Evaluating the State-of-Health of Lead Acid Flooded and Valve-Regulated Batteries:A Comparison of Conductance Testing vs. Traditional Methods - June 1993

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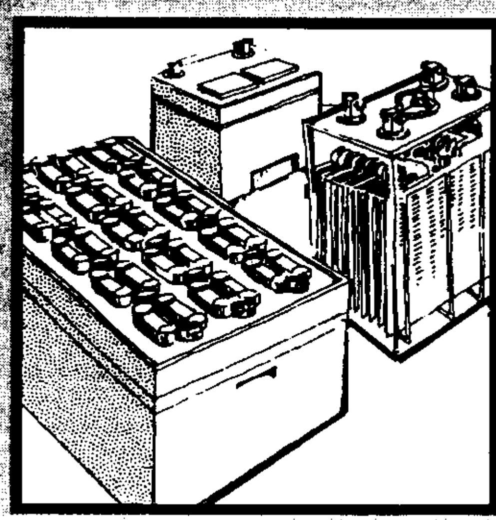

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EVALUATING THE STATE OF HEALTH OF LEAD ACID FLOODED AND VALVE-REGULATED BATTERIES: A COMPARISON OF CONDUCTANCE TESTING VS. TRADITIONAL METHODS

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Abstract:

In a series of papers presented at the International Lead Zinc Research Organization (ILZRO)[2], Battery Council International (BCI)[2] and International Telecommunications Energy (INTELEC)[3] conferences in 1992, two of the authors examined, through field and laboratory testing, the relationship of both traditional cell testing parameters and conductance testing with actual capacity testing of approximately 500 valve-regulated lead acid (VRLA) cells of various sizes, designs and in various applications. They concluded, that a significant number of VRLA cells had suffered premature capacity loss, which was not satisfactorily detected by individual cell float voltage or specific gravity (calculated) measurements. In contrast, their data showed a high degree of correlation between cell capacity and cell conductance.

This new study provides additional evidence of the extent of premature capacity degradation of VRLA cells, including cells of newer designs. It quantifies, more explicitly, the inability of cell float voltages or specific gravity to provide early warning of these significant capacity failures. It provides additional data which demonstrates the high degree of correlation between conductance and capacity and provides striking evidence of the ability of conductance testing to provide early warning of premature capacity failure of VRLA cells.

Additional data are provided on teardown post-morta analysis of a series of cells exhibiting a wide range of measured capacities. Although the established failure modes among these cells were significantly varied, it is extremely encouraging to report that their performance was accurately predicted by the conductance values obtained.

The paper also describes the results of initial tests of conductance/capacity relationships in flooded lead acid cells, of the type used by both electric power utilities and telecommunications organizations to provide standby reserve power. The accuracy of conductance data to predict, correctly, cell capacity behavior is contrasted with predictions resulting from the conventional test parameters of cell float voltages and measured specific gravities. Again, with flooded cells, the data indicates a significantly improved capability to detect low capacity cells, based on conductance, than would be obtained with either cell float voltage or specific gravity measurements.

Application Background:

Electric Utility, Telecommunications Companies and Railroads typically have hundreds of large battery systems located in their generating plants, central/transmission offices and signaling / crossing locations. The batteries can represent several million dollars of cost and may help to protect billions of dollars in assets.

Traditionally, flooded battery maintenance practices in the electric power industries have followed specific guidelines as defined by the Institute of Electrical and Electronic Engineers (IEEE) standards, or by special standards developed by the specific industry, itself. These practices recommend testing to be performed on a scheduled basis. Traditional measurements of float voltage and specific gravities in addition to scheduled service tests have been the primary methods utilized for determining battery state-of-health in these industries. Most have good intentions of implementing battery maintenance programs. However several 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 has to maintain. 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" capacity tests are postponed temporarily or indefinitely except when it appears that a major fault has developed in a particular battery string.

Until recently, the lack of available published standards for the testing and maintenance of valve-regulated lead acid (VRLA) batteries, coupled with manufacturers' "maintenance-free" claims have resulted in a wide discrepancy in testing and maintenance among users. Practices vary widely. Some sites monitor daily readings of individual cell float voltage readings, in plants containing several thousand individual VRLA cells in a single location, while at the the same site, no plan exists for scheduled capacity testing. Other sites utilize carefully scheduled periodic capacity testing. However, the majority of users practice any or all maintenance possibilities in between these two extremes.

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.

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 [2,3,4,5]. Other measurements of cell impedance have also been actively pursued as possible methods for evaluating cell/battery condition [6,7,8,9]. These earlier studies indicate that the application of conductance measurements in a maintenance practice appears to be 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. This concept has recently been introduced into IEEE Draft Standards for maintenance of VRLA cells.

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.

VRLA Usage In Electric Power, Railroad and Telecommunications Applications:

Over the last ten years, Valve-Regulated Lead Acid (VRLA) batteries have been rapidly deployed into many different applications. Usage of VRLA batteries is increasing, especially in applications where their "maintenance free" promise appears attractive. Both GEL (Gelled Electrolyte) and AGM (Absorbed Glass Mat) valve regulated lead acid (VRLA) designs covering a wide range of sizes and capacities are now available for deployment in wholly new types of applications and for replacement of aging flooded battery technology. Their attractive features parallel the business changes which include reduction in manpower, and budget reductions that are forthcoming not only in the electric power and telecommunications industries but in many other industries as well. 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 to deal with 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.* Until very recently, it has not been sufficiently emphasized that the number and type of potentially serious failure modes of VRLA cells significantly exceeds those of conventional cells, whose primary failure mode results from positive grid corrosion and growth and subsequent loss of contact to the positive active material. In stark contrast to this single failure mode for flooded cells, VRLA cells are potentially succeptible to a significantly longer list of possible "fatal" problems. In VRLA cells, post seal or 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 also cause capacity loss; internal corrosion and loss of contact between post/strap/plate lugs is also a major failure mode in VRLA cells. All these failure mechanisms 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 with conductance testing on approximately five hundred VRLA cells. They 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 > 36 hours - .85) or individual cell float voltage. In contrast, a high degree of correlation from R^2=0.80 to R^2=0.98, was shown to exist between discharge capacity and cell conductance. This early study emphasized 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.

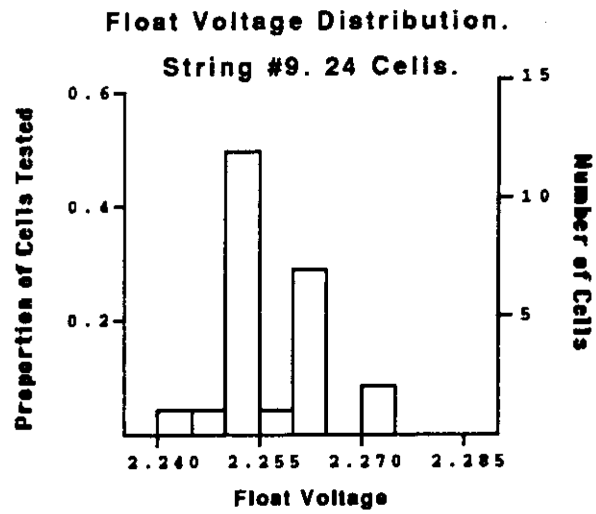

Figure 1

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 individual string 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.

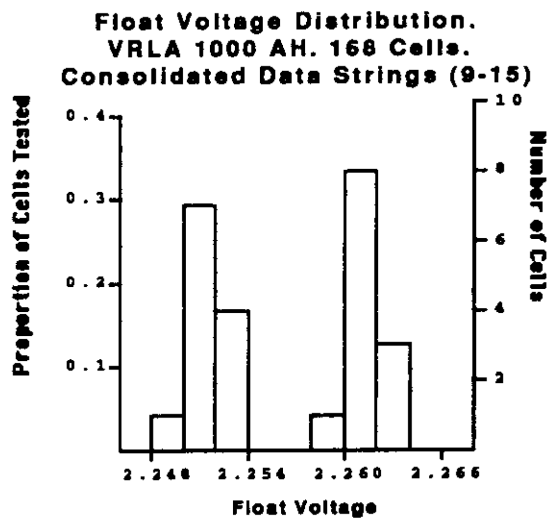

Figure 2

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**. **Figure 5** shows capacity distribution data for the 14 strings tested in this office. 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 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

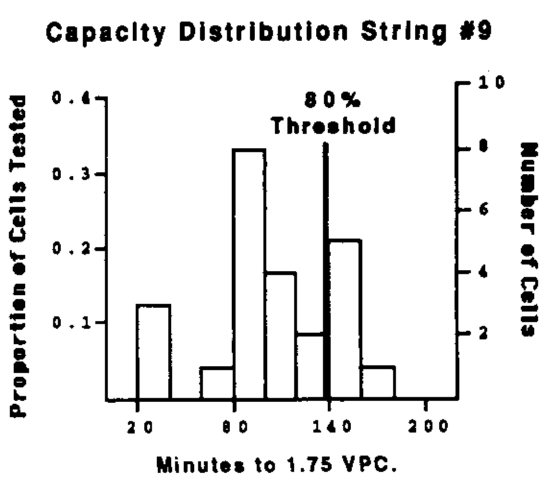

Figure 3

these same cells **figure 6** shows the total lack of correlation of float voltage and capacity for the single string. The results summarized in the box score of **figure 7** indicates float voltage provides an overall success rate of 25% (good + bad), but has a 0% success rate in predicting capacity failures. **Figure 8** also shows no correlation of calculated specific gravity and capacity for that same string. Here again, the box score of **figure 9** shows an overall successful prediction of 13%, but 0% prediction of low capacity cells. The same results are shown for the seven strings taken as a group in **figures 10 and 11** and in the box scores of **figures 12 and 13**. By contrast **figures 14 and 15** 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 16** reveals a bar graph plot of conductance and capacity for the single

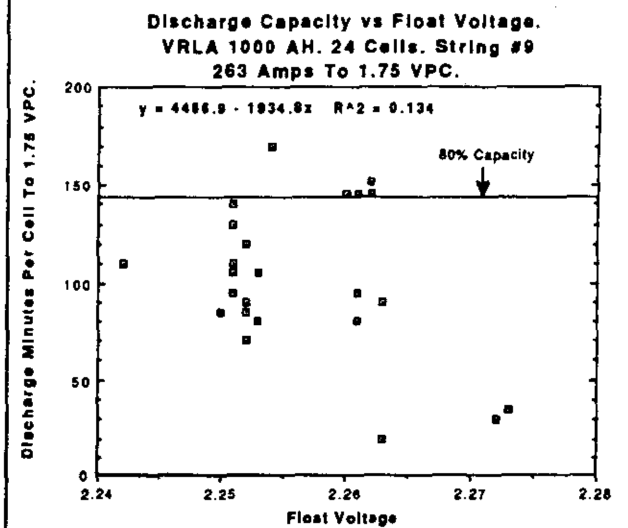

Figure 6

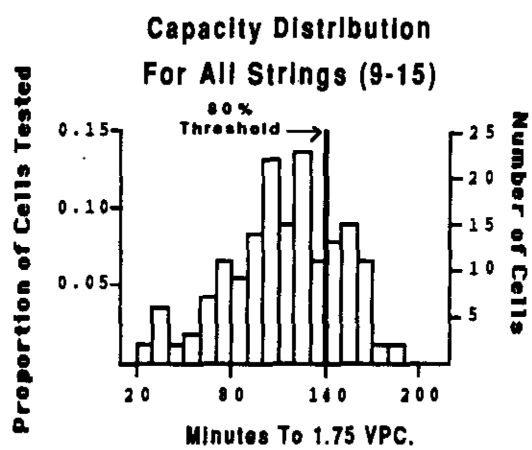

Figure 4

Float Voltage Test Outcome

Capacity Test Outcome	Bad	Good
Good	0	6
Bad	0	18

Total 24 Cells

Correct Assessment Overall: $\frac{6}{24} = 25\%$

Correct Assessment of Failures: $\frac{0}{18} = 0\%$

Figure 7

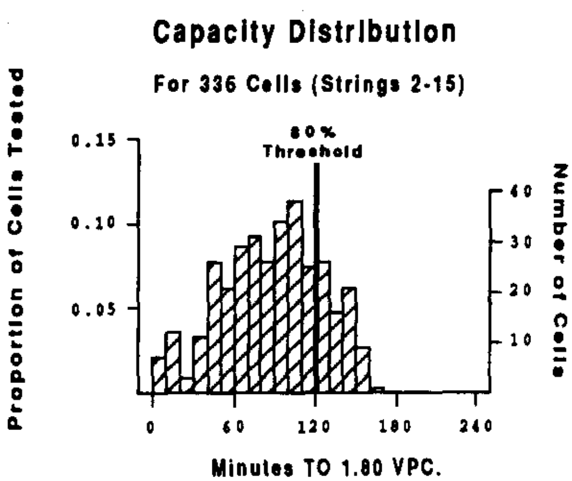

Figure 5

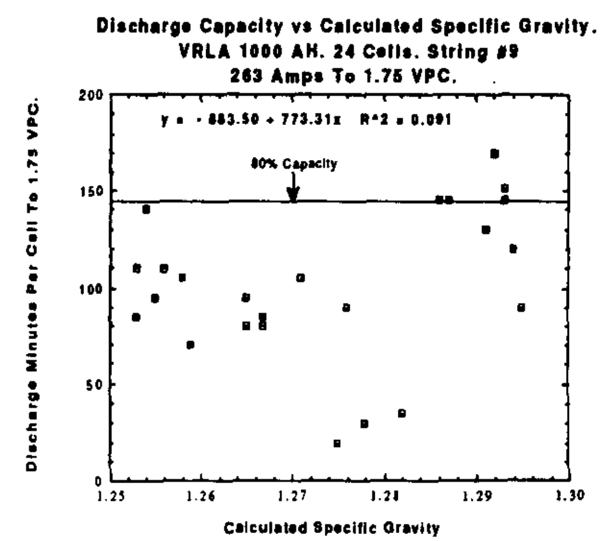

Figure 8

Calculated Specific Gravity Test Outcome

Capacity Test Outcome	Bad	Good
Good	0	3
Bad	0	21

Total 24 Cells

Correct Assessment Overall: $\frac{3}{24}$ =13%

Correct Assessment of Failures: $\frac{0}{21}$ = 0%

Figure 9

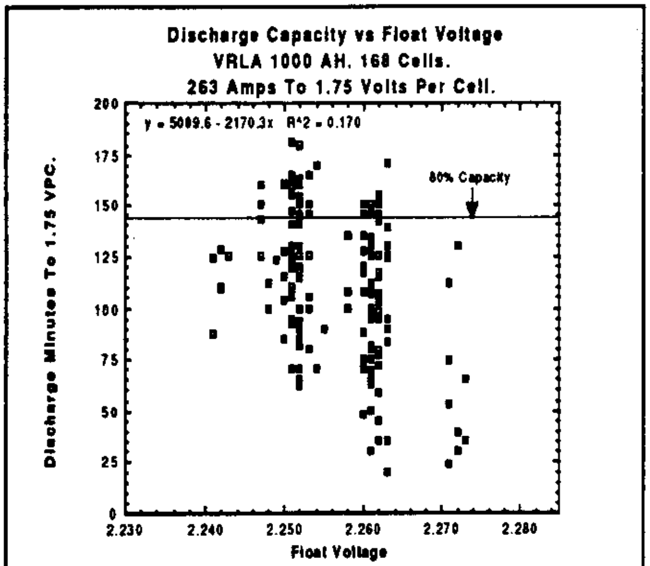

Figure 10

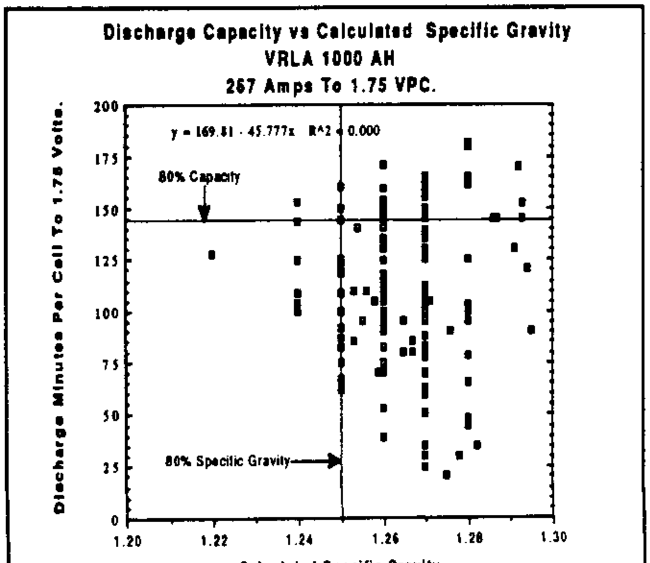

Figure 11

Float Voltage Test Outcome

Capacity Test Outcome	Bad	Good
Good	0	22
Bad	0	146

Correct Assessment Overall: $\frac{22}{168}$ = 13%

Correct Assessment of Failures: $\frac{0}{146}$ = 0%

Figure 12

Calculated Specific Gravity Test Outcome

Capacity Test Outcome	Bad	Good
Good	3	11
Bad	17	137

Total 168 Cells

Correct Assessment Overall: $\frac{28}{168}$ = 16%

Correct Assessment of Failures: $\frac{17}{154}$ = 11%

Figure 13

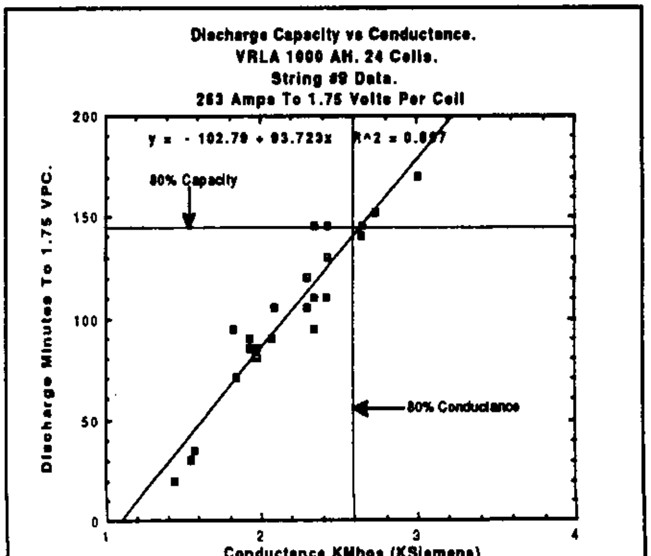

Figure 14

string. The results are summarized in **figure 17** 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% overall, and 95% accurate in detecting failed cells. The box score of **figure 18**, for the 168 cells, shows 88% overall accuracy, and 98% accuracy in detecting bad cells. **Figure 19** shows the correlation of conductance vs capacity for the 336 cells of the entire plant with a R^2 correlation coefficient of 0.86. **Figure 20** shows an overall accuracy of 88%, with an accuracy of 98% in detecting low capacity cells (<80%).

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

Capacity Test Outcome	Conductance Test Outcome: Bad	Conductance Test Outcome: Good
Good	2	3
Bad	18	1

Correct Assessment Overall: $\frac{21}{24} = 88\%$

Correct Assessment of Failures: $\frac{18}{19} = 98\%$

Analysis of String #9 24 Cells.

Figure 17

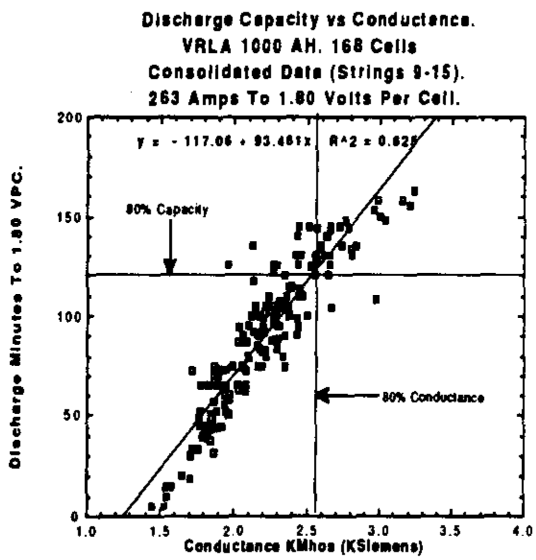

Figure 15

Capacity Test Outcome	Conductance Test Outcome: Bad	Conductance Test Outcome: Good
Good	17	21
Bad	127	3

Correct Assessment Overall: $\frac{148}{168} = 88\%$

Correct Assessment of Failures: $\frac{127}{130} = 98\%$

Analysis of Strings (9-15) 168 Cells.

Figure 18

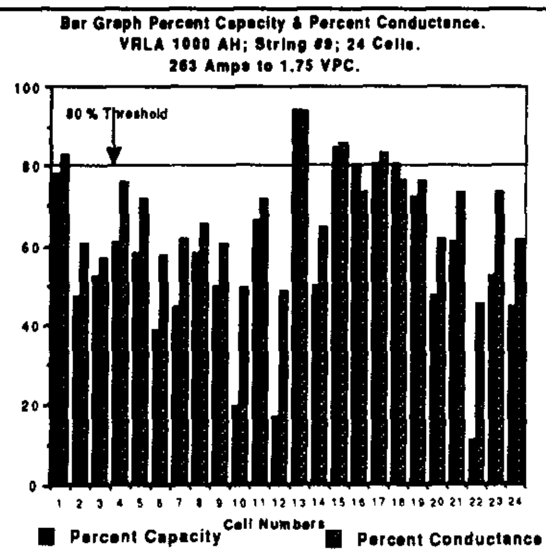

Figure 16

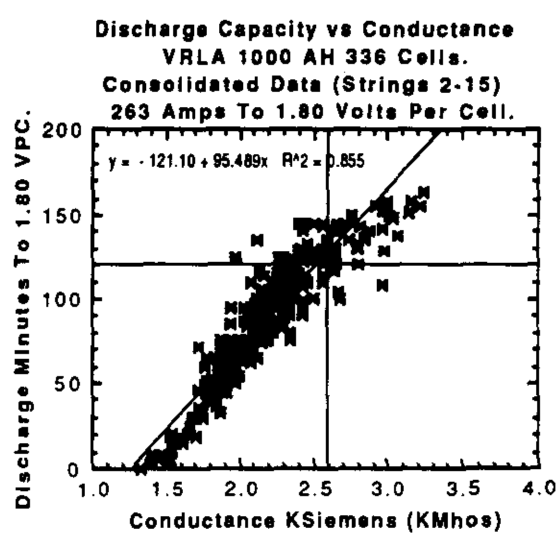

Figure 19

Conductance Test Outcome

Capacity Test Outcome	Bad	Good
Good	37	34
Bad	259	6

Analysis of Strings (2-15) 336 Cells.

Correct Assessment Overall: $\frac{293}{336} = 88\%$

Correct Assessment Failures: $\frac{259}{265} = 98\%$

Figure 20

in eight parallel strings were evaluated. **Figure 21** shows the wide capacity 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 22** and indicate excellent correlation. For these cells, the box score (**Figure 23**) shows an overall prediction accuracy of 88% while successfully predicting low capacity cells with an accuracy of 96%. These results demonstrate again the effectiveness of conductance in characterizing the 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

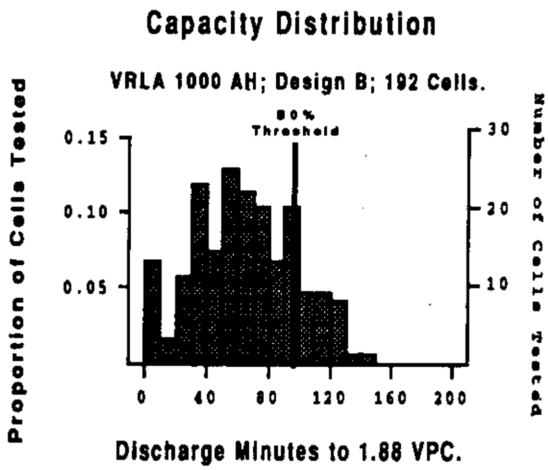

Figure 21

Conductance Test Outcome

Capacity Test Outcome	Bad	Good
Good	16	10
Bad	159	6

Total 191 Cells

Correct Assessment Overall: $\frac{169}{191} = 88\%$

Correct Assessment of Failures: $\frac{159}{165} = 96\%$

Figure 23

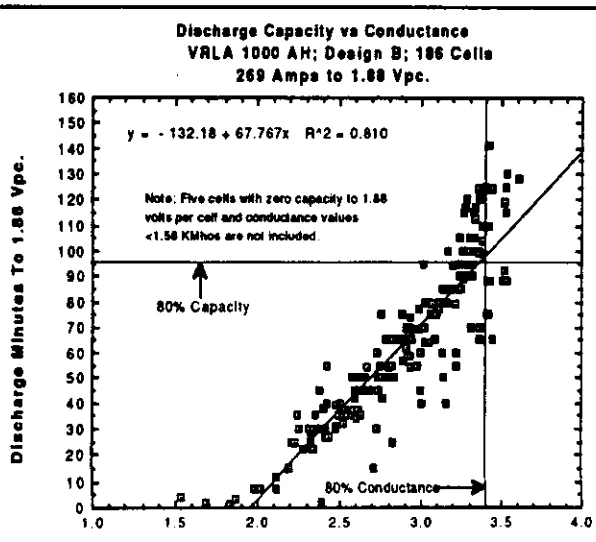

Figure 22

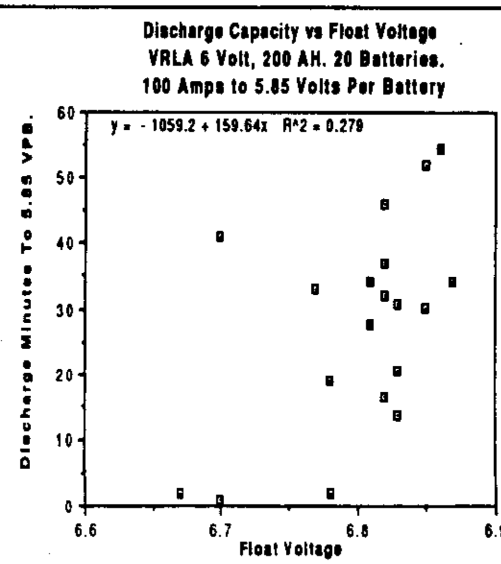

Figure 24

pulled off-line to perform both conductance and discharge testing. **Figure 24** shows the poor correlation of float voltage measurements as compared to the discharge capacity results. **Figure 25** 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, medium, high conductance and two new cells were sent to Midtronics lab for capacity testing. **Figure 26** reveals the correlation of conductance and discharge capacity for the six cells. **Figure 27** 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.

Subsequent post morta examination indicated subtle differences in dry-out which accounted for the difference in capacity between the lowest capacity (26 minutes/9% capacity) cell and the cell which achieved (112 minutes/38% capacity). The differences in performance between the best (270 minutes/91% capacity) cell and the 2nd worst (105 minutes/35% capacity) cell resulted from differences in degree of positive grid corrosion.

Despite these differences in failure modes (some of which were quite subtle and subjective) in each case the conductance measurements correctly predicted both the poor performance and the specific ordering of capacity performance, from the highest to the lowest.

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 electric utility substation locations on flooded products. Measurements of specific gravity, float voltage, conductance and discharge testing were performed. Thus far, the limited amount of flooded

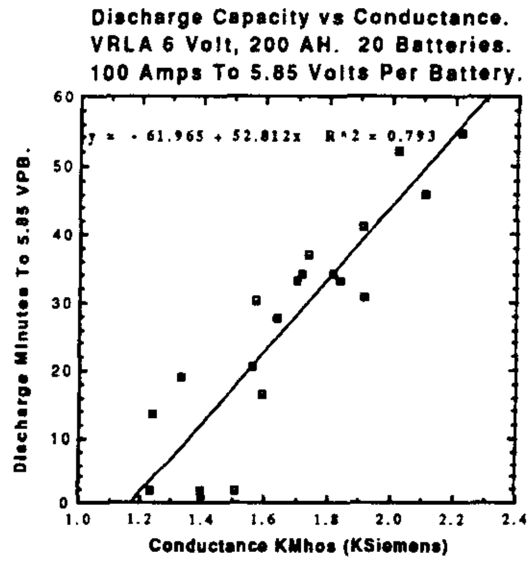

Figure 25

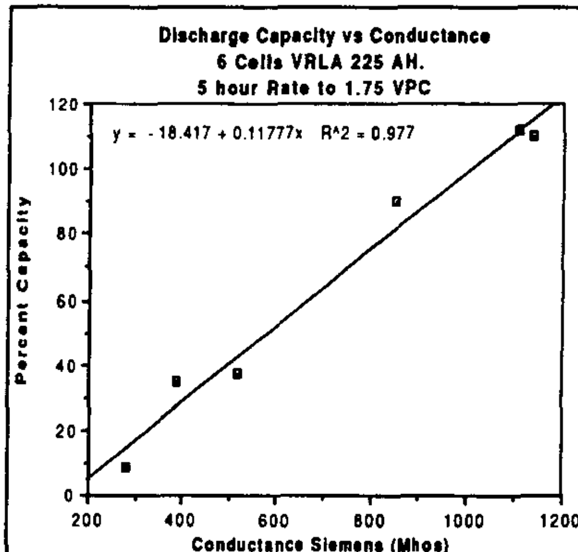

Figure 26

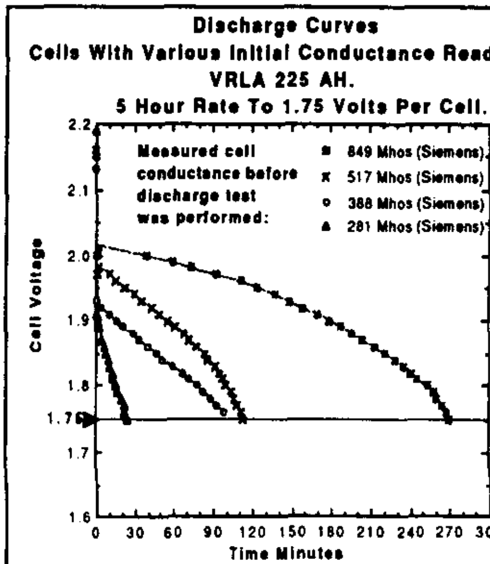

Figure 27

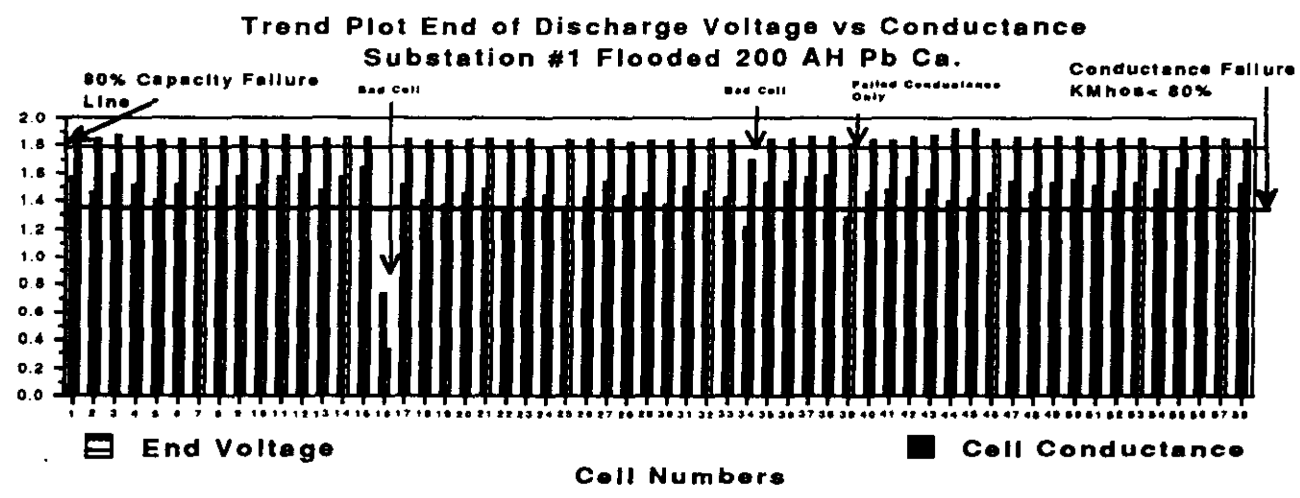

Figure 28

battery data show significant correlation of conductance and capacity. The results also 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 28 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 29** 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 by both conductance and capacity tests. One cell which failed conductance did not also fail the capacity criteria. The resultant conductance test accuracy is extremely good at 98.3 percent overall and 100% correct in detection of poorly performing cells.

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.

Capacity Test Outcome	Conductance Test Outcome: Bad	Conductance Test Outcome: Good
Good	1	55
Bad	2	0

Total 58 Cells
Substation #1

Correct Assessment Overall: $\frac{57}{58} = 98.3\ \%$

Correct Assessment of Failures: $\frac{2}{2} = 100\%$

Figure 29

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. **Figure 30** 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 31** 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 32** 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 33** presents the same data set in a bar graph plot. The results are summarized in **figure 34** and show a conductance test overall accuracy of 80 percent and again, 100% accuracy in detecting the bad cells. The conductance results represent a significant improvement in battery diagnostic sensitivity when compared to traditional measurements and would provide early 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 35** shows the specific gravity and percent capacity 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 36** 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

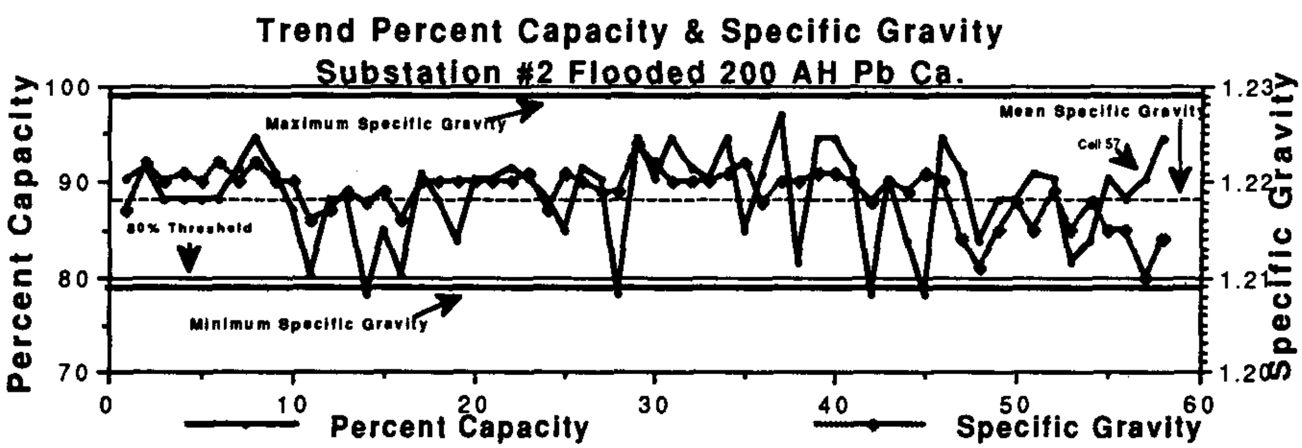

Figure 30

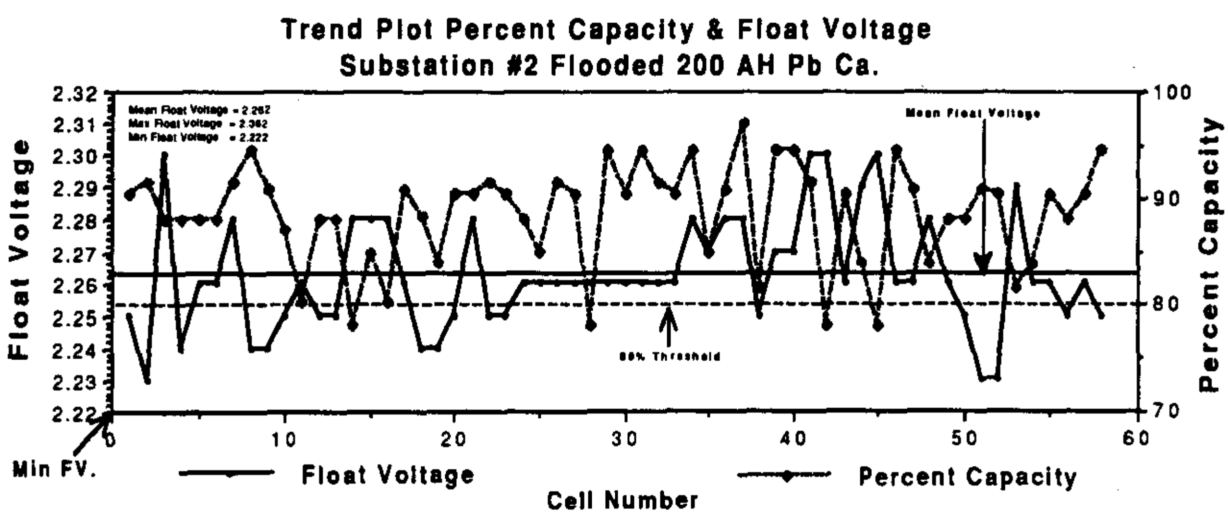

Figure 31

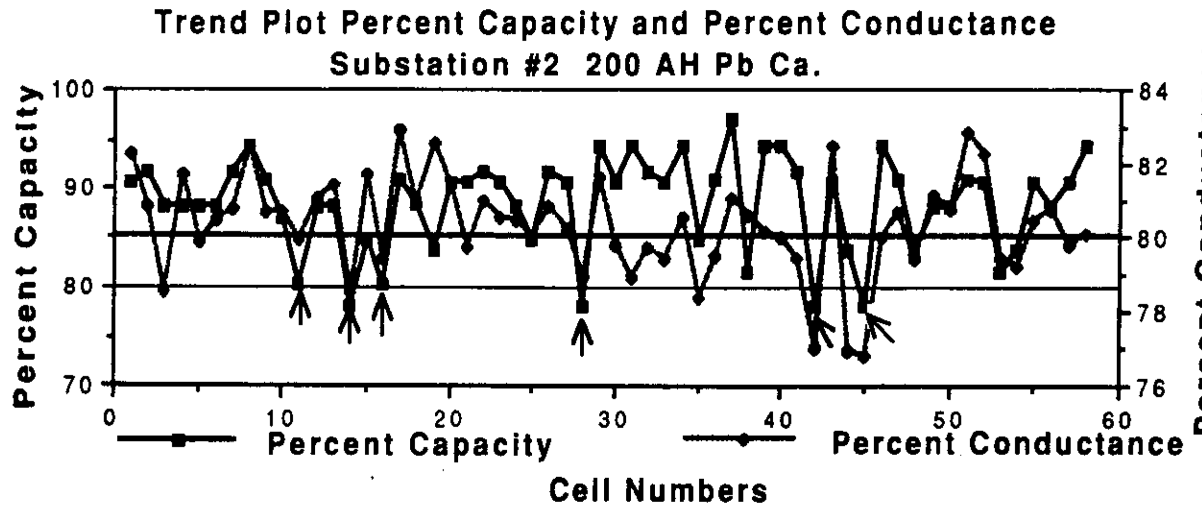

Figure 32

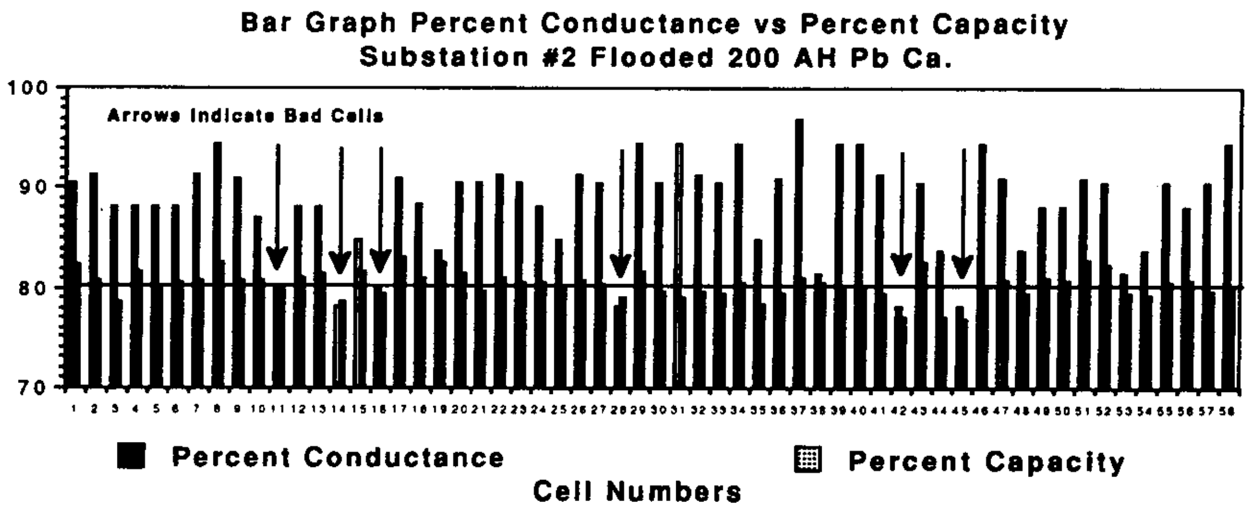

Figure 33

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 37** shows the trend relationship of conductance and capacity and **figure 38** shows the same data in a bar graph. **Figure 39** 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 overall accuracy in this case is 81 percent with 84% accuracy indicating low capacity cells. 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.

Conductance Test Outcome

Capacity Test Outcome	Bad	Good
Good	12	40
Bad	6	0

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

Correct Assessment of Failures: $\frac{6}{6} = 100\%$

Total 58 Cells
Substation #2

Figure 34

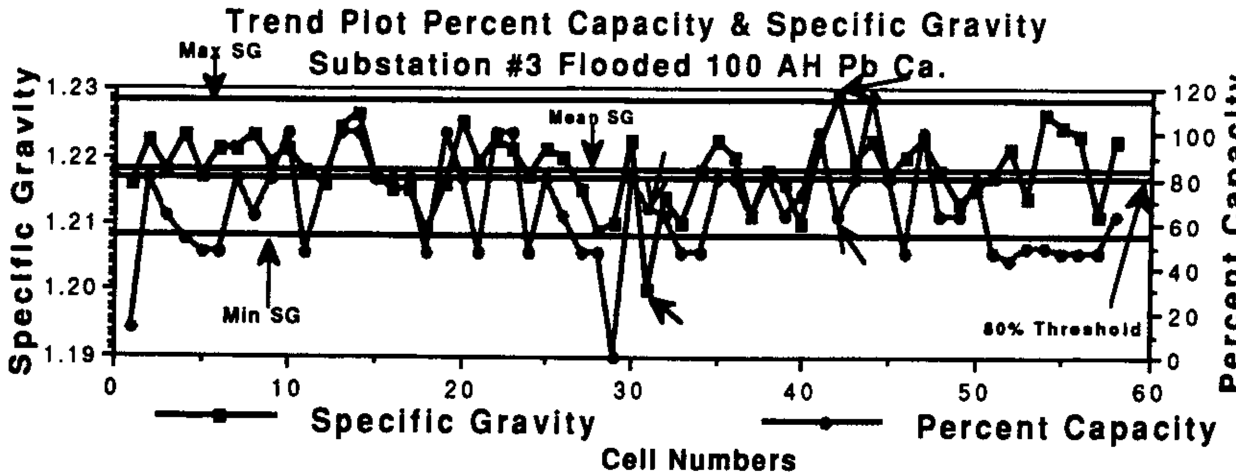

Figure 35

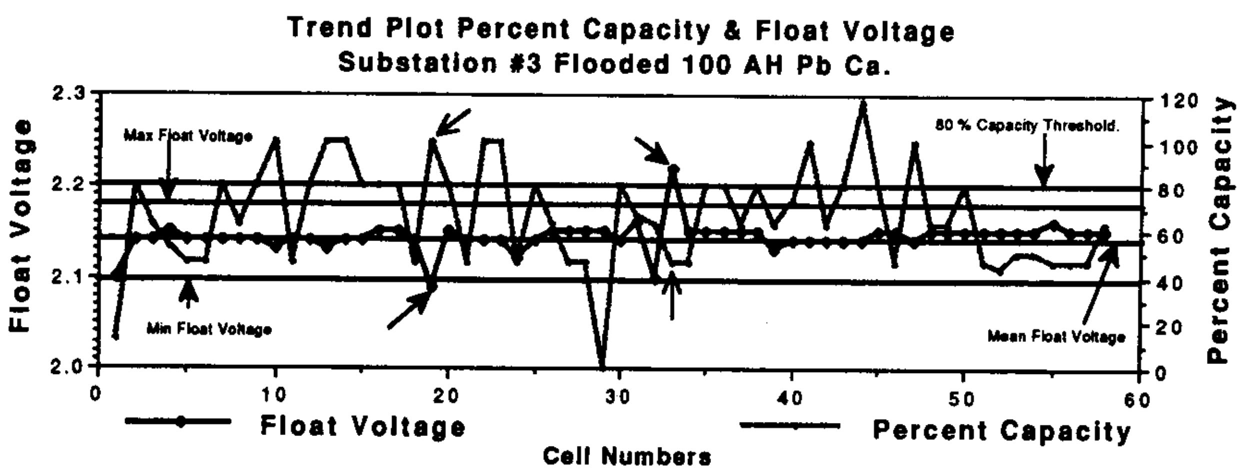

Figure 36

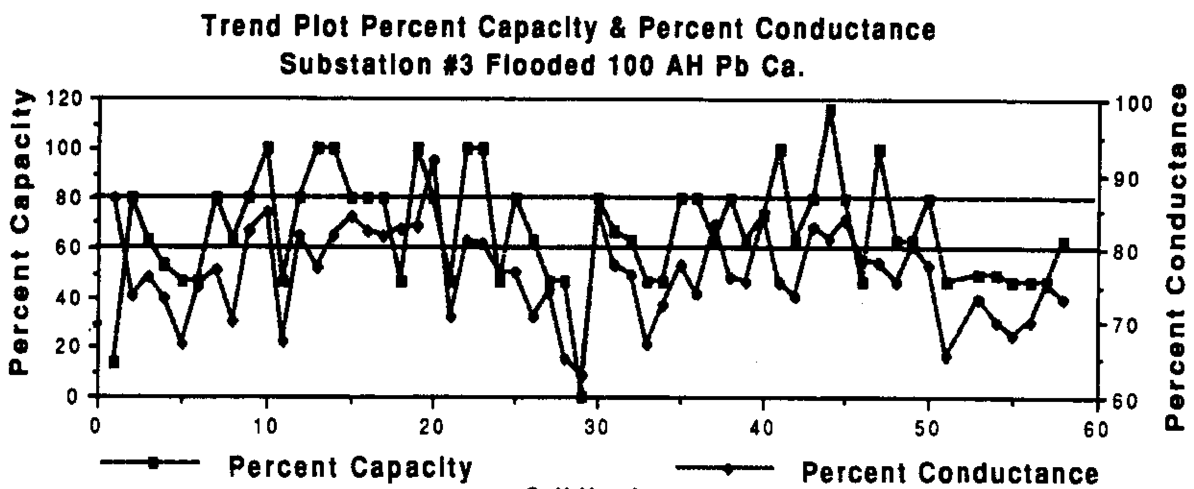

Figure 37

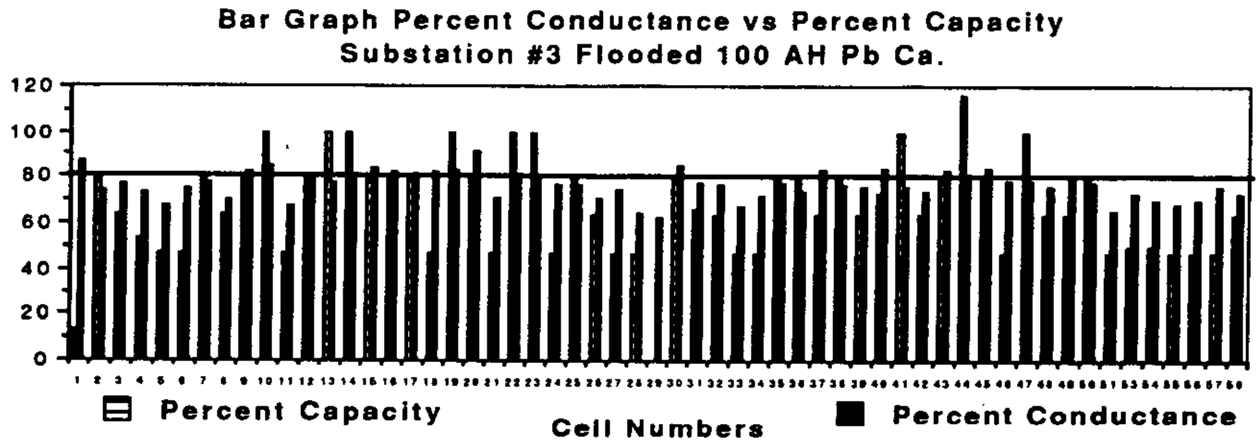

Figure 38

Temperature Data Analysis:

Figure 40 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 41 data shows the differences in the temperature/conductance slopes of AGM, GEL and flooded cell designs. A noticeable slope difference is observed between the AGM design and GEL or 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 41** shows variations among different battery designs, it can be seen from the data that as a rule of thumb, a temperature correction factor of 0.5 % per °F (0.9% per °C) may be utilized for AGM and 0.75% per °F (1.35% per C°) may be utilized on Flooded and GEL battery designs.

Conclusions:

Valve-Regulated Lead Acid (VRLA) Cells:

With the ever increasing usage of VRLA cells in Electric Utility and Telecommunications 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-

Conductance Test Outcome

Capacity Test Outcome	Bad	Good
Good	5	15
Bad	32	6

Total 58 Cells
Substation #3

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

Correct Assessment of Failures: $\frac{32}{38} = 84\%$

Figure 39

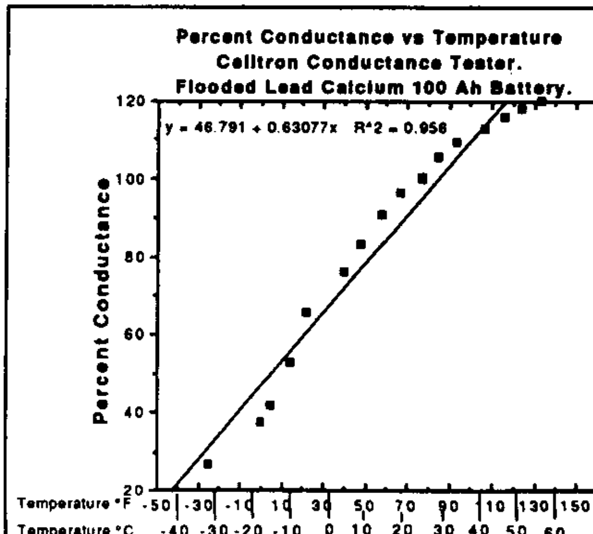

Figure 40

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/MFG:	Correction %/°F	Correction %/°C
Battery Mfg A 6 volt 200AH	0.50%/°F	0.90%/°C
Battery Mfg B 12volt 225 AH	0.40%/°F	0.72%/°C
Battery Mfg B 12volt 300 AH	0.47%/°F	0.85%/°C
Battery Mfg B 12volt 95 Ah	0.51%/°F	0.92%/°C
Battery Mfg B 12volt 95Ah	0.50%/°F	0.90%/°C
Battery Mfg 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/MFG:	Correction %/°F	Correction %/°C
Battery Mfg B 12volt 100 Ah	0.73%/°F	1.31%/°C
Battery Mfg B 6volt 200Ah	0.67%/°F	1.21%/°C
Battery Mfg B 12volt 31Ah	0.75%/°F	1.35%/°C
Battery Mfg 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/MFG:	Correction %/°F	Correction %/°C
Battery Mfg C 6volt 100Ah	0.712%/°F	1.28%/°C

Figure 41

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 with cell 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:

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 (Absorbed Glass Mat), GEL (Gelled Electrolyte) and conventional (flooded) lead acid cells.

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