Internal Ohmic Measurements and Their Relationship to Battery Capacity

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INTRODUCTION

Internal ohmic measurements are used to determine the *health* of a battery by monitoring the internal resistance of its individual cells. Resistance, impedance, and conductance test equipment all measure some form of a cell's internal resistance. The term *internal ohmic measurement* is a generic term referring to a measurement of a battery cell's internal resistance using any one of three available technologies — conductance, impedance, or resistance.

As a battery cell ages and loses capacity, its vital internal components (plates, grids, and connection straps) undergo unavoidable degradation. This natural degradation causes an increase in the resistance of a cell's internal conduction path. Internal ohmic measurements are intended to measure this change in resistance. A measured increase in resistance or impedance (or decrease in conductance) indicates likely degradation in a cell's internal conduction path. The degree of degradation in a cell's conduction path can be correlated to the battery aging process, which in theory can be correlated to a cell's capacity.

A number of factors can affect the internal resistance and capacity of a cell simultaneously. However, not all factors affect a cell's capacity to the same degree as they affect internal resistance, or vice-versa. Fortunately, there is a general correlation in which most factors that increase internal resistance do tend to decrease capacity. Table 1 shows the effect of various factors on cell internal resistance and cell capacity.

Table 1 – Factors Affecting a Cell's Internal Resistance

Factor	Internal Resistance	Capacity	Comments
Grid corrosion	Increase	Decrease	Natural aging process
Grid swelling and expansion	Increase	Decrease	Includes loss of contact between active material and grid
Loss of active material	Increase	Decrease	Cycling or natural aging
Discharge	Increase	Decrease	Either self-discharge or discharge into a load
Sulfation	Increase	Decrease	Attributable to undercharging
Internal short circuits and hydration	Decrease	Decrease	Internal short circuits due to mossing or sediment buildup might cause resistance to decrease
Temperature decrease	Increase	Decrease	
Temperature increase	Decrease	Increase	Contributes to premature or accelerated aging in long term; effect here is in terms of immediate effect
Rated cell capacity	Decrease	Increase	Resistance tends to decrease as cell size (cell capacity) increases
Dryout	Increase	Decrease	VRLA cell failure mode by loss of electrolyte water
Negative plate discharge	Increase	Decrease	VRLA cell failure mode in which negative plate forms higher resistance lead sulfate
Negative strap corrosion	Increase	Decrease	VRLA cell failure mode – extent of resistance change not known
Loss of compression	Increase	Decrease	VRLA cell failure mode in absorbed glass mat cells by relaxation of glass mat

To summarize, an increase in internal resistance is expected to correlate with a decrease in a cell's capacity in most cases. Each type of internal ohmic test equipment will respond to an internal resistance increase as follows:

- Conductance tester — decrease
- Impedance tester — increase
- Resistance tester — increase

PROJECT DESCRIPTION

The Electric Power Research Institute (EPRI) recently completed a project to assess the viability of using internal ohmic measurements as an indicator of battery capacity. Internal ohmic measurements were taken with the following test equipment:

- Conductance— Midtronics Celltron Plus
- Impedance— AVO Biddle MBITE
- Resistance— Alber Cellcorder

Approximately 3,000 cells were included in the test program, including both VRLA and vented lead acid batteries. The batteries were almost exclusively used in electric utility applications: generating plants, substations, and communication centers. Internal ohmic measurements were taken prior to performing a capacity test on each stationary battery. The discharge test results were evaluated and a percent capacity was calculated for each cell. Each internal ohmic measurement was then compared to the calculated cell capacity to determine if a relationship was apparent. As part of the data acquisition and analysis, guidelines were developed to assist users with the implementation of the technology.

PROJECT RESULTS

This project successfully demonstrated that internal ohmic measurements can detect degraded cells. Furthermore, all evaluated measurement technologies — conductance, impedance, and resistance measurements — were shown to be effective. The key results are summarized below.

Correlation Between Instruments

All three instrument types used during this project provided equivalent results. A correlation was always observed between the instruments, although the exact correlation varied with battery type. The test results support a conclusion that any of the three parameters — conductance, impedance, or resistance — can be monitored with equivalent results. Figures 1 and 2 show the typical correlation observed between instruments.

Figure 1 – Correlation of Impedance to Conductance Measurements

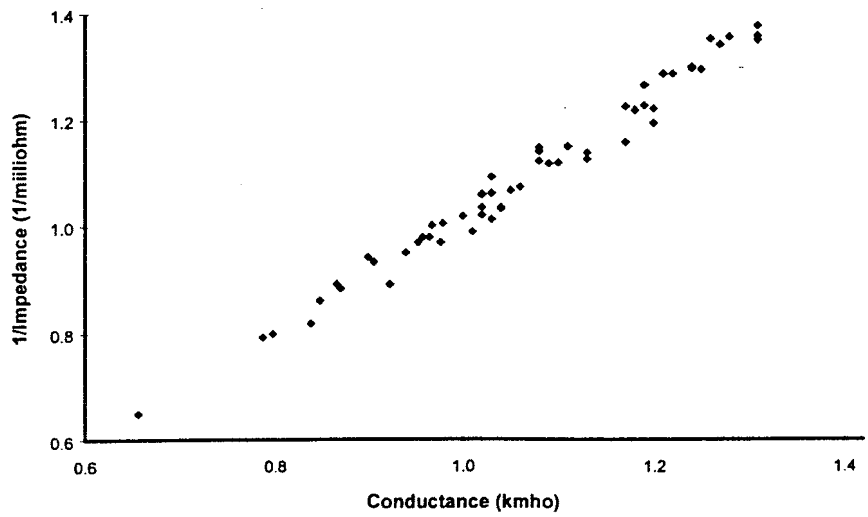
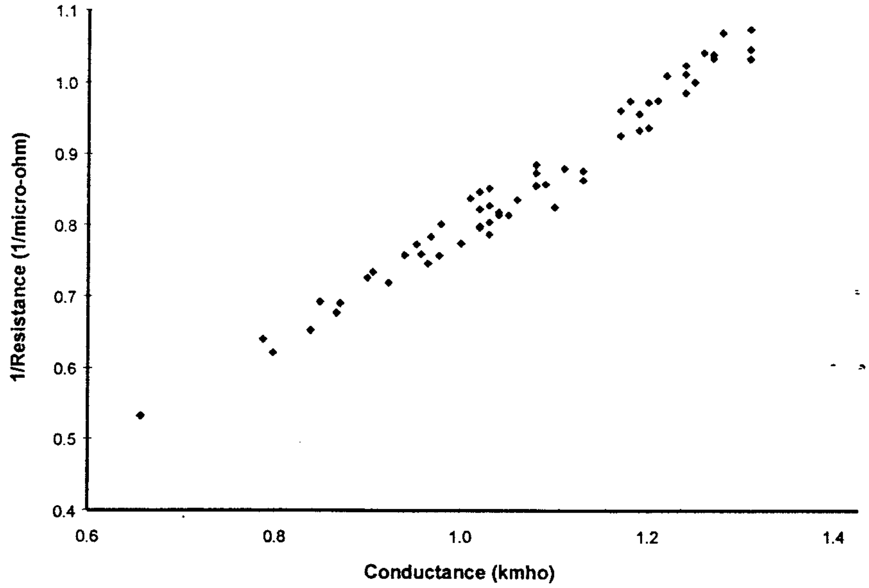


Figure 2 – Correlation of Resistance to Conductance Measurements



Correlation to Capacity When a Battery Has Bad Cells

Internal ohmic measurements were normally taken before a battery capacity test. After the battery capacity test was completed, the capacity of each cell was calculated based on its end voltage upon completion of the capacity test. Then, internal ohmic measurements were compared to the individual cell capacities to determine the trend in performance.

Internal ohmic measurements do show a correlation to capacity and readily identify low-capacity cells in a battery string. Figures 3 through 5 show the test results of a 48-V battery in which the cells had near 100% capacity, except for two very low capacity cells (each <50% capacity). As can be seen with each type of internal ohmic measurement, a clear trend with respect to capacity can be seen. This type of behavior was commonly observed when a battery had a combination of good and bad cells.

Figure 3 – Comparison of Conductance to Cell Capacity

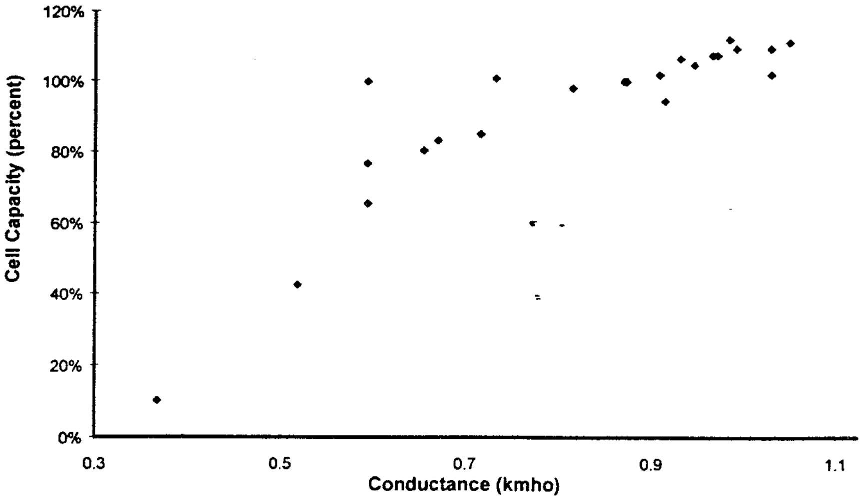


Figure 4 – Comparison of Impedance to Cell Capacity

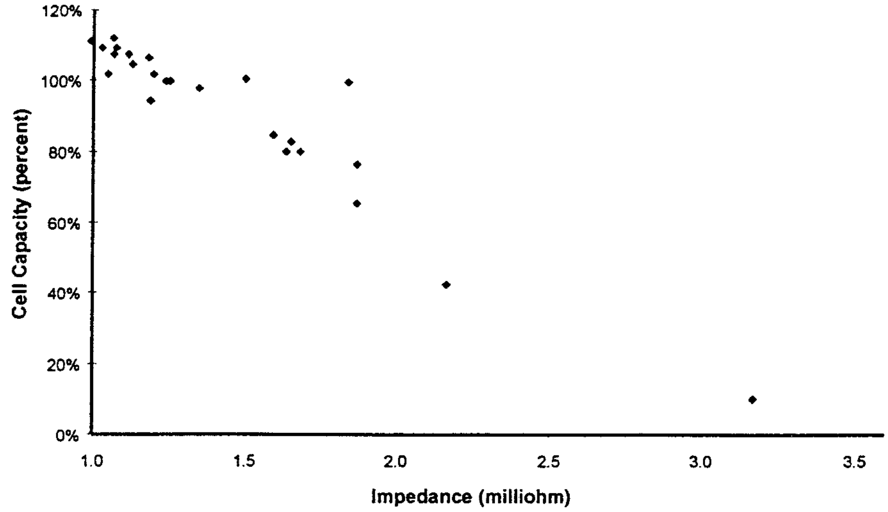
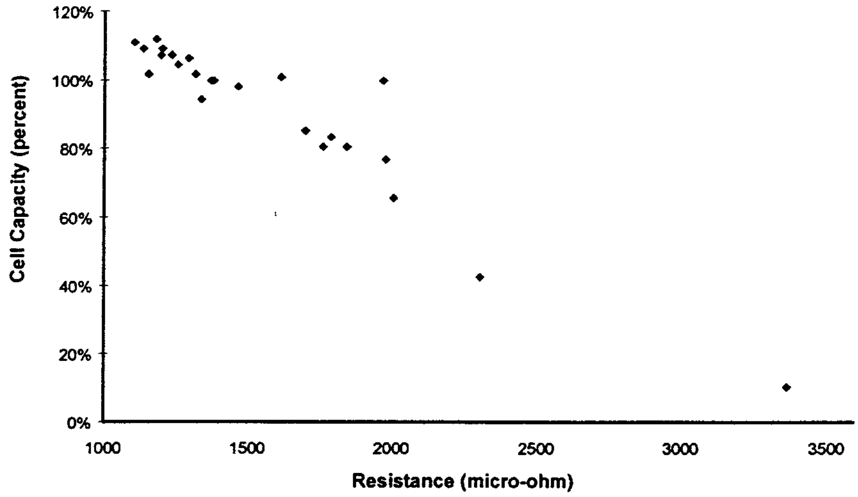


Figure 5 – Comparison of Resistance to Cell Capacity



Figures 6 through 8 show the test results of a VRLA battery with less than 80% capacity. In this case, none of the cells had 100% capacity. Even so, a clear trend with respect to capacity can be observed.

Figure 6 – Comparison of Conductance to Cell Capacity

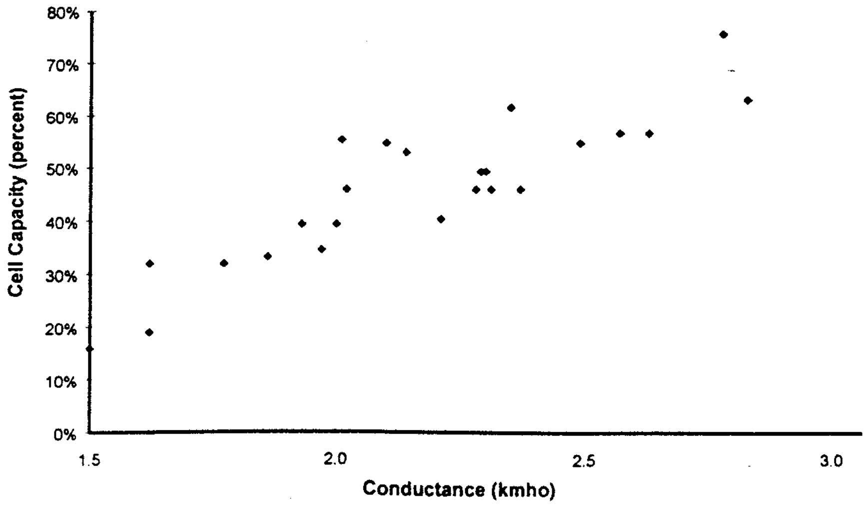


Figure 7 – Comparison of Impedance to Cell Capacity

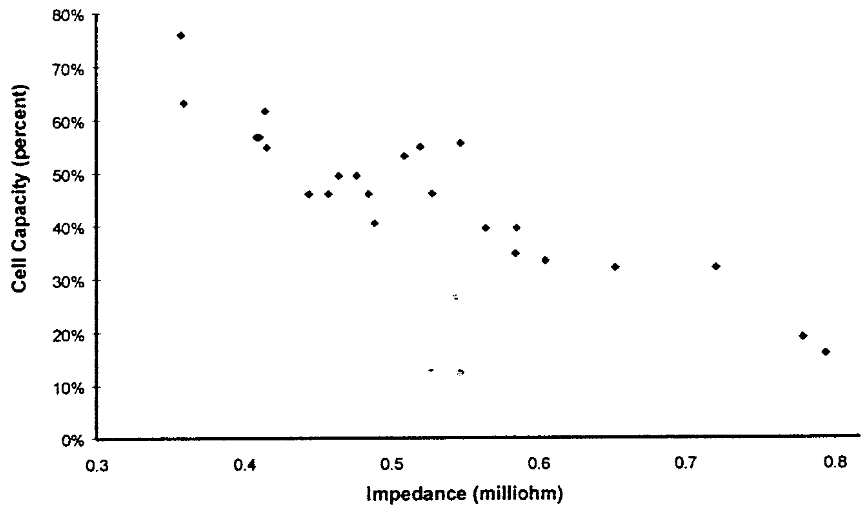
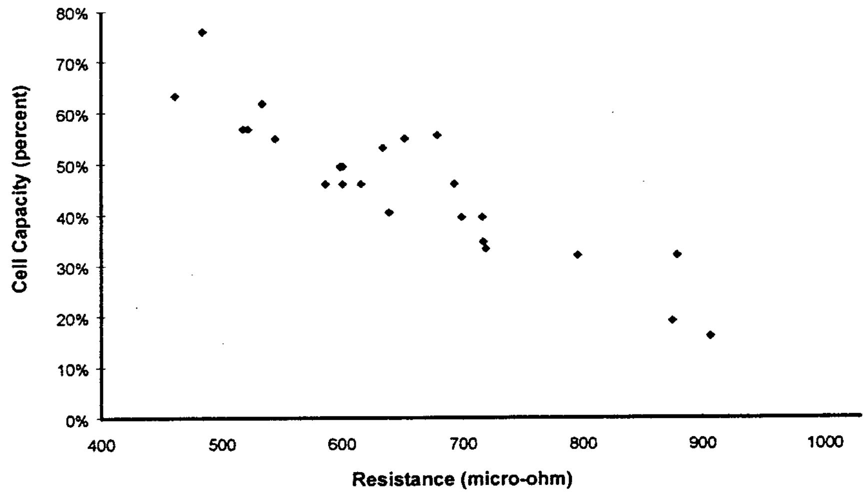


Figure 8 – Comparison of Resistance to Cell Capacity



Capacity as a Function of the Nominal Internal Ohmic Value

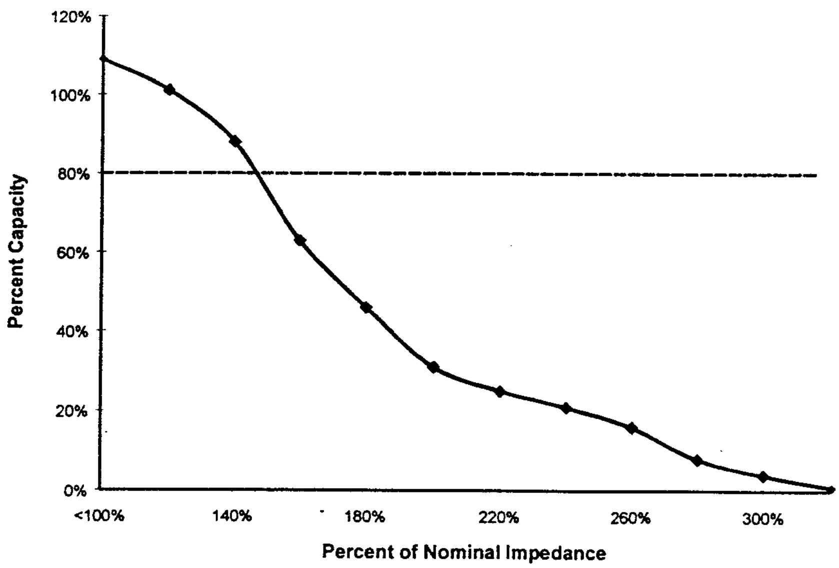
VRLA batteries evaluated during this project tended to have a wider range of capacity on a per cell basis than did vented cells, and most VRLA batteries had some cells with low capacity. Table 2 shows an evaluation of the average cell capacity as a function of internal ohmic value. For each cell, the measured internal ohmic value was converted to a percent of nominal value based on the expected internal ohmic value when the cell was new. After the discharge test, the capacity of each cell was calculated based on its end voltage compared to the expected end voltage for the discharge rate. As can be seen, capacity clearly decreased with increasing impedance, increasing resistance, or decreasing conductance.

Table 2 – Percent Cell Capacity as a Function of the Nominal Internal Ohmic Value

Percent of Nominal Conductance	Average Percent Capacity	Percent of Nominal Impedance	Average Percent Capacity	Percent of Nominal Resistance	Average Percent Capacity
>100	106	<100	109	<100	109
90 - 100	100	100 - 120	101	100 - 120	102
80 - 90	92	120 - 140	88	120 - 140	85
70 - 80	73	140 - 160	63	140 - 160	56
60 - 70	50	160 - 180	46	160 - 180	36
50 - 60	23	180 - 200	31	180 - 200	36
40 - 50	8	200 - 220	25	200 - 220	20
30 - 40	2	220 - 240	21	220 - 240	18
20 - 30	.8	240 - 260	16	240 - 260	15
10 - 20	.3	260 - 280	8	260 - 280	9
<10	0	280 - 300	4	280 - 300	4
		>300	.9	>300	1

The impedance data provided above in Table 2 has been graphed in Figure 9 to further illustrate the observed loss of capacity as the impedance increased. Graphs for conductance and resistance measurements yield similar results.

Figure 9 – Percent Cell Capacity as a Function of Nominal Impedance



Although there is data scatter, the following conclusive observations can be made regarding the impedance test results (similar observations can be made for conductance and resistance measurements):

- Most cells had less than 80% capacity once impedance increased to 150% of the nominal impedance (a 50% increase).
- All cells had less than 50% capacity once impedance increased to 200% of the nominal impedance (doubled).
- All cells had less than 25% capacity once impedance increased to 250% of the nominal impedance (a 150% increase).
- All cells were dead once impedance increased to 300% of the nominal impedance (tripled).

General Guidelines for Test Equipment Use

During the project, it was always known which cells were bad because a capacity test was performed in conjunction with the internal ohmic measurement of each cell. The challenge that users face when taking internal ohmic measurements is how to interpret the results so that low capacity cells can be identified. In many cases, the user will have to make a go/no-go decision on the battery based solely on the internal ohmic measurements. A three-step evaluation process is recommended as follows:

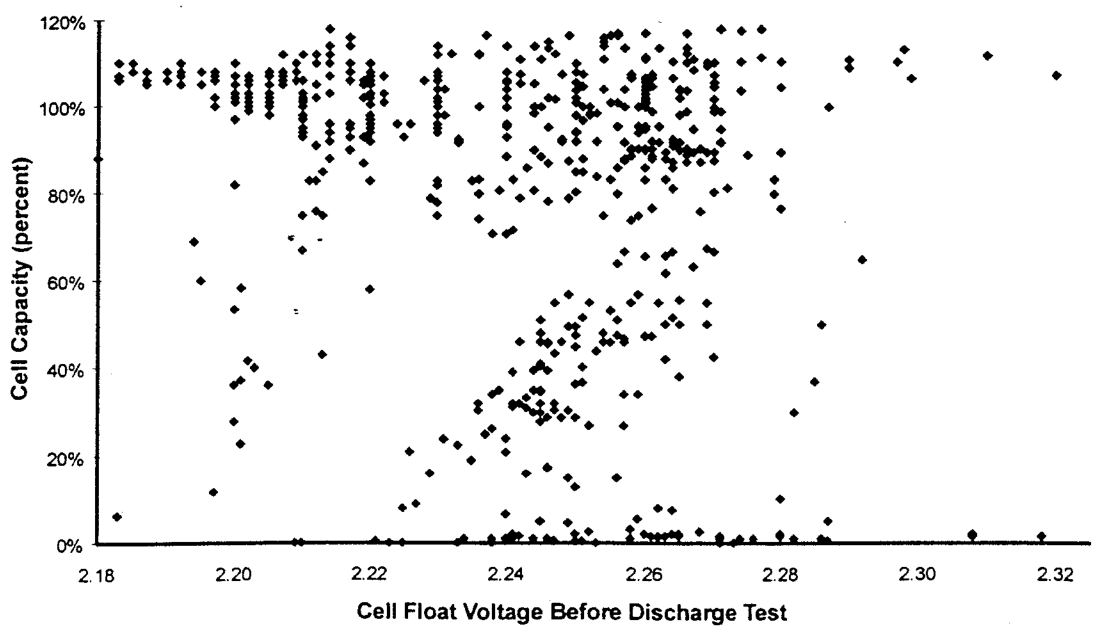
1. First, understand what internal ohmic value is expected for the model of cell to be checked. This expected value is referred to as the *nominal value* and is the typical value of a 100% (or better) capacity cell. This nominal value does not have to be precise, but should be representative of the expected value. The nominal value varies widely with cell size (ampere-hours) and design.
2. After all cell measurements have been taken on a battery, compare each measurement to the average internal ohmic value for the battery. If there is a wide variation in the data, compare the measurements to the expected nominal value instead.
3. Evaluate the variation in the measurements. A battery with a large variation in internal ohmic values likely has bad cells. Also, if several cells are identified as bad based on significantly poor values, it is possible that other bad cells exist but do not readily stand out from the data set because the data for the very poor cells masks their presence.

Step 2 above is the basic method of identifying low capacity cells and appears to work well when there are only a few bad cells in an otherwise good battery. Step 1 above provides an additional measure of assurance; a battery with all bad cells can be difficult to evaluate by a simple comparison to the average value of the measurements. Step 3 provides a final check to confirm that the results make sense.

OTHER PROJECT OBSERVATIONS

Internal ohmic measurements appear to be particularly valuable for VRLA cells. In general, VRLA cells have very few other maintenance checks that can be performed. Electrolyte checks cannot be performed because the cell is sealed. And, a detailed visual inspection cannot be performed because of the cell construction and the opaque container. Battery manufacturer operating manuals typically specify periodic monitoring of battery and cell float voltage; however, the data acquired by this project indicate that cell float voltage measurements are not a satisfactory predictor of cell capacity. Figure 10 shows the lack of correlation between cell capacity and float voltage observed by this project.

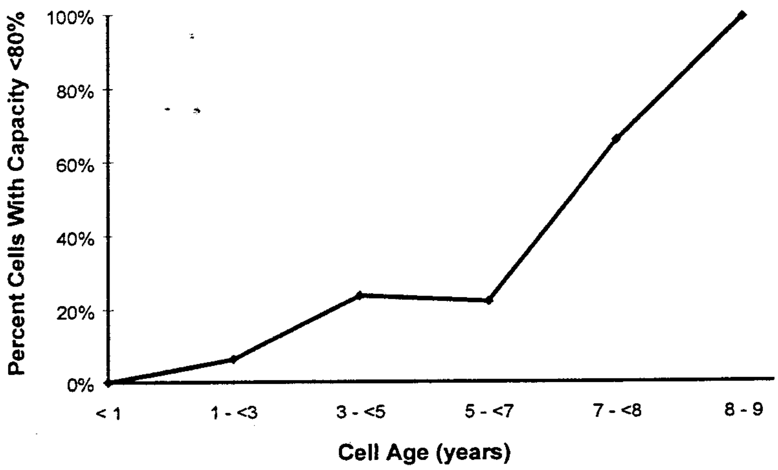
Figure 10 – Comparison of Float Voltage to Cell Capacity



As can be seen in Figure 10, cells with an ideal float voltage of 2.25 volts had capacities ranging from 0% to over 100%. An improper float voltage does require correction so that the battery is maintained in accordance with the manufacturer's instructions. However, a proper float voltage does not alone assure adequate cell capacity.

Most VRLA batteries evaluated during this project had some low-capacity cells. Figure 11 shows the percentage of identified low capacity cells as a function of battery age. New VRLA batteries almost always performed very well. Conversely, cell failure rates in VRLA batteries over 8 years old approached 100%. Although the sample of batteries evaluated by this EPRI project might not be representative of all VRLA battery types and applications, the observed failure rates are still worthy of consideration.

Figure 11 – Failure Rates Observed With VRLA Cells



CONCLUDING REMARKS

A relationship was observed between internal ohmic measurements and capacity. However, these measurements can not tell us everything regarding battery capability or condition. Some points to consider are:

- An increase in internal resistance (as measured by resistance or impedance testers) or a decrease in conductance (as measured by a conductance tester) was correlated to a reduction in cell capacity.
- An increase in internal resistance indicates that something inside a cell is changing. However, we often have no way of knowing what particular aging, degradation, or failure mode is at work inside the cell; we only know that something is changing. For example, we can not distinguish between dryout or plate corrosion inside a VRLA cell. Although the two degradation mechanisms might have a similar effect on an internal resistance change, they may have a somewhat different effect on cell capacity. The practical implication of this is that there will likely be some degree of data scatter in any correlation between capacity and internal ohmic measurements. This does not really imply a shortcoming of internal ohmic measurement technology, but it does mean that we will likely be limited to identifying *good* or *bad* cells rather than making claims that a certain internal resistance indicates a *particular* cell capacity.
- Users are typically concerned with the *battery* capacity. Internal ohmic measurements are taken on individual *cells.* A single cell with low capacity does not necessarily mean that the battery has low capacity. This is a key difference between a battery capacity test and battery health as determined by internal ohmic measurements. A battery capacity test really does determine the battery's capacity. Internal ohmic measurements have the ability to identify degradation in individual cells. Although internal ohmic measurements can identify low capacity cells (which is certainly valuable), the technology does not predict overall battery capacity. If you need an accurate measure of the overall battery capacity, perform a battery capacity test.

It is fair to admit that the technology is not perfect. Data scatter is large enough that internal ohmic measurements might never be able to predict *precise* cell capacity. But, those who resist the use of internal ohmic measurements because the technology is not "perfect" can be compared to those critics who refuse to wear their automobile seat belts because a few people have been trapped in their car following an accident. The fact is that seat belts save lives in spite of a few exceptions. Similarly, internal ohmic measurements can and do find bad cells. A high internal resistance most likely indicates that a cell has an internal capacity-limiting problem. At the very least, abnormal internal ohmic measurements are cause for further investigation. Finally, there are no real alternatives for monitoring VRLA cells, short of performing frequent capacity tests. As shown in this paper, traditional checks of VRLA cells, such as float voltage measurements, should not alone be considered a viable method of assuring cell reliability.

REFERENCES

1. EPRI TR-108826, *Battery Performance Monitoring by Internal Ohmic Measurements, Application Guidelines for Stationary Batteries*
2. EPRI TR-106826, *Battery Performance Monitoring by Internal Ohmic Measurements, Emergency Lighting Unit Batteries*
3. EPRI TR-100248-R1, *Stationary Battery Guide — Design, Application, and Maintenance*