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Field Application of Conductance Measurements Used to Ascertain Cell/Battery and Inter-Cell Connection State-of-Health In Electric Power Utility Applications

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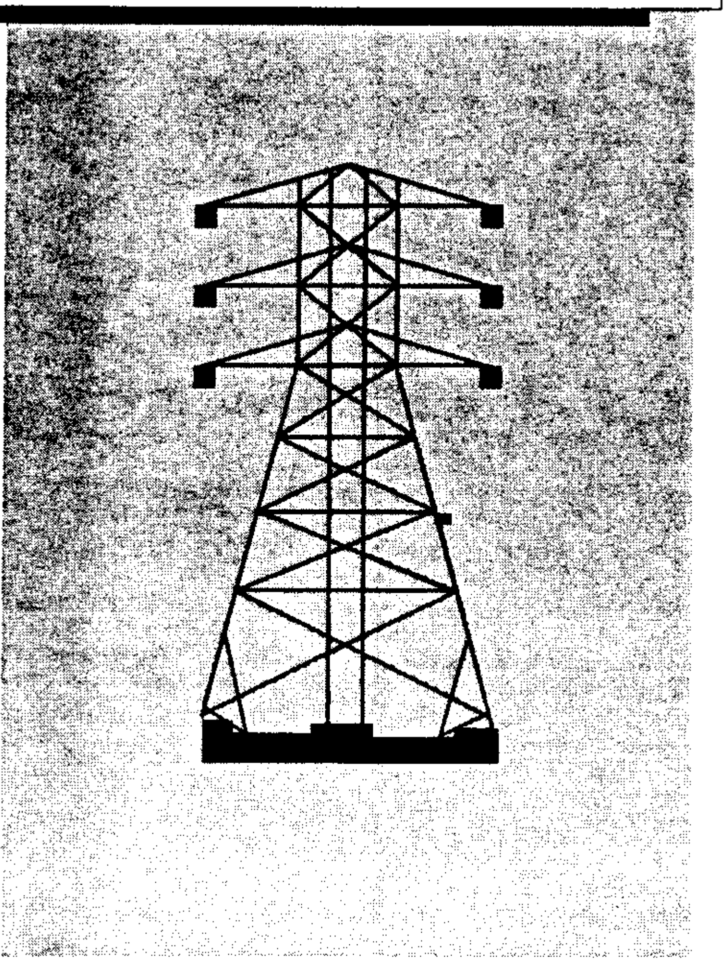

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Field Application of Conductance Measurements Used to Ascertain Cell/Battery and Inter-Cell Connection State-of-Health In Electric Power Utility Applications

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Abstract:

This paper introduces the use of conductance measurements as a practical technique to monitor the state of health of lead acid batteries in stationary standby service.

It presents the results of cell conductance and ampere-hour capacity field tests on more than 700 valve-regulated lead acid (VRLA) batteries, representing a wide range of cell types, sizes, applications and manufacturer. The results show close correlation of conductance and capacity and demonstrate the ability of the conductance technique to provide early detection of premature capacity loss or failure. In marked contrast, the data also show that neither individual cell float voltages or calculated specific gravities can give adequate warning of these failures.

Initial results of limited tests of cell conductance and ampere-hour capacity on flooded (vented), conventional lead acid cells, show similar correlation, with conductance measurements capable of detecting both serious and marginal capacity failures.

In addition, data are provided to allow temperature compensation of conductance measurements for both Gelled Electrolyte (GEL) and Absorbed Glass Mat (AGM) Value-Regulated Lead Acid (VRLA) cells, as well as for conventional flooded lead acid cells.

The paper also illustrates the utilization of conductance measurements as a practical technique to measure and insure the integrity of intercell connections.

Application Background:

Each Electric Utility may have several hundred large battery systems located in their generating plants, their own large substations and customer substations. The batteries can represent several million dollars of cost and may help to protect billions of dollars in assets. Batteries are required to provide a reliable source of DC power used for switching, relaying communications, power transformer system protection, emergency lighting, circuit breakers and other equipment in the event of an AC power outage. The batteries are also used to provide an emergency source of DC power needed to aid in safe system shutdowns and in station restoration.

Traditionally battery maintenance practices in the electric power industry follow specific guidelines as defined by the Institute of Electrical and Electronic Engineers (IEEE) standards. These practices recommend testing to be performed on a scheduled basis. Traditional measurements of float voltage and specific gravities in addition to annual service tests have been the primary methods utilized for determining battery state-of-health in the electric utility industry. Most electrical utilities have good intentions of implementing battery maintenance programs. However several utilities have started such programs only to abandon some aspects of the program because of manpower, cost of equipment and cost of maintenance personnel necessary to keep the program in operation, not to mention the sheer number of battery strings each utility has to maintain. Discussions with area supervisors have revealed that because of their work load and manpower cuts all they can do is to take monthly or quarterly float voltages and specific gravity readings. More often than not, "scheduled annual" capacity tests are postponed temporarily or indefinitely except when it appears that a major fault has developed in a particular battery string.

The conductance measurement is based upon the adaptation of the technology first reported by Dr. Keith S. Champlin[1]. In recent years several studies have been performed utilizing conductance technology to ascertain the relative condition of batteries, and successful attempts have been made to correlate the conductance results to timed discharge tests [2,3]. Other measurements of cell impedance have also been actively pursued as possible methods for evaluating cell/battery condition [4,5,6,7,8]. The application of conductance measurements in a maintenance practice is superior to traditional methods of specific gravity and or float voltage measurements and can provide the user critical information of battery condition which can be used to make a decision to perform further diagnostic testing such as discharge capacity testing.

Conductance Technology:

Conductance is defined as the real part of the complex admittance and is measured in the Systems International (SI) unit of Mhos, or the international unit: Siemens. The AC conductance test is performed by applying a low frequency AC voltage signal of known frequency and amplitude across a cell/battery and observing the AC current that flows in response to it. The AC 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. Since only the in-phase current component is considered, the effects of spurious capacitance and inductance, which predominantly influence the out-of-phase component are minimized.

Two types of Midtronics industrial conductance testers were utilized in performing the field tests. The first type is the "Celltron" tester which is a self contained, fully portable tester designed to measure the conductance of a single cell or three cell battery over a wide range of sizes from 10 to 8000 ampere-hours. The second type of tester is the "Midtron" tester which is a self contained, fully portable tester designed to measure the conductance of three and six cell batteries over a wide range of sizes from 2 to 600 ampere-hours.

Discussion of VRLA Future in Electric Power Utility Applications:

Over the last ten years, Valve-Regulated Lead Acid (VRLA) batteries have been rapidly deployed into many different applications. The acceptance and deployment of VRLA batteries in the electric power industry has begun relatively slowly. However, according to our reports, utility usage of VRLA batteries is increasing, especially in substation and emergency lighting (ELB) applications where their "maintenance free" promise appears attractive. Both GEL and AGM valve regulated lead acid (VRLA) designs covering a wide range of sizes and capacities are now available for deployment and replacement of aging flooded battery technology. Their attractive features parallel the business changes which include reduction in man power, and budget reductions that are forthcoming not only in the electric power industry but in many other industries. Many trained and highly skilled battery specialists are becoming extinct. Many of the new personnel replacing these people have minimal battery knowledge and have several areas of responsibility with which to deal on a daily basis. Thus the expectations of reduced maintenance of the VRLA battery design parallel the desires of many people responsible for battery maintenance. However *reduced maintenance* does not mean *no maintenance.* The number and type of potentially serious failure modes of VRLA cells significantly exceeds those of conventional cells whose primary failure mode results from grid corrosion/growth and loss of contact to the active material. In VRLA cells post seal, jar-cover leakage, and valve malfunction all cause dry out; grid corrosion and growth also cause dry out in addition to loss of grid/paste contact; loss of plate/separator/electrolyte compressive contact can cause capacity loss; internal corrosion and loss of contact between post/strap/plate lugs all result in a decrease in capacity. Since all of these factors also result in a decrease in conductance it is clear the conductance measurement should provide the maintainer an indication of potential cell/battery failure.

In a series of papers presented at the International Lead Zinc Research Organization (ILZRO) and Battery Council International (BCI) conference in May of 1992 [2] and a significantly more detailed paper presented at the International Telecommunications Energy Conference (INTELEC-1992) [3] two of the authors examined through field and laboratory testing, the relationships of traditional testing parameters and conductance testing on approximately five hundred VRLA cells and concluded first that a significant number of VRLA cells had suffered serious premature capacity loss which was not satisfactorily detected by either individual cell specific gravity (calculated from open circuit voltage) or individual cell float voltage. In contrast, a high degree of correlation from (0.80 to 0.98) was shown to exist between discharge capacity and cell conductance. This emphasizes the utility of conductance testing in detecting VRLA cells which showed premature capacity loss. The correlation was found to be equally high for VRLA cells ranging from 200 to 1000 Ah in size, in series strings of 48 to 360 volts and in battery plants containing from three to 15 strings in parallel.

Experimental Tests Performed on VRLA Cell/Batteries:

In 1992 and 1993 a series of tests was performed on more than 700 VRLA cells in telecommunication, UPS and railroad signaling applications. In the majority of tests individual cell float voltages, specific gravities (calculated from open circuit voltages) and conductances were measured prior to individual battery string discharges. Of the more than 26 battery strings tested using Alber discharge equipment, data, typical of individual string

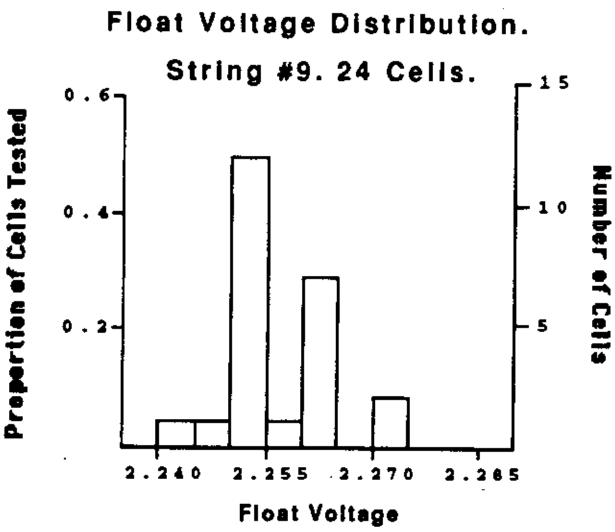


Figure 1

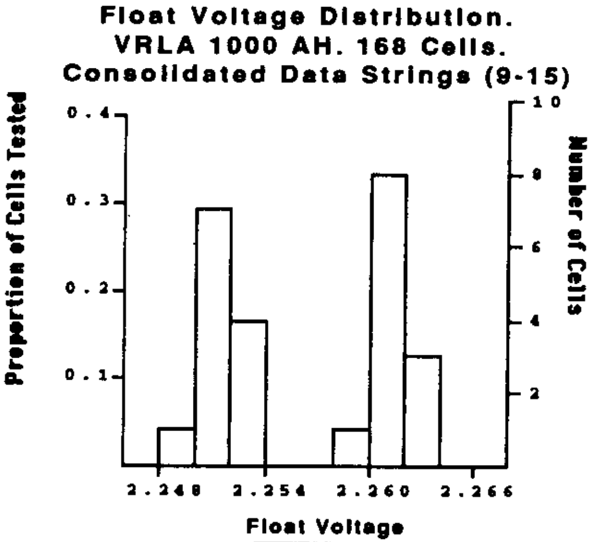


Figure 2

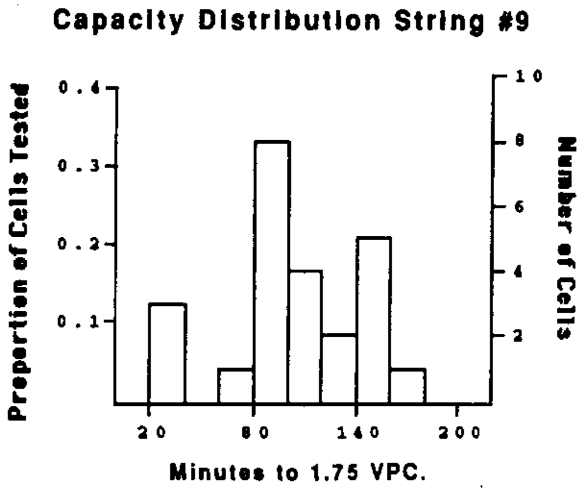


Figure 3

results, are shown in this section as well as composite test data for plants in which as many as 15 strings of similar cells were connected in parallel.

In a large (15 strings, 24 cells each, 1000 AH cell) telecommunication transmission plant, typical single string 24 cell float voltage distribution data are shown in figure 1. Combined float voltage distribution data for seven strings (168 cells) are shown in figure 2. In all cases float voltages are within the manufacturer's accepted range. Capacity distribution data for the same string are shown in figure 3 and for the same seven strings are shown in figure 4. In figure 5 capacity distribution data for the 14 strings tested are shown. In marked contrast to the float voltage data the capacity data, both within each string and for the plant as a whole shows a tremendous variation in capacities from zero minutes to 180 minutes. Most of the cells

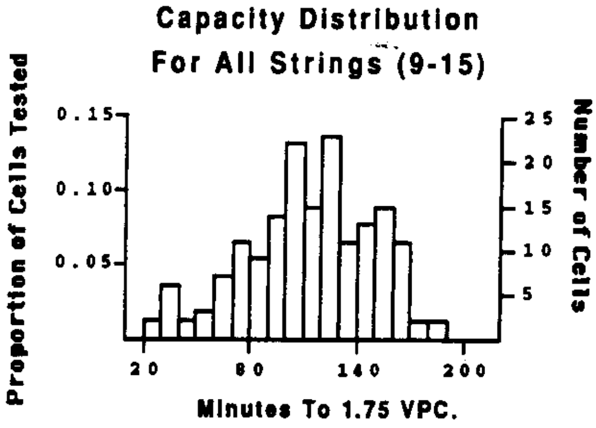


Figure 4

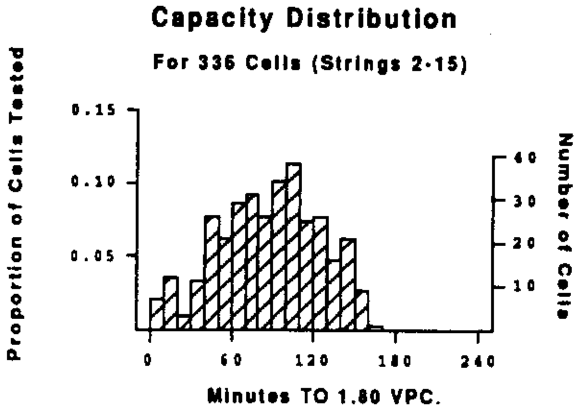


Figure 5

display capacities below their rated value (150 minutes to 1.80 VPC.) and a majority fall below the 80 percent failure rating of 120 minutes at this discharge rate. It should be noted that these cells have been in standby service for only 25 percent of their rated lifetime. For these same cells figure 6 shows the total lack of correlation of float voltage and capacity for the single string. Figure 7 also shows no correlation of calculated specific gravity and capacity for that same string. The same results are shown for the seven strings taken as a group in figures 8 and 9. By contrast figures 10 and 11 show the excellent correlation of conductance and capacity, with a correlation coefficient of 0.897 for the single string and 0.825 for the seven strings taken as a group. Figure 12 reveals a bar graph plot of conductance and capacity for the single string. The results are summarized in figure 13 and show 21 of 24 cells meet both conductance and capacity criteria. Clearly 18 cells have failed both conductance and capacity criteria while only two cells that failed conductance did not also fail capacity and only one cell that failed capacity did not also fail conductance. The conductance test accuracy in this case is 88%. Figure 14 shows the correlation of conductance vs capacity for the 336 cells of the entire plant with a R^2 correlation coefficient of 0.86.

In a more recent test of telecommunication VRLA cells of the same size but of a newer design in a different transmission plant 192 cells arranged in eight series strings were evaluated. Figure 15 shows the wide distribution of these newer cells with many well below both their rated (120 minutes) and 80 percent failure (96 minutes) values. Again conductance/capacity correlations for these cells are shown in figure 16 and indicate excellent correlation. These results demonstrate again the effectiveness of conductance in characterizing the

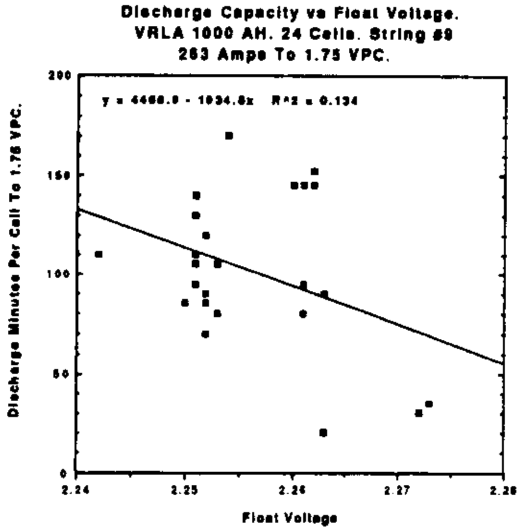


Figure 6

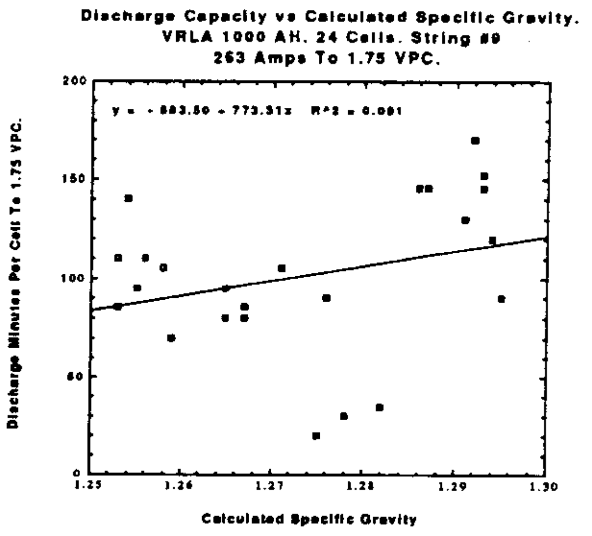


Figure 7

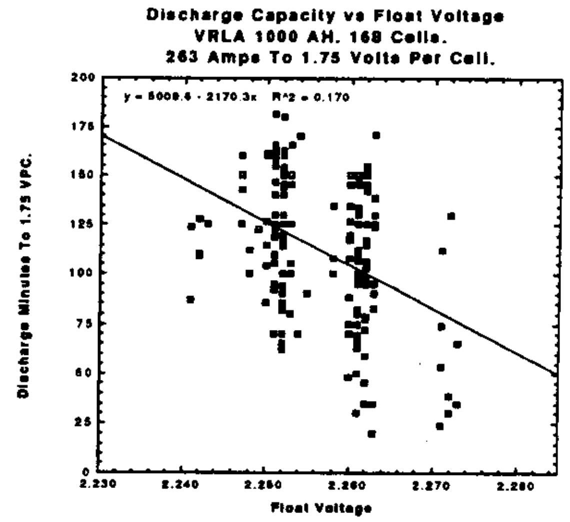


Figure 8

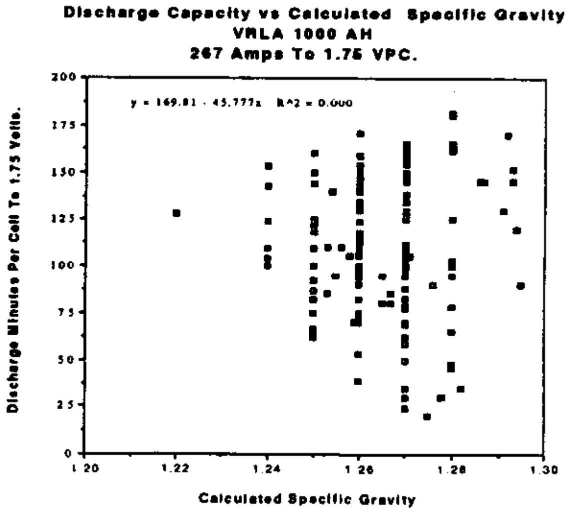


Figure 9

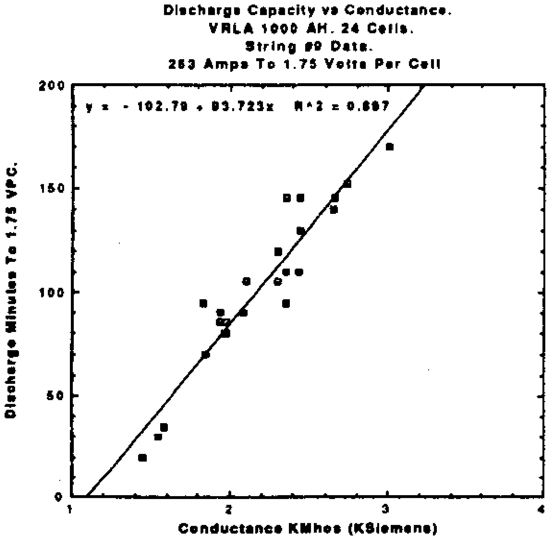
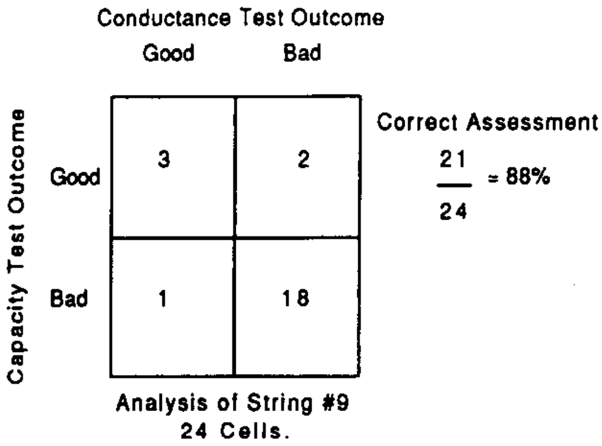


Figure10



Conductance Test Outcome

Capacity Test Outcome	Good	Bad
Good	3	2
Bad	1	18

Correct Assessment
21/24 ≈ 88%

Analysis of String #9
24 Cells.

Figure 13

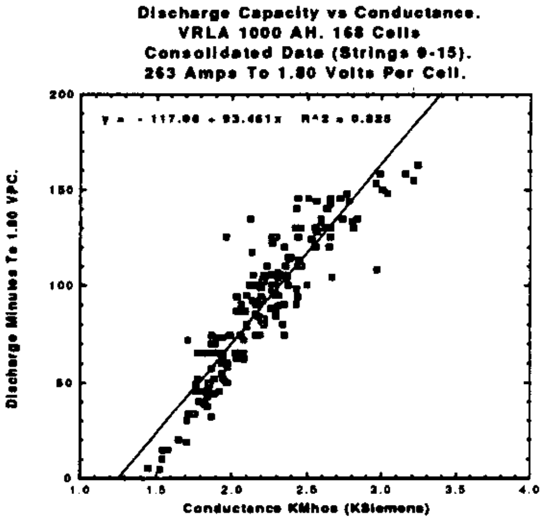


Figure 11

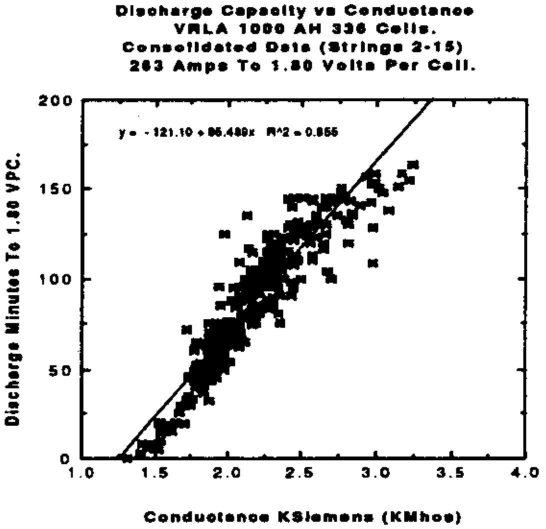


Figure 14

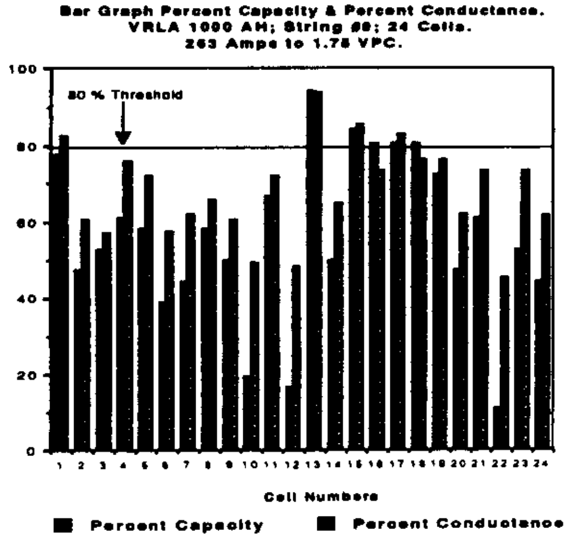


Figure 12

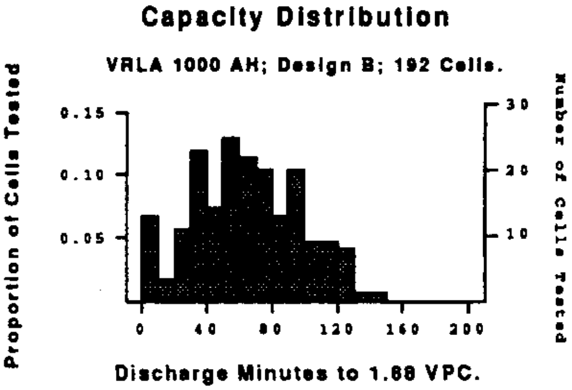


Figure 15

capacity distribution among VRLA cells in a given power plant and in detecting premature capacity failure.

Another series of tests were performed in a UPS application containing one hundred and eighty, six year old, 6 volt VRLA monoblocs of 200 ampere hour design. One of the three parallel strings was pulled off-line to perform both conductance and discharge testing. Figure 17 shows the poor correlation of float voltage measurements as compared to the discharge capacity results. Figure 18 shows the correlation of battery conductance to discharge capacity and again reveals excellent correlation.

Field testing was also performed in railroad signal site applications of VRLA 225 ampere hour design cells. Typical ages for these cells were three to four years. A sample of four cells exhibiting low,

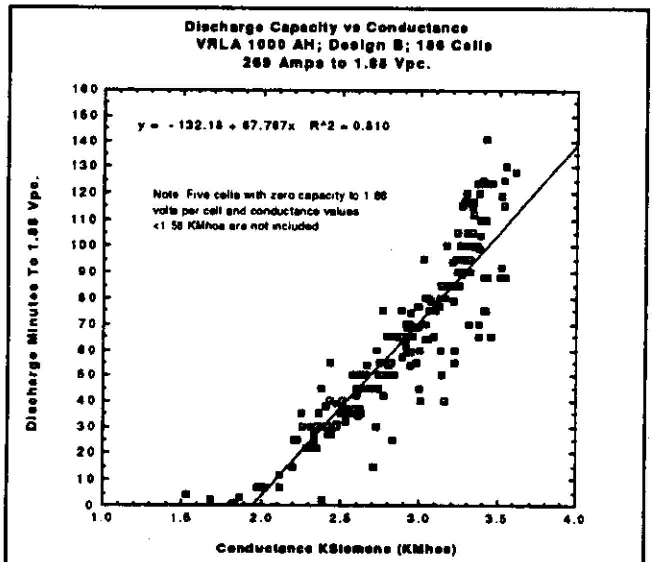

Discharge Capacity vs Conductance
VRLA 1000 AH; Design B; 186 Cells
269 Amps to 1.88 Vpc.

Figure 16

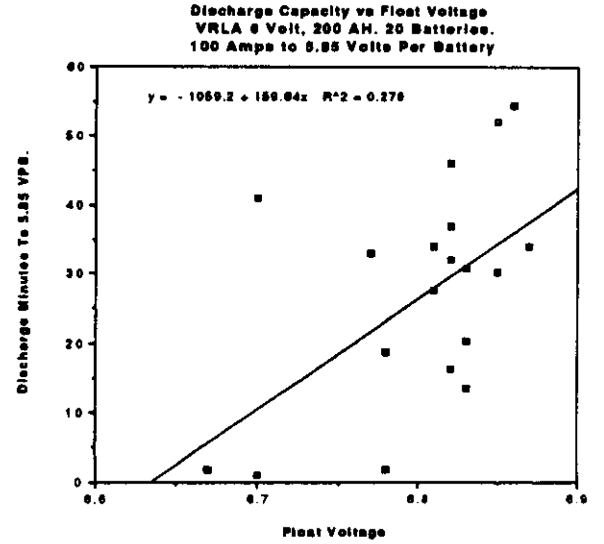

Discharge Capacity vs Float Voltage
VRLA 6 Volt, 200 AH. 20 Batteries.
100 Amps to 5.85 Volts Per Battery

Figure 17

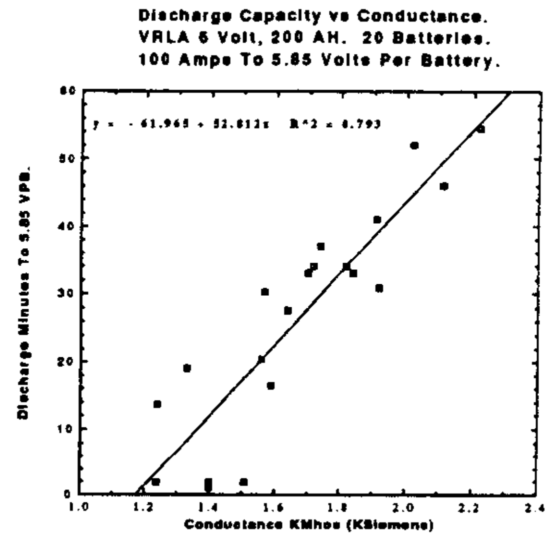

Discharge Capacity vs Conductance.
VRLA 6 Volt, 200 AH. 20 Batteries.
100 Amps To 5.85 Volts Per Battery.

Figure 18

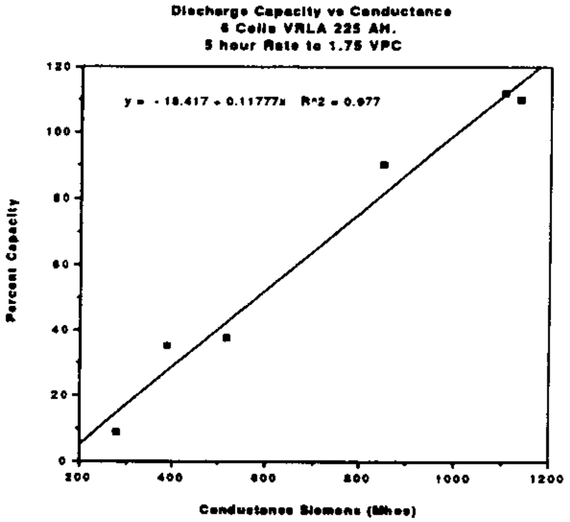

Discharge Capacity vs Conductance
6 Cells VRLA 225 AH.
5 hour Rate to 1.75 VPC

Figure 19

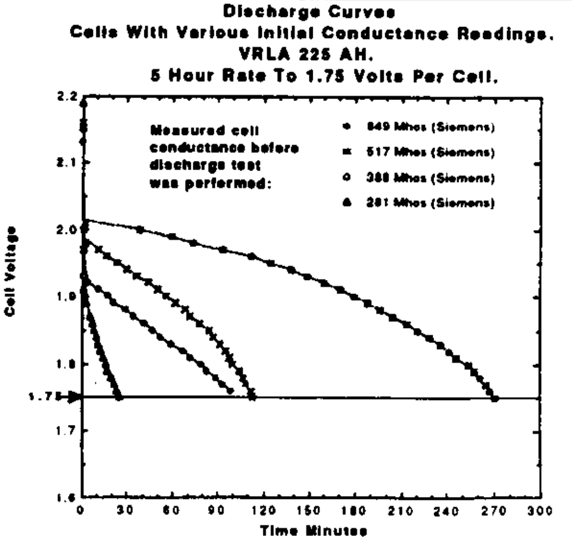

Discharge Curves
Cells With Various Initial Conductance Readings.
VRLA 225 AH.
5 Hour Rate To 1.75 Volts Per Cell.

Figure 20

medium, high conductance and two new cells were sent to Midtronics lab for capacity testing. Figure 19 reveals the correlation of conductance and discharge capacity for the six cells. Figure 20 reveals the discharge curves for the four cells removed from the field. Three subsequent recharge and discharge tests were performed with no appreciable improvement in cell condition measured by either conductance or discharge capacity.

While these represent only a small sample of the data collected to date on VRLA cells in a variety of applications they clearly demonstrate: 1. VRLA cells show a significant percent of premature capacity failures. 2. Further studies are underway to determine the extent of these characteristics. 3. Neither individual cell float voltage or specific gravity can give significant early warning of these failures. 4. Conductance measurements correlate extremely well with cell capacity and can provide early detection of premature capacity failure.

Experimental Flooded Battery Data:

Initial field tests were conducted in several substation locations on flooded products. Measurements of specific gravity, float voltage, conductance and discharge testing were performed. Thus far, the limited amount of flooded battery data that exist, are not adequate to draw an absolute correlation of conductance and capacity. However the results do reveal the conductance as being more sensitive to actual cell performance than traditional measurements of cell specific gravity or float voltage. The conductance measurement has been found to be a indicator of cell/battery performance and it finds cells that vary significantly from the rest of the population in capacity.

Described below are the results of three studies that were performed at three substation locations on three different manufacturers' cells.

The first test consisted of 58 batteries of 200 ampere-hour capacity. The battery string was approximately 20 years old and of a Pb Ca grid alloy design. The test was performed at a 98 amp load for 60 minutes to an end voltage of 1.81 volts per cell.

Figure 21 reveals a bar graph plot of conductance vs end voltage at 60 minutes for substation #1. Since the end voltage at a specific time is not linear, it is difficult to draw a perfect correlation between the the voltage at the end of 60 minutes and conductance. Nevertheless, the end voltage and conductance do trend very closely. Figure 22 shows that 57 of 58 cells meet both the conductance and 80 percent end of discharge voltage criteria, clearly two cells are shown to be poor performers, while only one cell which failed conductance did not also fail the capacity criteria. The resultant conductance test accuracy is extremely good at 98.3 percent.

A second series of tests were performed at substation #2. This battery was less than one year old, 200 AH Pb Ca design. Discharge testing was performed on the 58 cell battery at a 30 minute rate to 1.75 volts per cell. This data set reveals the results of several measurement parameters such as; specific gravity, float voltage, conductance, and timed discharge capacity and explores the relationships and sensitivities of each measurement.

In order to describe the sensitivities of specific gravity, float voltage and conductance as they relate to actual timed discharge capacity, a trend analysis plot for each technique is presented. Figures 23

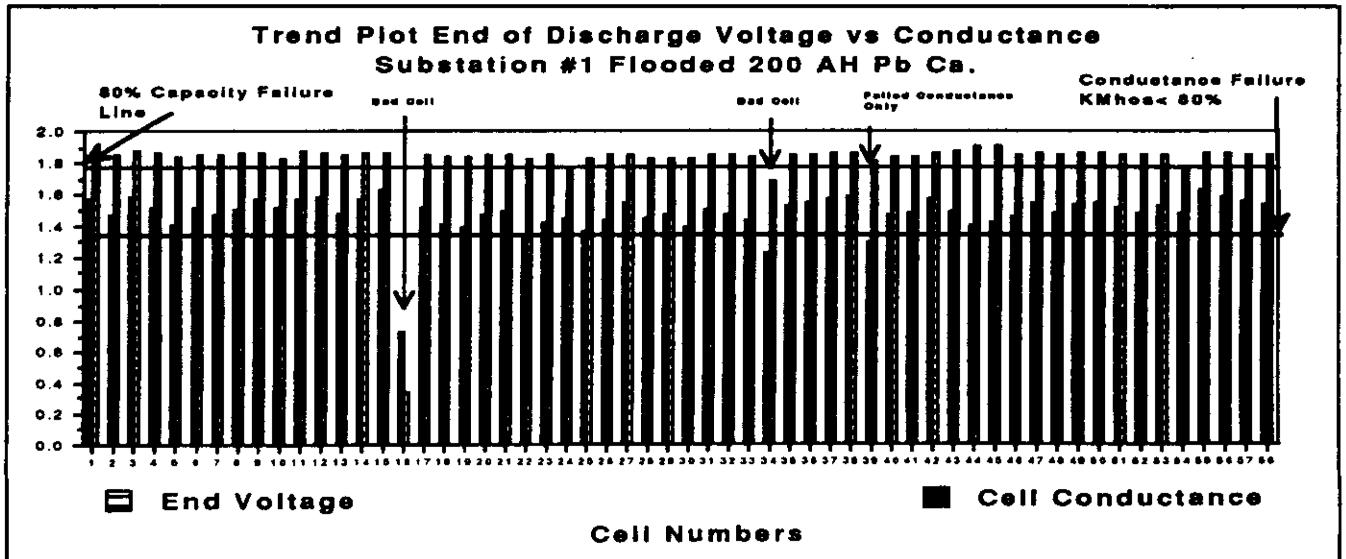


Figure 21

Conductance Test Outcome

Capacity Test Outcome	Good	Bad
Good	55	1
Bad	0	2

Correct Assessment:

$\frac{57}{58} = 98.3\ \%$

Total 58 Cells
Substation #1

Figure 22

shows six cells at or slightly below the 80 percent capacity limit, for those 6 cells, specific gravity gives no indication of capacity loss. It is curious that the only specific gravity value at the low limit (cell #57) corresponds to a 91 percent capacity. Figure 24 shows the same 6 cells as slightly below 80 percent capacity but their float voltages are either at the mean or well within + 40mV of the mean and therefore give no indication of low capacity cells. Figure 25 shows the trend analysis of conductance and percent capacity. Both capacity and conductance are in agreement for the six failed cells as indicated by the arrows. While 12 cells appear to have failed conductance but did not also fail the capacity criteria, it should be noted that 8 of the 12 cells only failed conductance by 1 percent. Figure 26 presents the same data set in a bar graph plot. The results are summarized in figure 27 and

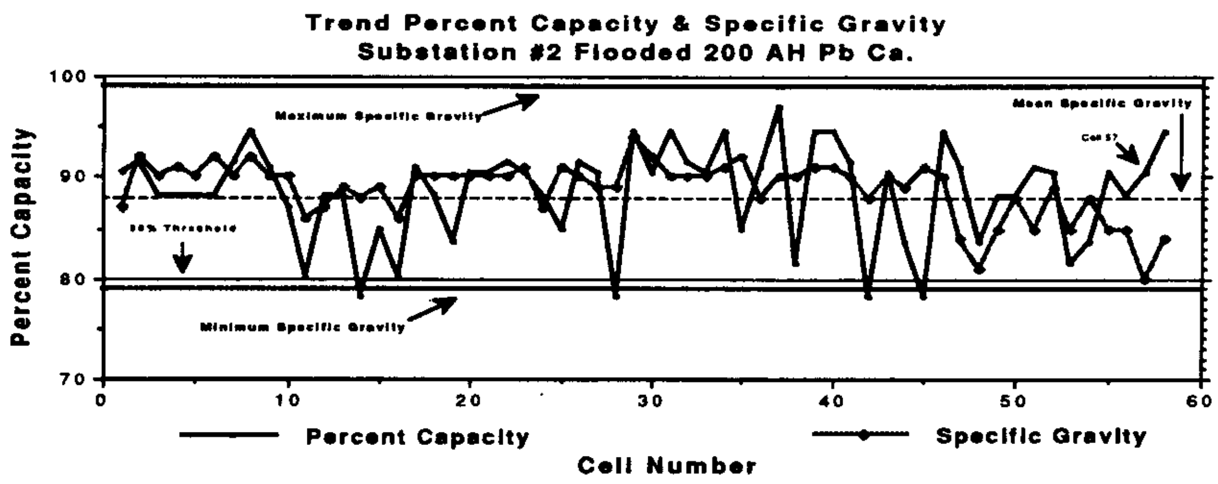


Figure 23

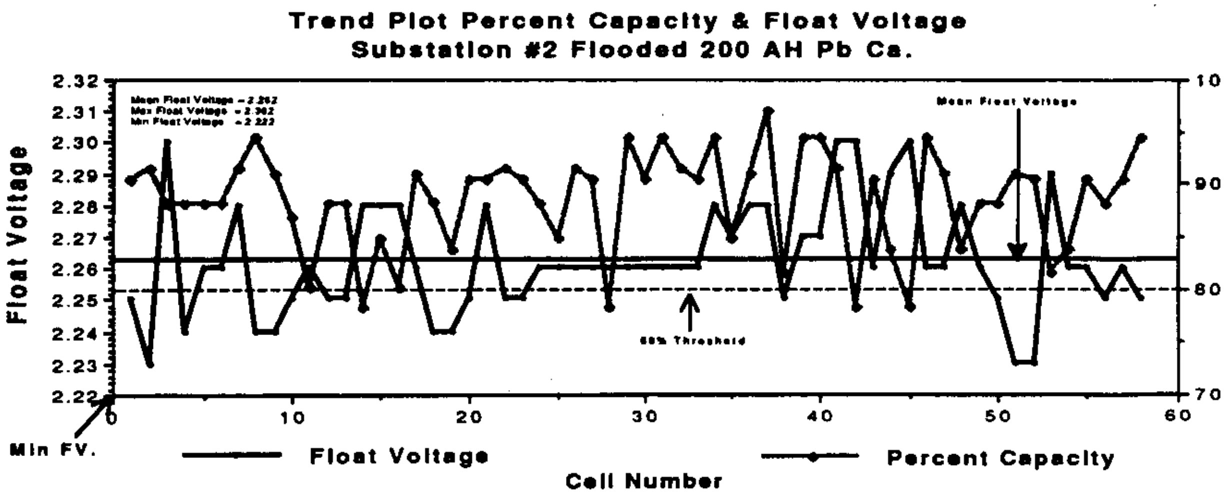


Figure 24

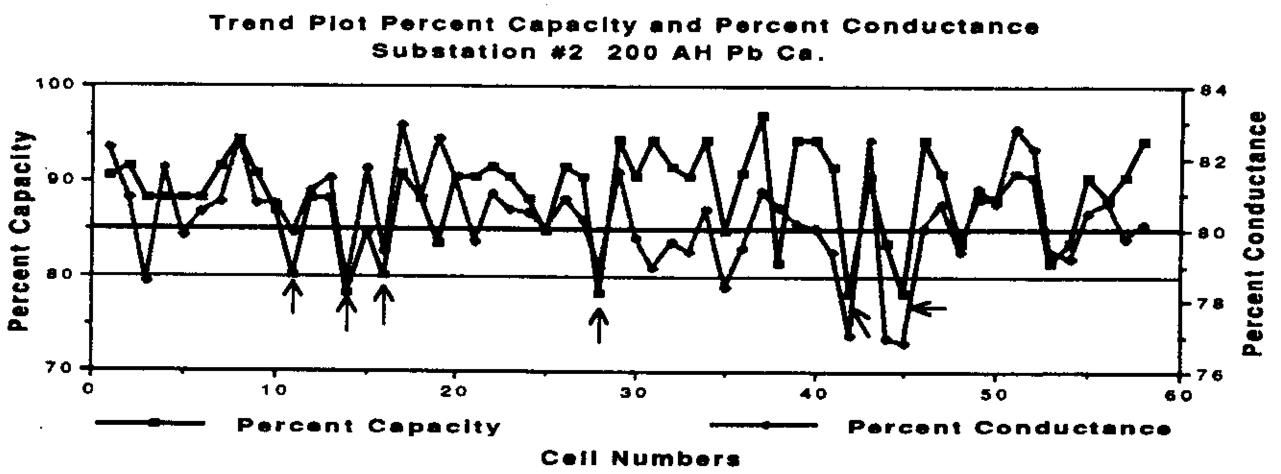


Figure 25

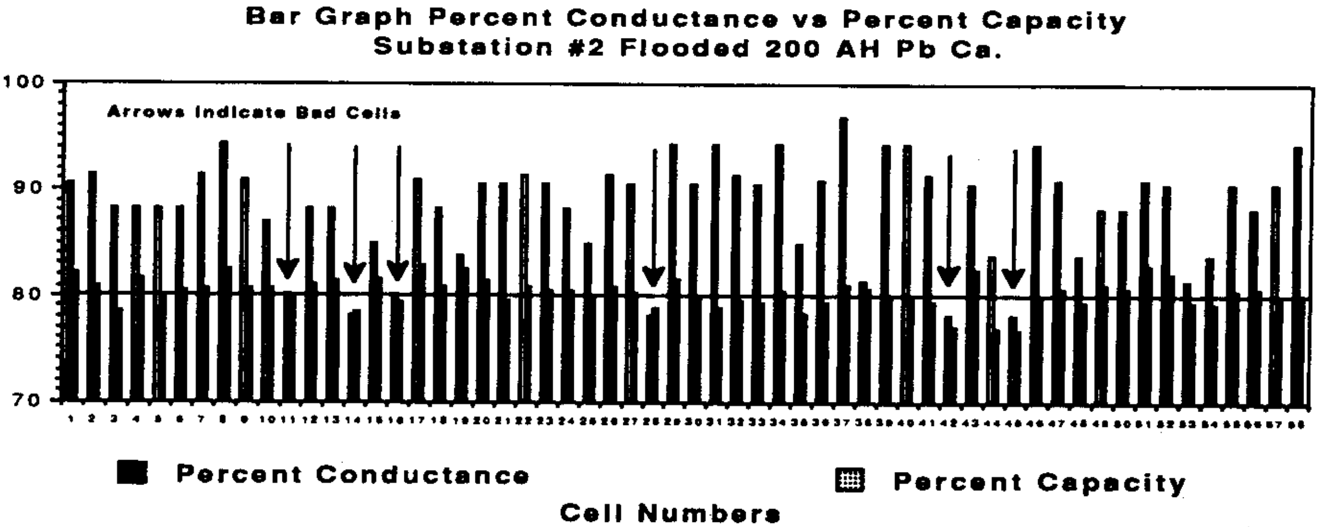


Figure 26

show a conductance test accuracy of 80 percent. The conductance results represent a significant improvement in battery diagnostic sensitivity when compared to traditional measurements and would provide warning to the user of poor cell/battery state-of-health.

The third study (Substation #3) consisted of measurements of specific gravity, float voltage, conductance and discharge testing on 58 cells. The battery string was approximately 20 years old and of a Pb Ca, 100AH design. The battery was discharged at the 30 minute rate (59 amps) to an end voltage of 1.84 volts-per-cell. The results are similar to that mentioned above. However several more cells are in poor health as indicated by both timed discharge capacity and conductance. Figure 28 shows the specific gravity and percent capacity

Conductance Test Outcome

Capacity Test Outcome	Good	Bad
Good	40	12
Bad	0	6

Correct Assessment: $\frac{46}{58}$ = 80%

Total 58 Cells
Substation #2

Figure 27

relationship. Of the 38 low capacity cells only one cell shows low specific gravity and one specific gravity value above the high limit which would normally indicate high capacity. Figure 29 shows 38 of 58 low capacity cells while only one low capacity cell shows voltage below the manufacture's recommended minimum and one low capacity cell shows voltage above the manufacturer's maximum. All other low capacity cells are well within the manufacturer's recommended float voltage range. It is curious that the one cell (cell #19) which is below the low voltage limit shows one of the highest capacities. As you can see it would be very difficult to make a prediction of how each cell would perform using either measurement. By contrast figure 30 shows the trend relationship of conductance and capacity and figure 31 shows the same data in a bar graph. Figure 32 summarizes the results and shows that 47 of 58 cells meet both the conductance/capacity criteria. Clearly 32 cells failed both conductance and capacity criteria while only 6 cells which failed capacity did not also fail conductance and 5 cells that failed conductance did not also fail capacity. The conductance test accuracy in this case is 81 percent. Clearly the lower conductance as seen for the majority of failed cells would have given early warning to the user that the battery was in a poor state-of-health.

Temperature Effects on Conductance:

Some applications require that batteries be installed and operated in uncontrolled environments where a vast range of temperatures are seen throughout the year. It is well known fact that the battery temperature affects the performance of lead acid batteries especially at cold temperatures. Because conductance measurements can be obtained

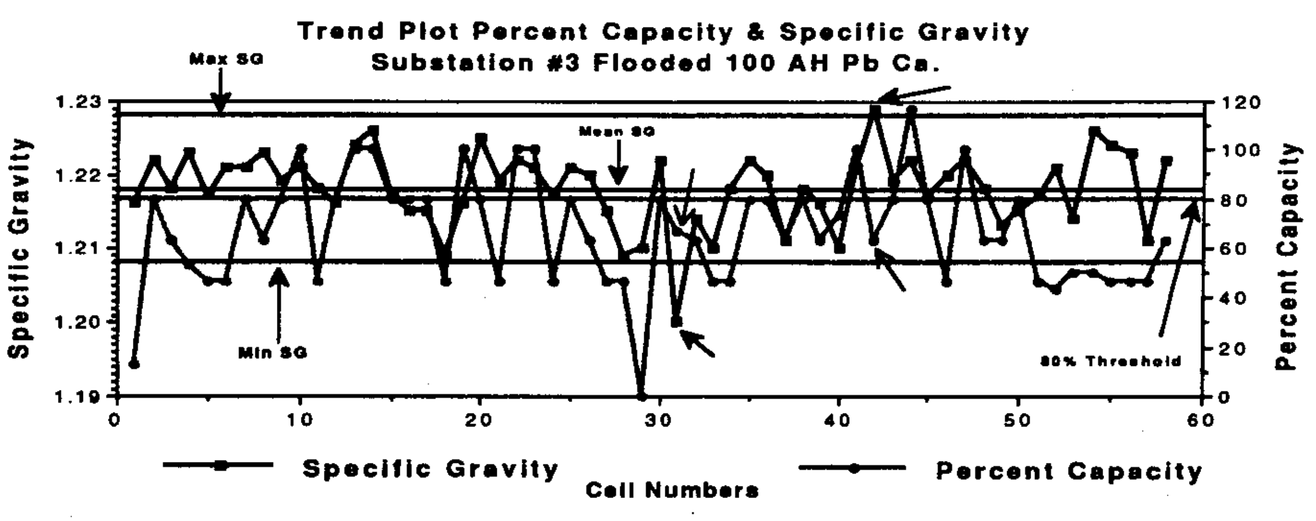


Figure 28

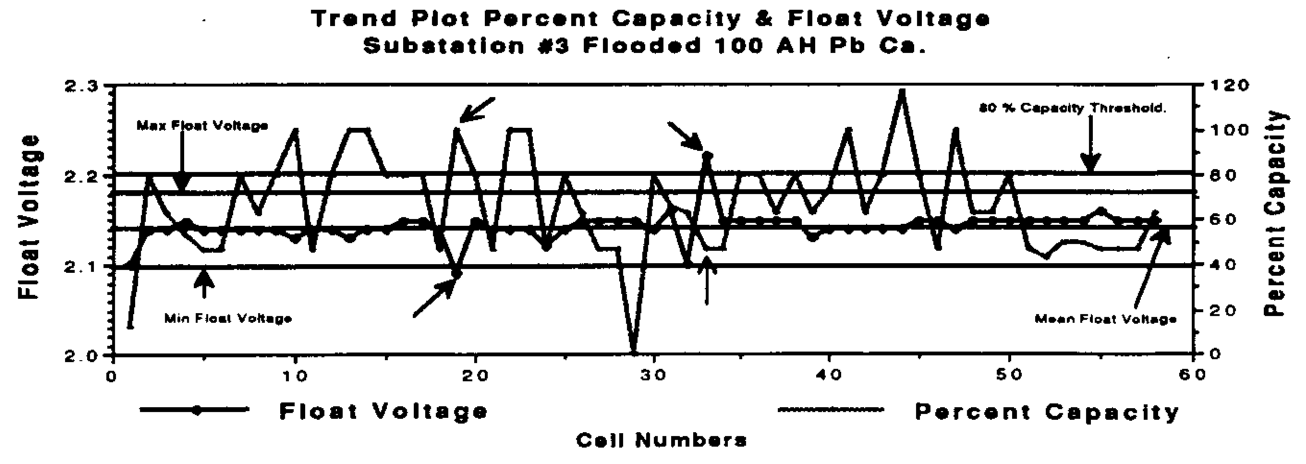


Figure 29

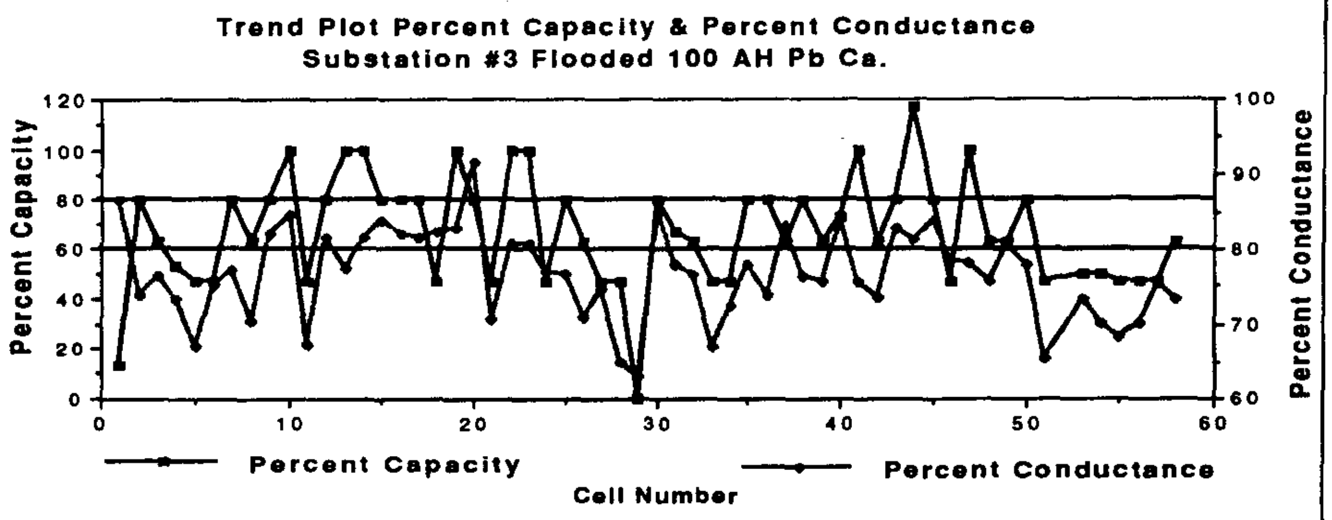


Figure 30

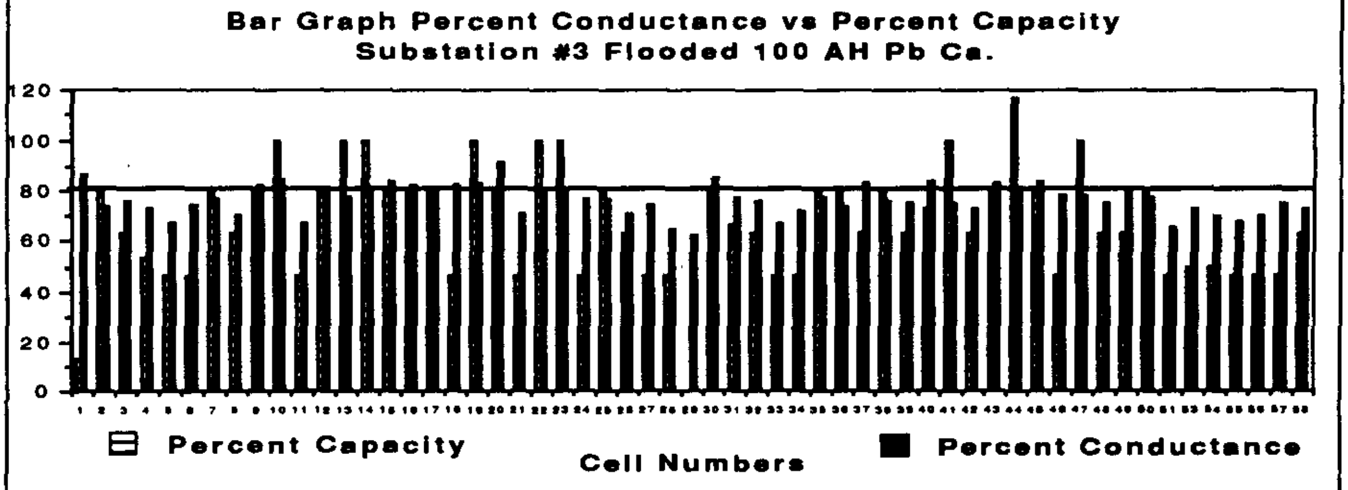


Figure 31

several times throughout the year and under various climate conditions, the effect of temperature on the conductance measurement should be considered. Midtronics and others have performed tests to observe the effect of temperature on conductance measurements and below list the results.

Test Plan:

Prior to testing each battery was fully charged and left open circuit for 36 hours prior to the initial conductance measurement. The open circuit battery was then chilled and then heated in 5 or 10 degree increments at 24 hour intervals to allow the thermal mass to achieve the set point temperature. The battery was first chilled to minimize the cell self discharge rate at higher temperatures.

		Conductance Test Outcome	
		Good	Bad
Capacity Test Outcome	Good	15	5
	Bad	6	32

Correct Assessment: $\frac{47}{58}$ = 81%

Total 58 Cells
Substation #3

Figure 32

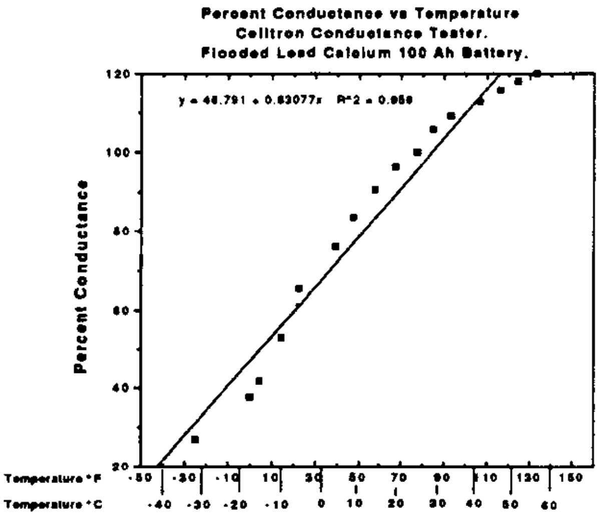


Figure 33

Temperature Data Analysis:

Figure 33 shows temperature data which represents a strong linear relationship with R^2 correlation coefficient greater than 0.95 for conductance and temperature. The data listed is representative for a temperature range of -40°F to 120°F (-40°C to 48.8°C).

Figure 34 data shows the differences in the temperature/conductance slopes of AGM, GEL and flooded cell designs. A noticeable slope difference is observed for the AGM design and flooded designs. The data also show that the conductance/temperature slope characteristics for the GEL design closely resemble that of the flooded battery design.

While figure 34 shows variations among different battery designs, it can be seen from the data that as

Battery Design Type: VRLA-AGM (Absorbed Glass Mat Design)
Temperature Bandwidth: -40°F to 120°F (-40°C to 48.8°C)
used for slope characterization.

Battery type/MFR:	Correction %/°F	Correction %/°C
Battery Mfr A 6 volt 200AH	0.50%/°F	0.90%/°C
Battery Mfr B 12volt 225 AH	0.40%/°F	0.72%/°C
Battery Mfr B 12volt 300 AH	0.47%/°F	0.85%/°C
Battery Mfr B 12volt 95 Ah	0.51%/°F	0.92%/°C
Battery Mfr B 12volt 95Ah	0.50%/°F	0.90%/°C
Battery Mfr B 12volt 95Ah	0.51%/°F	0.92%/°C

Battery Design Type: VRLA (Gelled Electrolyte):
Temperature Bandwidth: -40°F to 120°F (-40°C to 48.8°C)
used for slope characterization.

Battery type/MFR:	Correction %/°F	Correction %/°C
Battery Mfr B 12volt 100 Ah	0.73%/°F	1.31%/°C
Battery Mfr B 6volt 200Ah	0.67%/°F	1.21%/°C
Battery Mfr B 12volt 31Ah	0.75%/°F	1.35%/°C
Battery Mfr B 12volt 31Ah	0.74%/°F	1.33%/°C

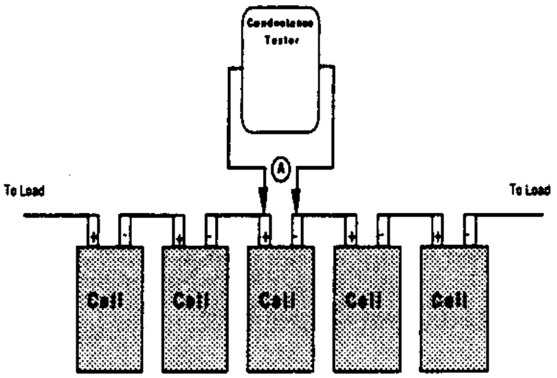
Battery Design Type: Flooded Lead Calcium 1.215 Sg.
Temperature Bandwidth: -40°F to 120°F (-40°C to 48.8°C)
used for slope characterization.

Battery type/MFR:	Correction %/°F	Correction %/°C
Battery Mfr C 6volt 100Ah	0.712%/°F	1.28%/°C

Figure 34

Proper Method For Checking Intercell Connection Integrity Using Conductance Test Equipment

1. Conductance test is made of cell alone (A).



2. Conductance of cell is used as a standard to measure the same cell plus one intercell connection.

3. Conductance percent reading is taken of cell plus intercell (B).

4. The percent loss from 100% equals the intercell loss.

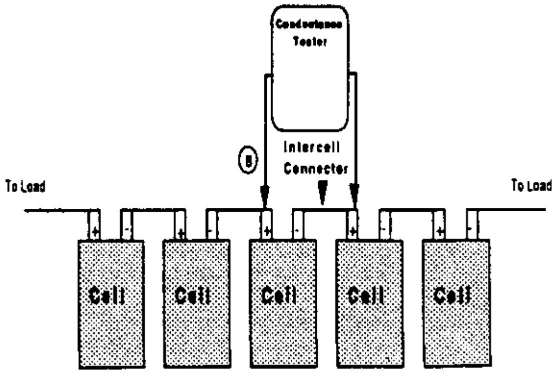


Figure 35

Cell#	Cell (Mhos) Conductance	Cell Plus Strap (Mhos) Conductance	Conductance % Loss * 10
1	2810	2480	882.562
2	2290	2090	912.664
3	2190	1360	621.005 **
4	1810	1690	933.702
5	2980	2630	882.550
6	1750	1130	645.714 **
7	2170	1980	912.442
8	1810	1680	928.177
9	2470	1430	578.974 **
10	2570	2310	898.833
11	2380	2150	903.361
12	2570	1660	645.914 **
13	2110	1930	914.692
14	2530	2270	897.233
15	2470	1210	489.879 **
16	1800	1700	944.444
17	2170	1980	912.442
18	1780	1050	589.888 **
19	1840	1690	918.478
20	2290	2080	908.297
21	1560	800	512.821 **
22	2160	1970	912.037
23	2040	1860	911.765

Figure 36

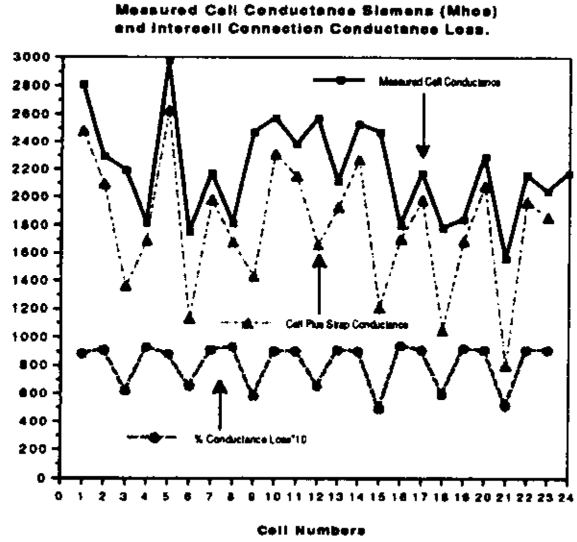


Figure 37

a rule of thumb, a temperature correction factor of 0.5 % per °F (0.9% per °C) and 0.75% per °F (1.35% per °C) may be utilized for AGM and Flooded/GEL battery designs respectively.

Use Of Conductance To Evaluate Intercell Connections:

The conductance testing technique used in this study shows how the use of the conductance measurement can provide a very meaningful measure of the relative quality of intercell connections. The test is performed by comparing the conductance of the cell-plus-intercell to the cell with which it is associated. Since the cell-plus-intercell number is typically lower than the cell's measured conductance, a properly maintained intercell connection will show a minimal loss of conductance.

Figure 35 shows the method used to make measurements of intercell connections. First the conductance of a cell/battery is measured. The conductance value can either be programmed into the instrument as a reference or the actual value can be used.

Next a measurement of that cell plus the intercell is made. If the cell conductance is used as a reference, the output then shows the interconnection loss as a percentage.

Figure 36 shows a series of cells, their conductance readings, and the reading of the cell plus the intercell connection on the positive side of the cell. It can be quickly noted that every third intercell connection causes a relative drop in conductance readings as would be expected since a cable connection is used between each three cell module, while the connections between adjacent cells is made via lead plated copper strap. While this is to be expected, it can also be noted that certain intercell connections have the effect of causing relatively lower cell-plus-intercell conductance readings, not obviously caused by end of module cable connections. Figure 37 shows cell conductance and the related cell plus inter-cell conductance. The difference between these graphs show the loss caused by an inter-cell connectors.

While we did not evaluate the exact causes of these conditions, it is reasonable to assume that potential loose connections, corrosion, improper crimping of cable lugs or other inter-cell defects could be observed in this way. Moreover, rather than using a separate instrument to measure the resistance in micro-ohms and then mathematically interpreting the data, conductance testing provides the user with the ability to easily use the tested cell as a reference to measure the quality of the relevant inter-cell connection.

Conclusions:

Valve-Regulated Lead Acid (VRLA) Cells:

With the ever increasing usage of VRLA cells in Electric Utility standby service, the results of this study and those reported elsewhere, indicate quite clearly that an effort is necessary to monitor their state of health and that conductance measurements provide the user a technique to do so. Based on the results of tests on more than 700 VRLA cells, ranging in size from 200-1000 ampere-hours, in battery strings of 24-360 volts, and in a wide variety of battery plant applications, containing as many as 15 strings in parallel, we can conclude:

1. Neither individual cell float voltage or calculated specific gravity can give significant warning of potential cell failure.

2. In all cases tested, conductance measurements correlate extremely well withcell capacity and can provide early detection of premature capacity failures, without regard to application, design, size or specific manufacturer of the particular VRLA cells involved.

3. The VRLA cells tested in this situation show a significant percent of premature capacity failures. Further studies, are currently underway to determine the extent of this condition.

Vented Lead Acid Cells:

Initial tests, reported in this study, show similar relationships with conventional flooded (vented) lead acid cells. Although the range of capacity degradation is generally much less than with VRLA cells, in the vented cells tested to date:

1. Capacity degradation is rarely, if ever, indicated by the conventionally measured parameters of cell voltage or specific gravity.

2. Conductance measurements correlate well with both serious capacity failures, as well as with capacities which have degraded just below the normally recommended 80 percent failure criterion and can provide warning of potential cell deterioration to the user.

3. Studies of vented cell capacity/conductance correlations are continuing and will add significantly to the limited data base established to date.

Measurement Techniques:

This paper also demonstrates the utility of the conductance test measurement for establishing, evaluating and maintaining the integrity of cell/ battery intercell connections.

Finally, this paper presents test data showing the relationship of conductance and temperature for cell conductances measured over a temperature range of -40°F to 120°F (-40°C to 48.8°C) and discusses a method for application of a temperature correction factor to AGM, GEL and conventional (flooded) lead acid cells.

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