When this occurs, a voltage drop, albeit a small one, is developed across the connection. Current is introduced into the connection and voltage measurement across it is achieved through the use of spring clips or spiked probes placed on the cell or unit terminals. Using the formula $R=E/I$, where E is the measured voltage drop across the resistance and I is the known current circulating through it, the DC resistance can be calculated. Figure 1 illustrates the simplified circuit. The calculation is done automatically and the end result is simply a displayed value, usually expressed digitally in milliohms or micro ohms on the instrument front panel. Some models will log the data to on-board memory for extraction at a later time. Some also can record additional data, including cell voltage and internal resistance.

TECHNIQUES IN THE MEASUREMENT PROCESS

In order to obtain a good degree of repeatability and to ensure accuracy, proper use of the instrument is very important. Proper test probe placement technique is essential in obtaining an accurate reading and depends on the specific battery under test. Let's look at the battery for just a moment. Because of the numerous battery manufacturer models, types of connection geometry and instruments available, it is wise to determine the kind of connection geometry a user will be dealing with first, *before* making an instrument purchase decision. Allowable space here does not permit discussion of all types of connection geometries. For the purposes of explanation and in keeping to the fundamentals, conventional connection schemes, such as those employed on many large flooded and VRLA batteries will be discussed in this to illustrate examples.

Figure 2 illustrates a basic cell-to-cell interconnection scheme. This is a simple single post connection. One measurement is made, post-to-post to determine the resistance of that connection. Figure 3 introduces the double post cell design. Here, two measurements must be made to determine overall connection integrity. Lastly, examine figure 4, where a triple post configuration requires that three measurements be made to complete the series of tests for this type of connection geometry. With all of these illustrations, the placement of the probes must be made directly to the cell post, allowing current flow from the post(s), through the connector(s) into the opposite post(s). These connections, which make up the majority of the cell-to-cell connections are called *intercell* connections. Measurement symmetry throughout the process must be maintained. As you will learn, it is required in order to make sense of the data that must be analyzed once the measurement process is complete.

Up this point, only identical cell-to-cell connections have been discussed. What about different length connections within the battery conductor loop? What about cable connections between racks, aisles and tiers of cells? The other connections cannot be ignored, for they too play a role in the overall performance of the battery. Keep in mind this is a series circuit and from a current flow point of view, the same value of current entering the connection must leave it.

Definitions

Let's get some additional terminology out of the way first. In addition to the intercell connection already discussed there are four additional connections that will be defined for clarification. *Inter-rack* connections are those connections made between cells utilizing one or more cable groups between racks on the *same tier*. *Intertier* connections are those connections made between cells utilizing one or more cable groups between *different levels* or tiers of cells. *Inter-aisle* connections are those connections made between cells where an *aisle or walkway* defines the space between the connected cells whether they are connected to a different tier at the other end or not. Lastly, we take into account the quality of the main cable lug connections at first and last cell in the battery. I term this the *post-to-lug* connection. The measurement technique for all but the latter connection geometry is really not significantly different than that used for the majority intercell connections. Post-to-lug measurements are slightly different. It is desirable to verify the integrity of the connection between the post(s) of the first cell and the main lug(s) that terminates to it. The varying geometries will result in differing resistances. This, therefore, is why the type of connection needs to be defined and why they must segregated to facilitate accurate analysis.

DATA ANALYSIS METHODS

Table 1 depicts an example of how the gathered data might appear in tabular format. This is strictly a numbers game from here. For simplicity, the assumption is that this is a <u>new</u> battery installation and all interconnections were assembled a in a manner consistent with the battery manufacturer's installation instruction. The battery employs a four post design and two sets of intertier cables are being utilized as well as a set of inter-aisle cables. Note the variations in resistance readings. This is to be expected when cable groups are used. The different data have been separated so as not to skew the final results. Each connection geometry must be analyzed separately and judged on it own set of criteria. Note that both guidelines of 10% maximum or 5 micro-ohms are applied. Because this is a new battery any readings that are higher than the maximum allowable should disassembled, cleaned and remade in order to reduce the resistance to within acceptable values.

Let's change the circumstances now, toward a battery that has been in service for 5 years. Now, a slightly different set of maximums are applied. Now we can allow a maximum resistance of 20% above the previously established baseline average. Refer to Table 2.

NO HISTORY, LOST HISTORY AND OTHER PITFALLS WORTH AVOIDING

Let's examine for a moment, at a situation that occurs all too often. The battery is installed, however baseline measurements are not taken or worse, the battery is never placed into a routine maintenance plan. Several years after commissioning, a maintenance plan is initiated. At that time, the service personnel have no history of interconnection resistance along with all other data necessary to determine battery health. What should be done? Treat the battery as "new" and establish a baseline by disassembling, cleaning and re-making several battery interconnections. Each type of connection geometry should be involved in the baseline development. Use these baseline numbers to evaluate connection resistance for the rest of the battery. Don't be surprised if considerable corrective maintenance is required to bring the battery back into compliance with the standards.

Is there a performance, acceptance or service test in the battery's future? Users would be well served to verify that connection integrity is within specification, especially if it has not been under recent care. Poor quality, high resistance connections will most assuredly make themselves known during the testing process.

Users should also keep in mind that at some point during the service life of the battery, a warranty claim might be filed with the manufacturer. Generally, the interconnections assembled on site are not warranted because the manufacturer has no control over installation methods, personnel, etc. unless they are of the variety welded at the factory. Check with the manufacturer of your battery if questions arise. For virtually all other concerns, however, documented maintenance history may well be required to settle claims.

During the installation phase of a new battery system, the installer should have a good working knowledge and the practical experience required to correctly install the battery as well as verify their work. That means a micro ohmmeter needs to be in the "toolbox" if the work performed is to be verified. The author has seen many installations where a micro ohmmeter was nowhere to be found upon completion of the installation. It's a must.

SUMMARY

- Because of the nature of its mission, the stationary battery cannot be overlooked from a maintenance perspective. Continued maintenance practices by trained personnel utilizing the right tools for the job, without doubt, are essential.
- Interconnection resistance measurements are a vital task in battery maintenance and cannot be ignored.
- A micro ohmmeter is the preferred test instrument to measure the DC resistance of battery interconnections.
- Determine the type of battery connection hardware, terminal construction and other physical characteristics of the interconnections before making a purchase decision.
- Baseline measurements are essential for a comparative standard by which future measurement results are to be reference. Baseline resistances can be established anytime, however they are best established at the time of installation.
- Each connection geometry much be considered separately when performing baseline and allowable maximum resistance values.
- Maintenance history is valuable information and may be required by the battery manufacturer when processing warranty claims for a variety of ailments it may experience over its service life.

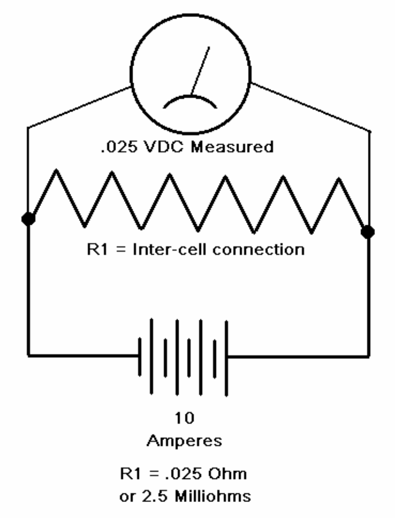

Figure 1
Simplified connection resistance
measurement circuit

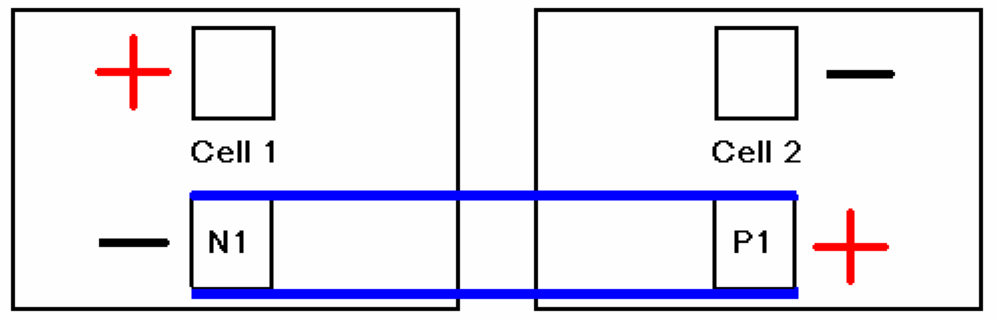

Figure 2
Conventional two-post cell using double strapped interconnections

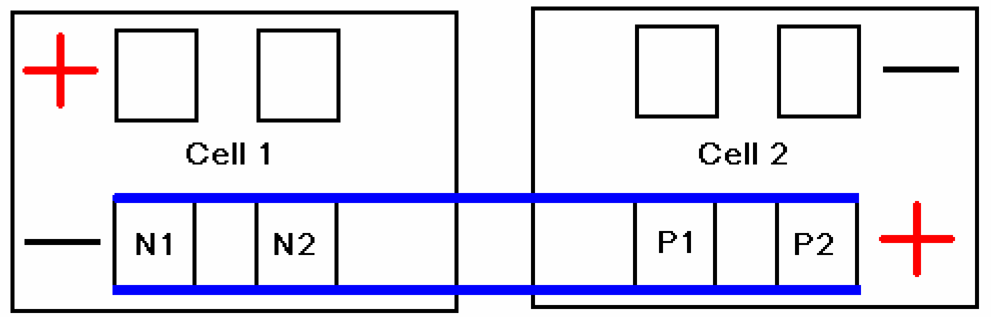

Figure 3
Conventional four-post cell using double strapped interconnections

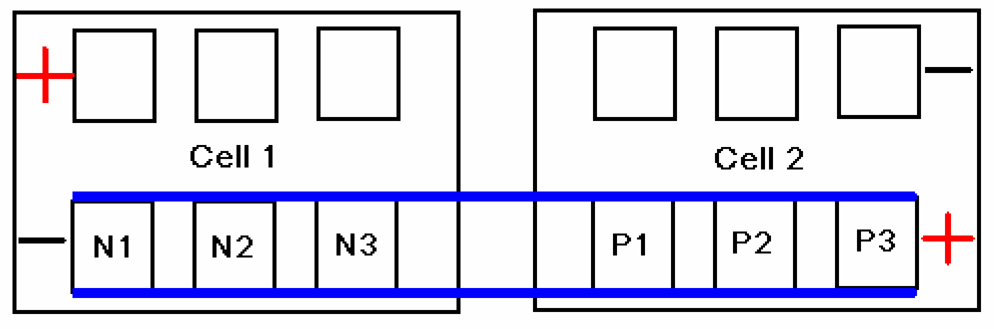

Figure 4
Conventional six-post cell using double strapped interconnections

Cell	Inter-cell N1–P1	Inter-cell N2–P2	Inter-tier N1–P1	Inter-tier N2-P2	Inter-rack N1-P1	Inter-rack N2-P2	Post to Lug 1	Post to Lug 2
1	34	33					8	7
2	31	30						
3	31	28						
4	33	38						
5	26	27						
6			150	160				
7	32	27						
8	25	33						
9	27	33						
10	28	26						
11	26	27						
12					235	245		
13	33	32						
14	33	27						
15	25	33						
16	27	33						
17	31	36						
18			155	168				
19	33	27						
20	30	26						
21	34	26						
22	33	28						
23	34	29						
24							9	8
Average	**30**	**30**	**153**	**164**	**235**	**245**	**9**	**8**
High	**34**	**38**	**155**	**168**	**235**	**245**	**9**	**8**
Max.	**35**	**35**	**168**	**180**	**259**	**270**	**14**	**13**

Table 1
Example of collected connection resistances readings
with summary data and maximum recommended resistance values for a new battery installation

Maximum Interconnection Resistance Guide Per IEEE Standards		
Battery Type & Service	**Standards Reference**	**Resistance Standards**
VRLA Maintenance	IEEE 1188-1996	Max. of 20% increase from previously established baseline
VRLA Installation	IEEE 1187-1996	Max. of 10% or 5 micro-ohms, whichever greater at time of installation
Flooded Maintenance	IEEE 450-1995	Max. of 20% increase from previously established baseline
Flooded Installation	IEEE 484-1996	Max. of 10% or 5 micro-ohms, whichever greater at time of installation

Table 2
(Ref 1 through 4)

References

1. IEEE Std 1188-1996, IEEE Recommended Practice for Maintenance, Testing and Replacement of Valve Regulated Lead Acid Batteries for Stationary Applications, Section 5 and, Annex D.

2. IEEE Std 1187-1996, IEEE Recommended Practice for Installation Design and Installation of Valve Regulated Lead Acid Batteries for Stationary Applications, Section 6.2.2 and Annex B.

3. IEEE Std 450-1995, IEEE Recommended Practice for Maintenance, Testing and Replacement of Vented Lead Acid Batteries for Stationary Applications, Sections 4.3.3, and 4.4.1.

4. IEEE Std 484-1996, IEEE Recommended Practice for Installation Design and Installation of Vented Lead Acid Batteries for Stationary Applications, Sections 6.2.2 and Annex A.1 through A.8.