OHMIC READINGS: A BATTERY MANUFACTURER'S PERSPECTIVE

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INTRODUCTION

The use of Ohmic measurements on lead acid stationary cells has been gaining popularity. EnerSys continues to actively evaluate our products' response to the commercially available test equipment. Over the past 2 years, we have been actively working with two major equipment manufacturers to understand the technology, its application and how our customers can better use this information.

This paper will examine 2 Volt VRLA, 12 Volt VRLA and 2 Volt Flooded stationary cells with specific focus given to the areas of

- As manufactured readings (T_{-0} readings)
- Relationship between the as manufactured readings and those published within the industry
- Changes in the readings over time (T_{90+} readings)
- Relationship between the major technologies (Resistance and Conductance)
- Future steps to be taken

The use and application of Ohmic measures is well documented throughout the industry including publications from IEEE, battery manufacturers and even the equipment manufacturers themselves. Collectively, these organizations recommend trending of the data over the lifetime of the cells. More and more, select users are requesting reference values that are used as ultimate min/max limit for their cells and to base warranty replacements on.

DEFINITIONS

The information in this section is taken from and paraphrases the wording in IEEE Standard 1187-1996.

Ohmic measurements provide information about cell or battery unit circuit continuity.

The internal Ohmic measurement of a cell consists of a number of factors, including, but not limited to, the physical connection resistances, the ionic conductivity of the electrolyte, and the activity of electrochemical processes occurring at the plate surfaces. With multicell units, there are additional contributions due to intercell connections. The resultant lumped measurement can be quantified using techniques such as the following:

a) Impedance measurements can be performed by passing a current of known frequency and amplitude through the battery and measuring the resultant ac voltage drop across each cell/unit. The ac voltage measurement is taken between the positive and negative terminal posts of individual cells or the smallest group of cells possible. Compute the resultant impedance using Ohm's law, which is normally done automatically by the meter.
b) Conductance measurements can be performed by applying a voltage of known frequency and amplitude across a cell/unit and observing the ac current that flows in response to it. The conductance is the ratio of the ac current component that is in phase with the ac voltage, to the amplitude of the ac voltage producing it.
c) Resistance measurements can be performed by applying a load across the cell/unit and measuring the step change in voltage and current. The Ohmic value is calculated by dividing the change in voltage by the change in current.

Many times, the conductance and impedance terms are mis or loosely used. Because of this, another set of definitions or concepts is included below

a. **Impedance (Z)** = R + jX where R is the resistive component (real part of impedance) and jX is the reactive component (imaginary part where sign can be + or – depending on whether the overall component is more capacitive or more inductive in the circuit).
b. **Admittance (Y)** = G + jB where G is the conductance component (real part) and jB is the susceptance (imaginary part).
c. **Z = 1/Y**

With the above stated, most Ohmic meters will focus on the real components of these items. It is because of this that direct correlations between the technologies is not preferred (to be discussed further later in the paper).

EQUIPMENT AVAILABILITY AND STANDARDIZATION

In the market today, battery users have many choices of Ohmic measurement equipment from many different manufacturers. As this market has developed, each manufacturer of test equipment has developed their own proprietary technology to better their product offerings. Unfortunately for the users, this developed into or caused incompatibility between the data and in many cases confusion on its applicability and use.

Additionally, this technology was originally developed to detect sudden and/or unpredictable failures of the early model VRLA products that were on the market. Development of what the values meant and how they could be correlated to the failures was a significant thrust of the work. Over the past few years, this technology has started to be applied to flooded (VLA) products with the hopes of determining a link to performance and/or life characteristics.

FACTORY OHMIC READINGS

When looking at the VRLA marketplace, it is becoming more common for customers to request or even require that Ohmic readings be supplied with quotations and/or cell shipments. This data, when supplied, can often be troublesome, inaccurate and at times misleading to the customer. However, it is understood that customers would like to use this data in two potential ways.

(1) Identification of suspect or weak cells/units – By analyzing the readings supplied from the manufacturers, customers may be able to determine if there are defects and/or problem cells in the supplied lot.

This may be a legitimate and useful technique that could help the battery manufacturers detect problem cells, however determining threshold values for non-conforming products would have to be developed and linked to the measured data.

(2) Baseline readings for later use – In this case, the customer desires to use the supplied data as the installed baseline for any future changes to be measured against.

This use of factory supplied Ohmic data as baseline data for the installation can be highly questionable and in some cases of little use to the customer. In order for the data to be of much use it should be taken while the cells are in a float-stabilized condition. Since most manufacturers do not float cells for long enough durations during the manufacturing process to significantly stabilize them there may be little added value as well as large discrepancies between what users see and what was provided to them.

With dozens of meter systems available in the industry it is not practical for the battery manufacturer to take readings with all possible available systems. The potential mix of impedance readings at the factory versus conductance or internal resistance readings by the customer makes this even more troublesome.

Additionally, even in the few instances where the factory readings are taken with the same equipment used by the customer; the factory data is not generally valid as “baseline” for trending purposes due to changes that occur in the cells during shipment, handling, storage and the first few months of actual service.

AS MANUFACTURED READINGS (T_{-0})

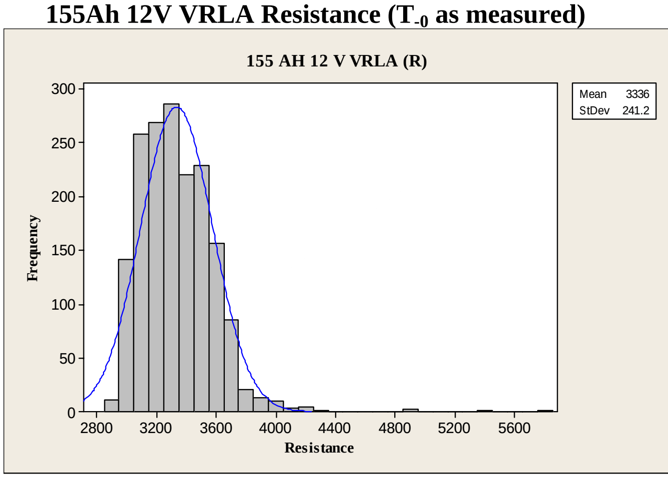
An early step in the investigation of these technologies involved gathering baseline data from the manufacturing plants and to analyze for stability. In doing so, over 28,000 data points were collected across various lead acid product lines. A key investigative item for this data was to look at stability and variation in the numbers. Again, the thought was whether or not this could be used to support claims that the data can be used as an outgoing Quality Control screen in the manufacturing. Some examples of this data are shown in the table below

Variation in As Measured (T_{-0}) Ohmic Readings

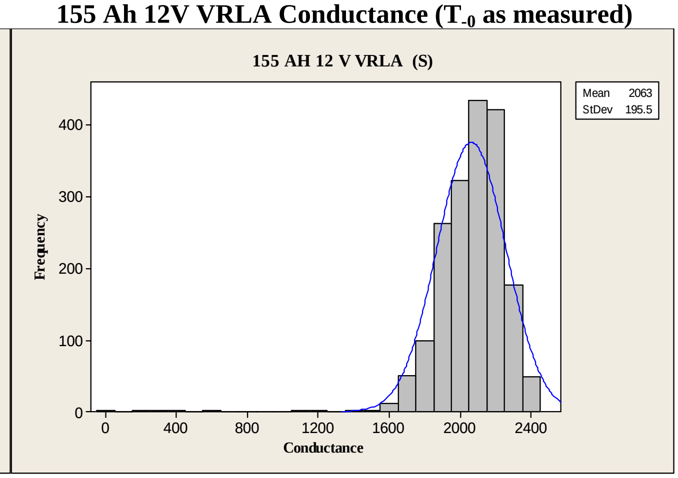
	u-Ohms	% Max - Min	Mhos	% Max - Min
3900 Ah 2V flooded	154	32%	8000	30%
155 Ah 12V VRLA	3350	86%	2401	63%
1105 Ah 2V VRLA	219	14%	4901	11%

Seeing the variation between the min and max values then forced a look at the raw data to see if the population distribution was normal or if we were seeing non-normal (i.e. bi-modal) distribution. Taking the product with the largest amount of variation between the min and max values (155Ah 12 V VRLA) we see that the data is fairly evenly distributed around the nominal value with only a few data points that could be considered outliers.

155Ah 12V VRLA Resistance (T_{-0} as measured)



155 Ah 12V VRLA Conductance (T_{-0} as measured)



The causes for the outliers continue to be investigated as we progress through our project, but in general we are seeing a stable value and normal distribution across all product lines.

RELATIONSHIP TO PUBLISHED DATA

Upon first starting this project, EnerSys found discrepancies between our plant obtained values and those values which are published by some of the equipment manufacturers for the same products. Admittedly, there is not much published data on the EnerSys products, however from the data that was available; we saw dramatic differences between this data and what we were measuring in our factory.

From working with the Ohmic equipment manufacturers, we understand that these published values have been obtained from actual field data with cells that are in various stages of charge, various ages and taken by different personnel.

Again, published data was somewhat scarce, however a specific example would be the 3900 Ah 2V flooded cell. Our T_{-0} values average 8,000 Mhos and 150 u-Ohms, while the published values (T_{90+}) are 10,900 mhos and 102 u-ohms. This is again why the use of data directly from the manufacturer and developed from newly produced batteries may not be helpful to establish field baseline values on installed cells.

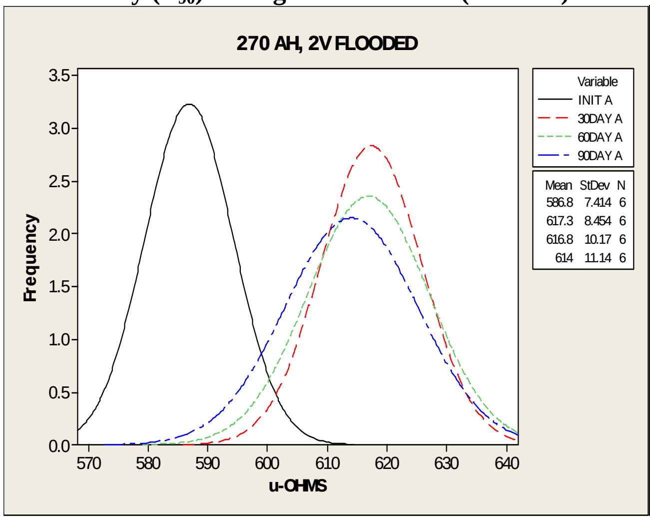
CHANGES IN READINGS OVER TIME (T_{90+} READINGS)

After seeing such discrepancies, a new phase of the evaluation began, namely one whereby several cells were placed on a float charge for 90 days. During these 90 days, the cells had Ohmic readings taken every 30 days and the changes from initial reading were monitored. This testing was performed on various products including 3900 Ah 2V flooded, 270 Ah 2V flooded, 155 Ah 12V VRLA and 1020 Ah 2V VRLA cells. For the purpose of illustration, data on 270 Ah 2V Flooded cells is included in this section.

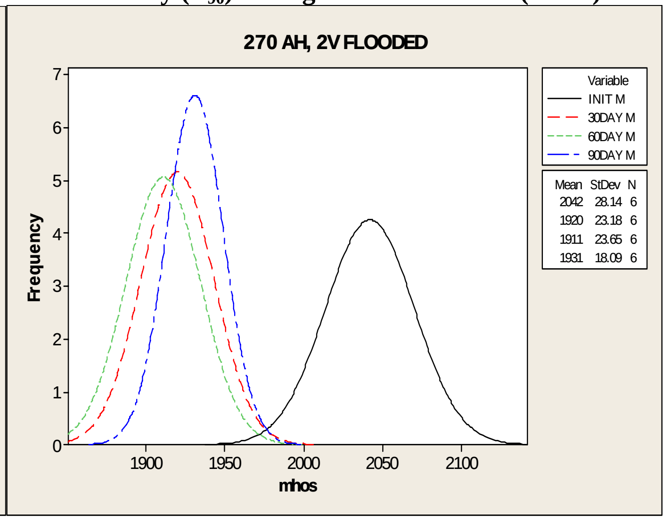
In many cases, these readings, taken after a cell has been on float for a period of time and in a float stabilized condition, are referred to as the time plus 90 day (T_{90}) readings.

In the illustrations below, the solid lines are the T_{-0} value measured at our finishing line and the dotted lines are the T_{30}, T_{60} and T_{90} values measured while on float charge at 2.25 volts per cell.

90 Day (T_{90}) Change in Resistance (u-Ohms)



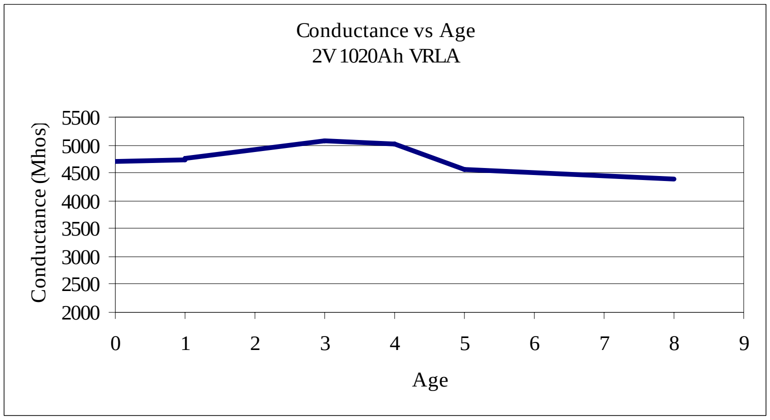
90 Day (T_{90}) Change in Conductance (Mhos)



This illustrates that the values do indeed change over time (Resistance increasing and Conductance decreasing in this testing). However, understanding the mechanisms that cause these changes during and after the float stabilization period will not be discussed in this paper. It does however reinforce that values obtained directly from the battery manufacturers and from the finishing lines may not be exactly what the end users will see in the as-installed applications.

As an additional investigative tool, we obtained field data on previously installed product. Specifically on some 2V 1020Ah VRLA cells, we found that our as-measured (T_{-0}) value of 3899 Mhos differed from the customers' first measured (T_{90+}) value (approximately 4800 Mhos). Again, overtime, the values continued to change and at approximately the 8 year mark were that of its "newborn" condition.

2V 1020Ah VRLA Impedance over installed life



Ongoing work is underway to link these cells to capacity testing that may have been carried out and see if there is any correlation between the Ohmic values and the demonstrated capacity. (For the data above, capacity testing was not carried out on the cells, however the cells are still in service and we hope to continue to follow them.) We are aware that at least one Ohmic measurement equipment manufacturer has attempted to validate/correlate Ohmic test values and the demonstrated capacity of cells as determined by a standard load test. Papers for this study have been published numerous times and presented at various battery industry forums since 1990.

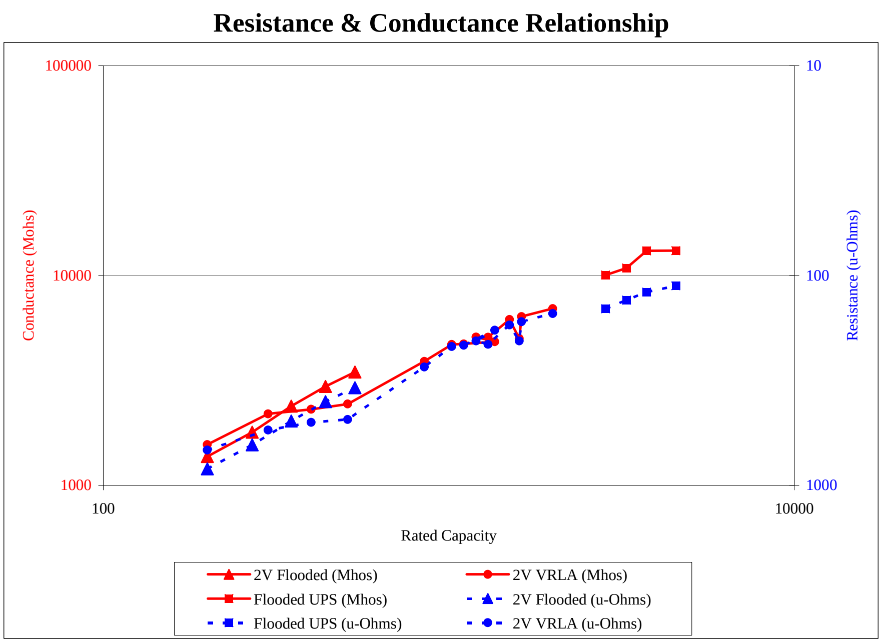
Regardless of what the % change in the Ohmic value is between the T_{-0} and the final commissioned value (T_{90+}), EnerSys recommends that the users develop baseline values for their specific installation.

These individual cell "baseline" readings will serve as a reference for trending purposes for comparison to readings taken later in life. Further, it is recommended to follow published standards such those issued by IEEE for battery maintenance. In the event a cell or battery Ohmic reading should vary significantly from the trend in baseline values or from others in the group, the cell/battery should be further evaluated to determine the cause.

RELATIONSHIP BETWEEN RESISTANCE AND CONDUCTANCE

Theoretically and put simply, conductance is the inverse of resistance (1/R). However field conversion of conductance and resistance values has not been fully researched. EnerSys has taken data (T_{-0} values) gathered in our program and compared them against each other. The method of doing so was to utilize a chart showing a dual axis log of conductance and resistance vs. the log of the cells' rated capacity. Initially, this was looked at with respect to the 2V VRLA cells only, but after seeing some form of correlation we expanded the evaluation to include other cells.

The chart below consists of 2V VRLA, 2V flooded switchgear and 2V flooded UPS cells. All solid lines in the chart below are the conductance values in Mhos and the dotted lines are values in u-Ohms.



The lines appear to be related, however drawing any conclusions about one measure simply being the inverse of the other cannot be made. There is an offset between the values, and upon closer examination, the offset is not consistent throughout the lead acid technologies examined, nor among product families (VRLA vs. flooded for example). Using advanced mathematics a correlation factor or offset can be determined, but it would be unique for almost every point/reading along the curve.

Further work will be done to investigate whether or not a valid correlation factor can be developed and whether or not this can be widely applied to a family or technology base. Until such a reliable factor is developed, our recommendation to users can be summed up with a simple statement - "Different meter - Different value"

FUTURE STEPS

Based on what we have seen, we will continue to investigate the following items

- Outliers in the plant readings (T_{-0}) readings. Why do they occur and do they indicate something occurring inside the battery?
- Changes in the Ohmic readings over the life of a battery. How do they change and what do the changes indicate with respect to functionality of the battery?
- With regards to the data being published throughout the industry, how is the obtained and how can users apply this data to cells that they may have in their installed base?
- With respect to the changes in Ohmic values over the life of a battery, is there a link to performance/capacity/life of the battery?
- What is acceptable variation that a user can expect to see in as received batteries? Further, what criteria should be used to judge acceptability of product in the field?

RECOMMENDATIONS/CONCLUSIONS

- Ohmic measurements taken at the manufacturing factory (T_{-0}) can be misleading and at times not useful as baseline data (T_{90}) for trending studies in field service.

- Ohmic measurements taken over time in field service (T_{90+}) can be used as a trending tool to identify cells that may require further evaluation. It is recommended that the user baselines each battery in a battery string individually and uses this battery-specific value to trend the health of the individual battery over time

- Ohmic readings depend greatly on the surface condition of the connection and the location of the connection of the instrument, and care must be taken for data trending (T_{90+}) to be effective.

- Ohmic readings are dependant on cell designs and straight calculations between measurement techniques should be made cautiously, and only with input from the equipment and battery manufactures.

- At this time, ohmic measurements have not proven to be a fully reliable substitute for capacity testing and should not be used to predict absolute capacity values.