Intelec '93: Field and Laboratory Studies to Access the State-of-Health of Valve-Regulated Lead-Acid and Other Battery Technologies Using Conductance Testing Part II - Further Conductance/Capacity Correlation Studies - Sept. 1993

Copy of Paper Presented to:

intelec 93

Paris, France
September 27-30, 1993

Field and Laboratory Studies to Assess the State-of-Health of Valve-Regulated Lead Acid and Other Battery Technologies: Using Conductance Testing

Part II: Further Conductance/Capacity Correlation Studies

by:
Mark J. Hlavac
Midtronics, Inc.
Dr. David O. Feder
Electrochemical Energy Storage Systems Inc.
Madison, New Jersey, USA
Thomas G. Croda
Sprint Communications,
San Mateo, California, USA
Dr. Keith M. Champlin
University of Minnesota, St-Paul, Minnesota, USA

MIDTRONICS

Midtronics, Inc.
8230 S. Madison Street
Burr Ridge, Illinois 60521
U.S.A.
Tel: (630) 323-2800
Fax: (630) 323-2844

Midtronics b.v.
Noord IJsseldijk 24
3402 PH - IJsselstein
The Netherlands
Tel: +31 306 873 100
Fax: +31 306 889 015

15th International Telecommunications Energy Conference

Field and Laboratory Studies to Assess the State-of-Health of Valve-Regulated Lead Acid and Other Battery Technologies Using Conductance Testing.

PART II: Further Conductance/Capacity Correlation Studies

Etudes de Vieillissement de Batteries Étanches et D'autres Batteries au Plomb en Utilisant la Technique de la Conductance.

PARTIE II: Études Prolongées de la Conductance/Capacité

Mark J. Hlavac
Midtronics, Inc.
Dr. David O. Feder
Electrochemical Energy Storage Systems, Inc., Madison, New Jersey, USA
Thomas G. Croda
Sprint Communications, San Mateo, California USA
Dr. Keith S. Champlin
University of Minnesota, Minneapolis, Minnesota, USA.

Mark J. Hlavac
Midtronics, Inc.
le Dr. David O. Feder
Electrochemical Energy Storage Systems, Inc., Madison, New Jersey, USA
Thomas G. Croda
Sprint Communications, San Mateo, California USA
le Dr. Keith S. Champlin
University of Minnesota, Minneapolis, Minnesota, USA.

Abstract:

This paper continues and significantly extends the results reported previously at Intelec '92 {3}. It demonstrates the high correlation of capacity and conductance on hundreds of cells in Telecommunication, U.P.S., Railroad signaling and other usages. It confirms the premature capacity loss of Valve Regulated Lead Acid (VRLA) cells reported previously and provides information on failure modes via post morta tear-down of some of the defective cells. Further it extends the correlation of conductance and capacity to flooded lead acid cells and provides preliminary data of capacity conductance correlation with flooded Nickel Cadmium (NiCd) batteries. It also introduces the results of techniques of noise suppression to allow on-line conductance measurements to be made on the batteries without interruption while the batteries continue in service.

Conductance Technology

Information on the theory and early background of conductance testing to measure battery state-of-health was discussed in a previous INTELEC publication {3} and will not be repeated here.

In the past two years conductance technology has been investigated with increasing interest and has been accepted in many areas of the telecommunications industry as a quick and reliable technique for determination of cell/battery state-of-health. Until recently, all reported conductance data had been measured with the cell/battery off-line. Discussions with maintenance personal who are currently utilizing conductance equipment have revealed the need, in certain applications, to measure cell/battery conductance on-line. The fact that the system is on-line does not immediately imply that there will be difficulty performing conductance measurements. The measurement stability is directly related to the magnitude of the AC noise current on a particular system. Measurements under float conditions in the telecommunications environment have generally shown less than 3 amps peak-to-peak of AC noise current. But the AC noise current measurements performed in UPS (uninterruptable power supply) applications have shown greater than 25 amps AC peak-to-peak. In applications where the AC noise current is greater than 1 amp peak-to-peak, a newly designed proprietary noise elimination circuit can be utilized to obtain the conductance measurement. Data presented in this paper will show that whether the conductance measurement is performed on-line with noise elimination or off-line, the effect of float charging the cell/battery has a minimal effect on the conductance measurement and no appreciable effect on the correlation of cell/battery conductance to its timed discharge capacity. Additionally, conductance technology is currently being developed for battery monitoring systems and will soon be used to interrogate the battery system remotely.

All of the conductance tests were performed with Midtronics Celltron and Midtron products.

For additional information on the theory of operation and types of testers utilized in this research, refer to the proceedings of Intelec 92' Washington D.C. Part I Conductance/Capacity Studies, Conductance Technology Section.

VRLA Usage in Telecommunication Environments and Other Stationary Standby 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 telecommunication industry 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 succeptable 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 500 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 -0.85) 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.

Experimental Tests Performed on VRLA Cell/Batteries

In 1992 and 1993 additional tests were performed on more than 1200 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 35 battery strings tested using Midtronics conductance testers and Alber discharge equipment, data, typical of 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.

Transmission Plant #1: VRLA AGM, 1000 AH, Design A, Manufacturer A

As reported in the previous Intelec publication {3}. Field testing was performed in this telecommunication transmission site on 15 parallel strings. In this paper, further data analysis for this plant are shown, with percent accuracies for detecting both good and bad cell combined results and in identifying low capacity cells (< 80%). The data presented in the previous paper showed poor correlation of either float voltage or specific gravity to discharge capacity. **Figure 1** shows the box score analysis for float voltage vs. capacity for this same data and shows an overall successful prediction of 13% (good+bad) and 0% success in finding failed capacity cells (<80%). Box score analysis for calculated specific gravity vs. capacity also show similar results. By contrast **figure 2** shows the correlation of conductance vs. capacity for the entire plant (strings 2-15) with an R^2 correlation coefficient of 0.86. **Figure 3** shows the box score analysis

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: $\frac{0}{146} = 0\%$

Total 168 Cells

Figure 1

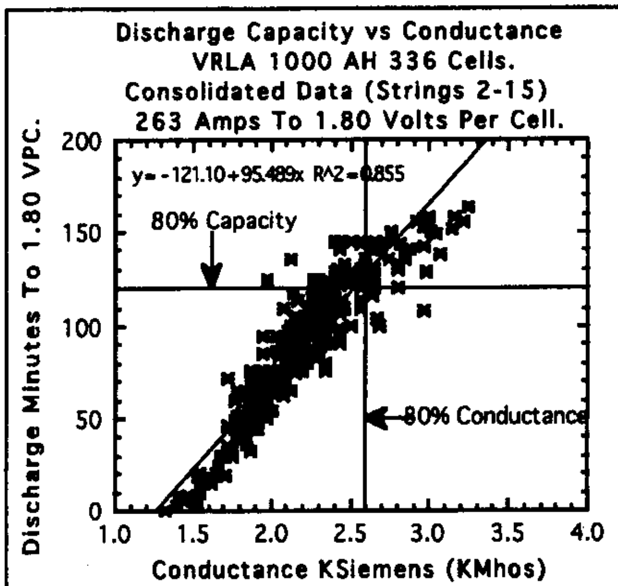


Figure 2

Conductance Test Outcome

Capacity Test Outcome	Bad	Good
Good	37	34
Bad	259	6

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

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

Analysis of Strings (2-15) 336 Cells.

Figure 3

for these same strings with an overall accuracy of 88% (good+bad) and an accuracy of 98% in detecting failed capacity cells (<80%).

__Transmission Plant #2: VRLA AGM, 1000 AH, Design B, Manufacturer A__

In another transmission plant test of VRLA cells of 1000 AH size but of a newer design, 192 cells arranged in eight parallel strings were evaluated by conductance and discharge capacity tests. In this section, 24 cell data from string #8, typical of the other strings tested will be discussed in detail. **Figure 4** shows capacity distribution data for string #8. The capacity distribution shows significant capacity range with the majority of cells falling well below the 80% capacity failure threshold (96 Minutes). **Figure 5** shows the correlation analysis for this string with an R^2 value of 0.91 showing excellent linear correlation, similar to that reported in the previous publication (3) for design A. A box score analysis is shown in **figure 6** and shows an overall successful prediction of 83% (good + bad), with conductance successfully predicting all the low capacity cells with an accuracy of 100%. **Figure 7** shows the composite analysis of capacity distribution for the entire plant as a whole and clearly 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. Overall conductance/capacity correlations for

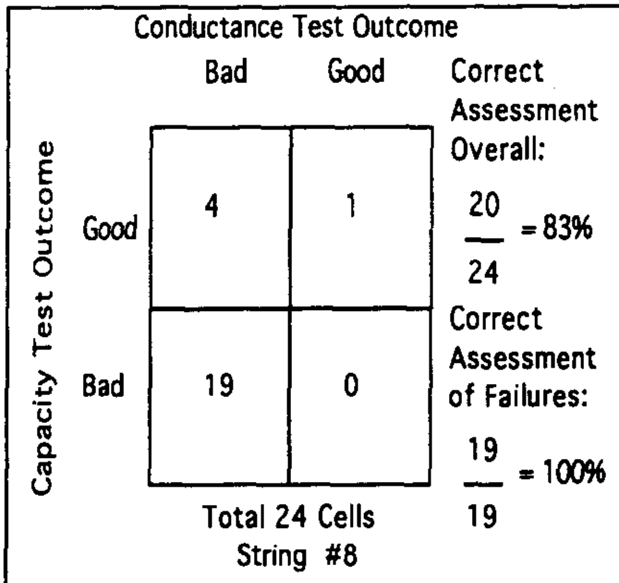


Figure 6

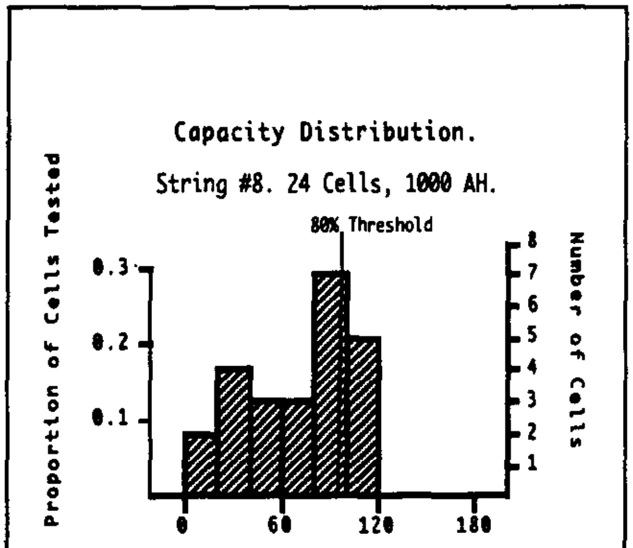


Figure 4

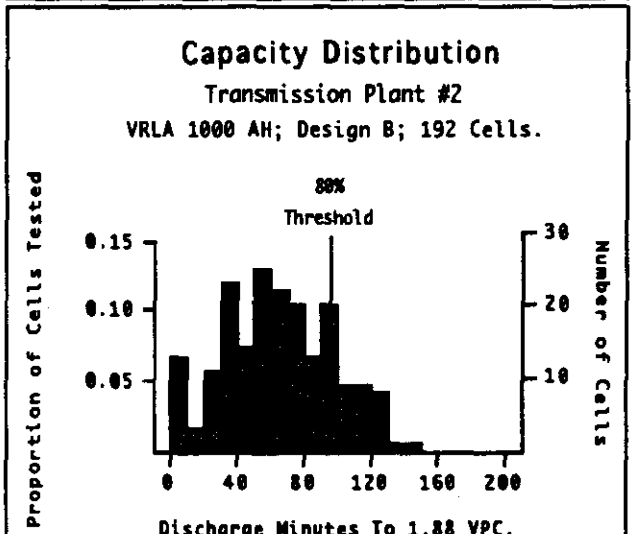


Figure 7

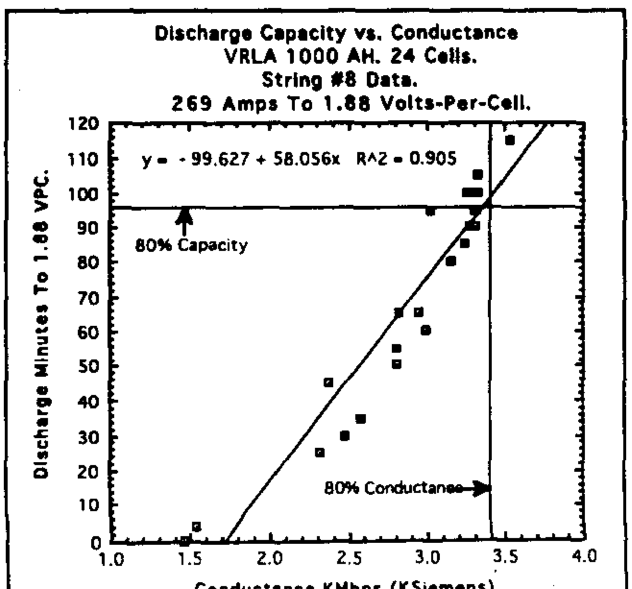


Figure 5

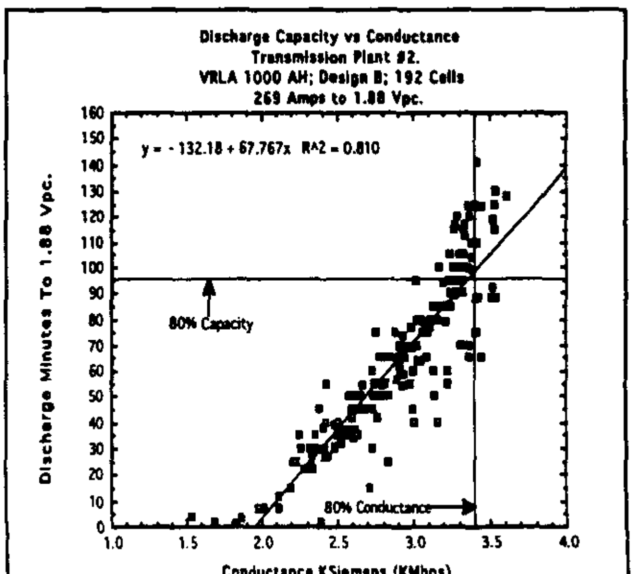


Figure 8

these cells are shown in **figure 8** and indicate excellent correlation R^2=0.81. For these cells, the box score (**figure 9**) shows conductance overall prediction accuracy of 89% (good+bad) while successfully predicting low capacity cells (<80%) 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.

Figure 10 shows the results of conductance measurements made on string #2 design B of this same transmission plant. Cell # 16 measured normal float voltage and 2.11 volts open circuit but gave zero conductance reading during the conductance test. Upon applying the 269 amp load current to this string, the string voltage immediately dropped below the low voltage cut-off and the Alber discharge equipment shut down within seconds, just as a real system might do under an AC outage. Tear down analysis of cell #16 revealed catastrophic corrosion of the negative strap. Manufacturer's analysis determined high antimony content in the buss lead, presumably due to the use of an incorrect burning stick in the manufacturing process.

<u>**Post Morta Examination: Transmission Plant #2**</u>

Twenty four cells from string # 8 and 6 cells from other strings were returned to the manufacturer and retested for capacity and conductance. Eight cells were then opened to determine the condition of the elements and diagnose the cause of failure. Twenty of the 24 cells from string #8 which had originally tested from 56% to 92% capacity, directly off load at the telephone office, recovered to 83% to 137% capacity after 3 discharge/recharge cycles. Recharges were performed on groups of 6 cells at a constant voltage rate of 2.35 volts-per-cell followed by 19 amps (C/50) constant current, until voltages stabilized to ± 10mV. The other four cells, which had originally tested, off load, at 8% to 63% capacity still failed after 3 cycles with capacities ranging from 0% to 70%. The 6 cells from the other strings which had originally tested at 0% to 19% capacity did not recover, with 3 cells still showing 0% capacity and the remaining three showing 8% to 19% capacity after three cycles.

Failure modes were determined for the 8 cells torn-down. Failures include: Item 1, partial or complete negative strap corrosion failure; Item 2, positive grid corrosion, growth and grid frame fractures; Item 3 dry out; Item 4 very low stack compression.

All but one of the cells showing very low capacities had evidence of internal iron contamination. The single high capacity cell (both off-float and at the manufacturer) showed no significant defects on tear-down.

Prior to final tests and prior to tear-down, conductance measurements were made on all cells. **Figure 11** shows percent capacity vs. conductance for the cells as tested at the telephone office and indicates a correlation coefficient of R^2=.940. Also plotted is the capacity/conductance correlation plot for the same cells as tested after the cycling and boost charging by the manufacturer. The correlation coefficient R^2=0.858 and regression lines are almost parallel.

Despite the variety of failure modes the original conductance data clearly detected those cells which would fail the off load capacity test and would have failed had commercial power failed. After cycling and boost charging, although many capacities improved (on average 25-30%), the conductance still correlated well (R^2=.858) to the improved capacities and clearly indicated those cells which failed despite attempts at resuscitation.

<u>**Transmission Plant #3: VRLA AGM, 1000 AH, Design B: Manufacturer A**</u>

In another telephone transmission site 1000 AH VRLA cells approximately four years in age were recently tested. Both conductance and discharge tests were performed on seven 24 cell strings. **Figure 12** shows the capacity distribution plot for the seven strings (168 cells) tested and reveals the majority of cells falling well below their 96

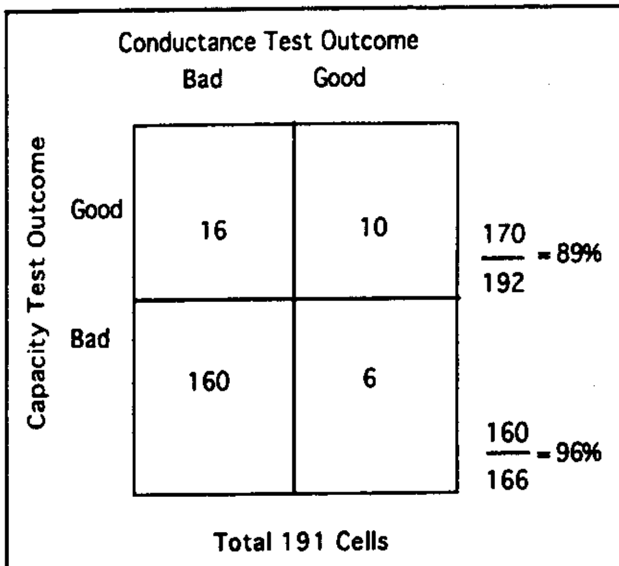


Figure 9

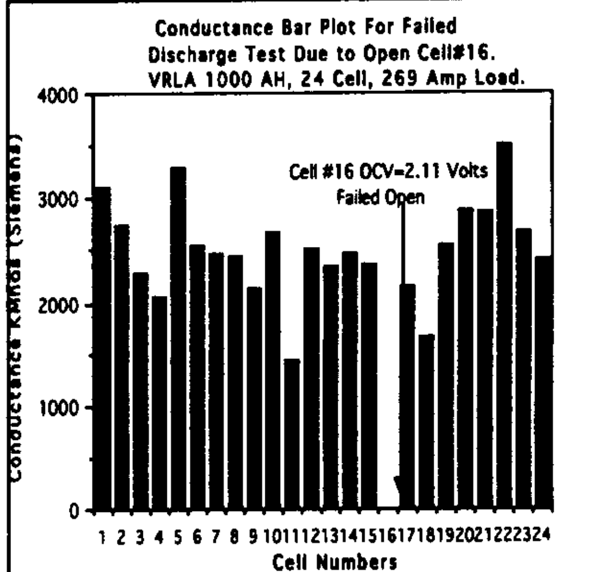


Figure 10

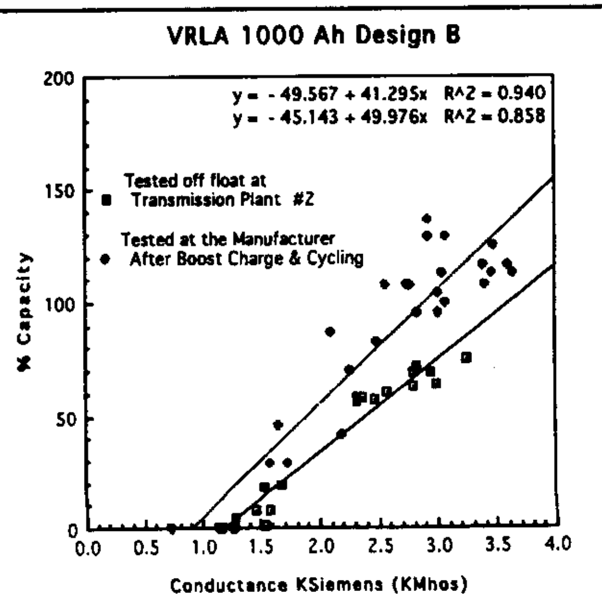


Figure 11

minute 80% capacity failure threshold. **Figure 13** shows the correlation of conductance and capacity for these same seven strings with an R^2 correlation coefficient of 0.81. **Figure 14** shows the box score analysis for the seven strings with an overall accuracy of 92% (good + bad) and an accuracy of 100% in finding low capacity cells (<80%).

UPS System: VRLA AGM, 200 AH, 6 Volt Monobloc, Manufacturer B

Recently tests were performed in a UPS application which contained 3 parallel strings of 63 six volt 200 AH batteries. Conductance was measured and discharge tests were then performed at the one hour rate to 5.64 (1.88 per cell) volts per battery. This battery had been in service for only three years of its expected 10 year design life. Capacity vs. conductance correlation for the single string data, typical of the other strings in this plant is shown in **figure 15** and shows an R^2 correlation coefficient of 0.79. **Figure 16** shows the box score analysis for this single string and reveals an overall accuracy of 92% (good + bad) and 90% accuracy in finding low capacity cells (<80%). These results again demonstrate the utility of the conductance test in locating poor capacity (<80%) monobloc batteries.

Conductance Test Outcome

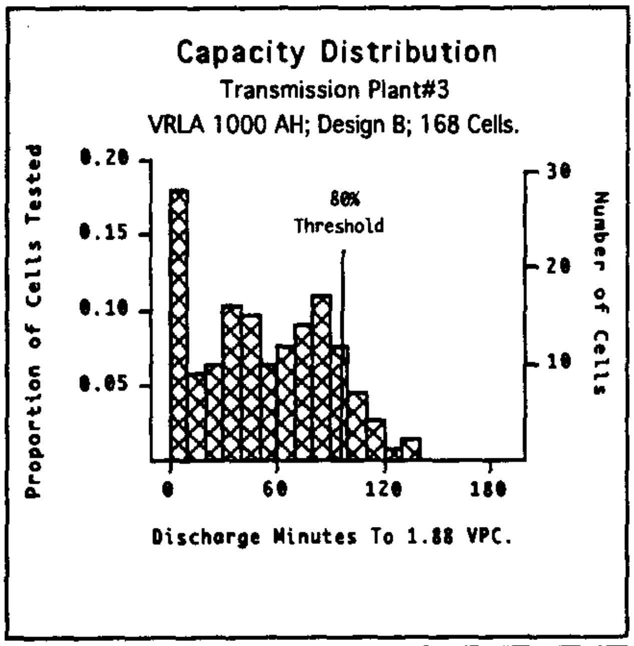
Capacity Test Outcome	Bad	Good
Good	13	2
Bad	153	0

Correct Assessment Overall: $\frac{155}{168} = 92.3\%$

Correct Assessment of Failures $\frac{153}{153} = 100\%$

Total 168 Cells
Transmission Site #3

Figure 14



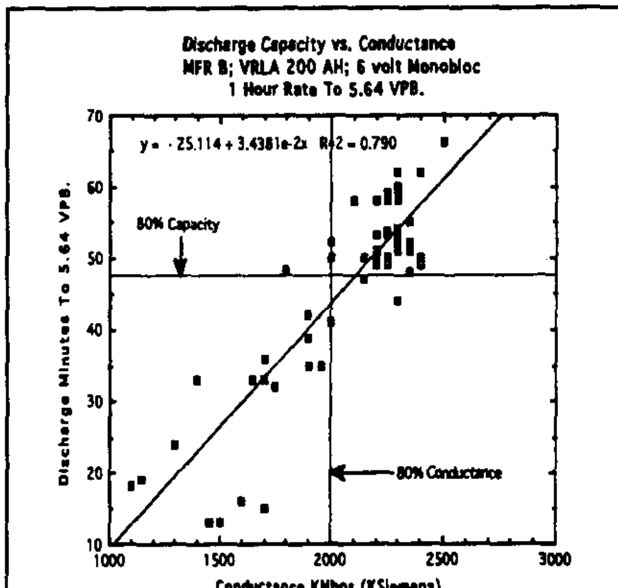


Figure 15

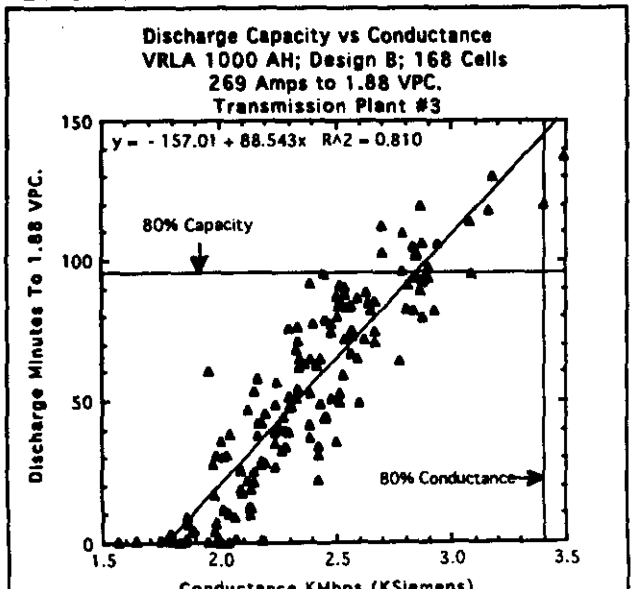


Figure 13

Conductance Test Outcome

Capacity Test Outcome	Bad	Good
Good	3	41
Bad	17	2

$\frac{58}{63} = 92\%$

$\frac{17}{19} = 90\%$

String #1 63 Cells

Figure 16

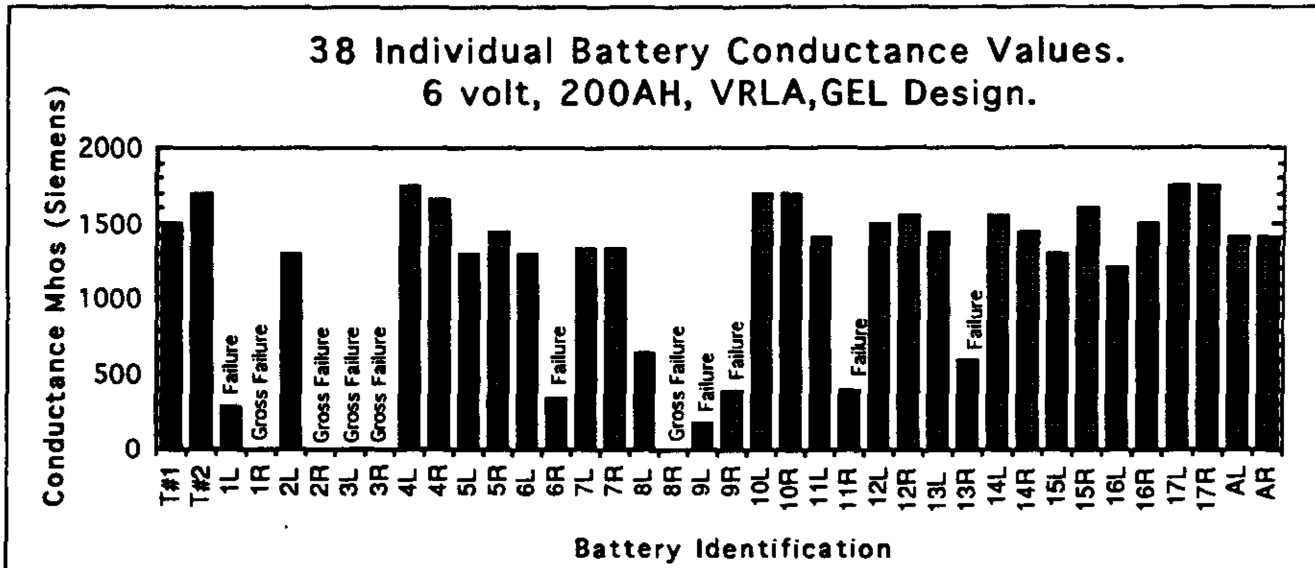


Figure 17

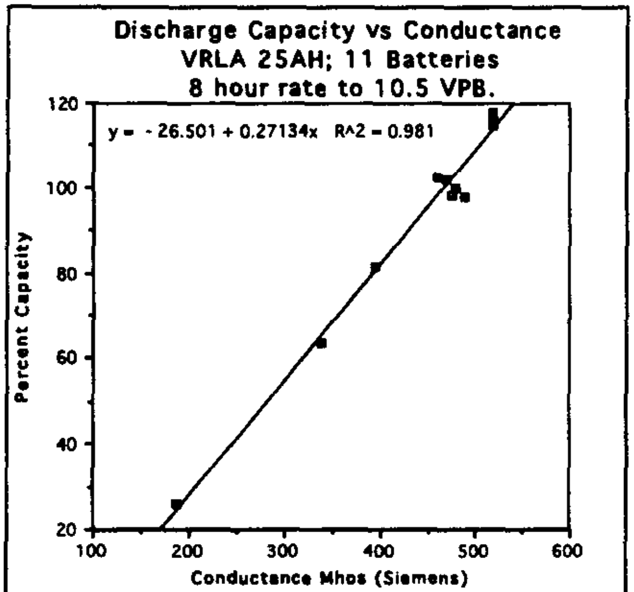


Figure 18

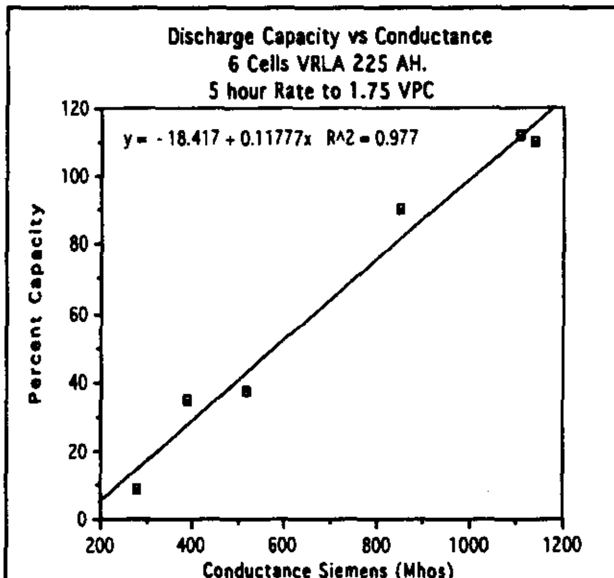


Figure 19

<u>Photovoltaic System: VRLA Gelled Electrolyte (GEL), 6 Volt Monobloc, Battery Manufacture B</u>

Conductance and discharge testing was performed on two year old gelled electrolyte (GEL) 200 AH six volt monoblocs used in photovoltaic (PV) powered stand-alone area lighting systems. Each system utilized two batteries for power. The short-term high rate discharge test was performed by connecting a fixed resistive load of .065 ohms, approximately 70 amperes at 6 volts for a period of 6 minutes. The battery voltage was recorded at 5,30,60,120,240,300,360 second intervals. **Figure 17** shows a conductance bar graph for these batteries and shows that batteries with zero conductance (1R, 2R, 3L, 3R, 8R) immediately failed the discharge test. Batteries 1L, 6R, 9L, 9R 11R and 13R also failed quickly under load. These results clearly demonstrate the capability of the conductance test in identifying poorly performing batteries.

<u>Subscriber Loop Carrier (SLC) VRLA AGM, 12 volt, 25AH, Battery Manufacturer C</u>

Testing has also been performed on batteries returned from the field as well as new batteries utilized in subscriber loop carrier (SLC) systems. These batteries ranged in age from one to eight years. Conductance measurements and discharge tests (8 hour rate to 10.5 volts-per-battery) were performed on these batteries. **Figure 18** shows the correlation plot of conductance and capacity for 11 batteries tested and shows an R^2 correlation coefficient of 0.981.

<u>Independent Telecommunication Study: VRLA AGM, 6 volt Monobloc, 100AH, Battery Manufacturer D</u>

In an independent study recently presented in May 1993 at the International Lead Conference in Venice, Italy (7), the author showed correlation results of both conductance and discharge capacity tests performed on 164, VRLA AGM monoblocs. From the study the author concluded: 1. A high degree of correlation R^2 =0.91 exists between timed discharge capacity and conductance. 2. The degree of correlation may depend on the discharge rate. 3. The conductance can be used to reject cells at end of life. 4. Catastrophic failure can be detected by conductance monitoring. 5. Initial calibration (conductance reference) of new AGM or GEL VRLA cells should be made against conditioned cells. These reported results, in addition to several other studies recently performed, again demonstrate the ability of conductance testing in finding premature capacity loss of VRLA cells.

POST MORTA ANALYSIS - 225 AH CELLS						
CELL #	CONDUCTANCE VALUES Siemens (Mhos) IN FIELD	IN LAB	@ TEARDOWN	CAPACITY IN LAB	@ TEARDOWN	TEARDOWN OBSERVATION
1	1012	849	640	91%	98%	Pos. grid corrosion
2	925	517	508	38%	43%	Neg. burns loose; very slightly dry
3	409	388	433	35%	42%	Pos. limited discharge; Pos. grid corrosion
4	449	281	232	9%	18%	Sightly dry

Figure 20

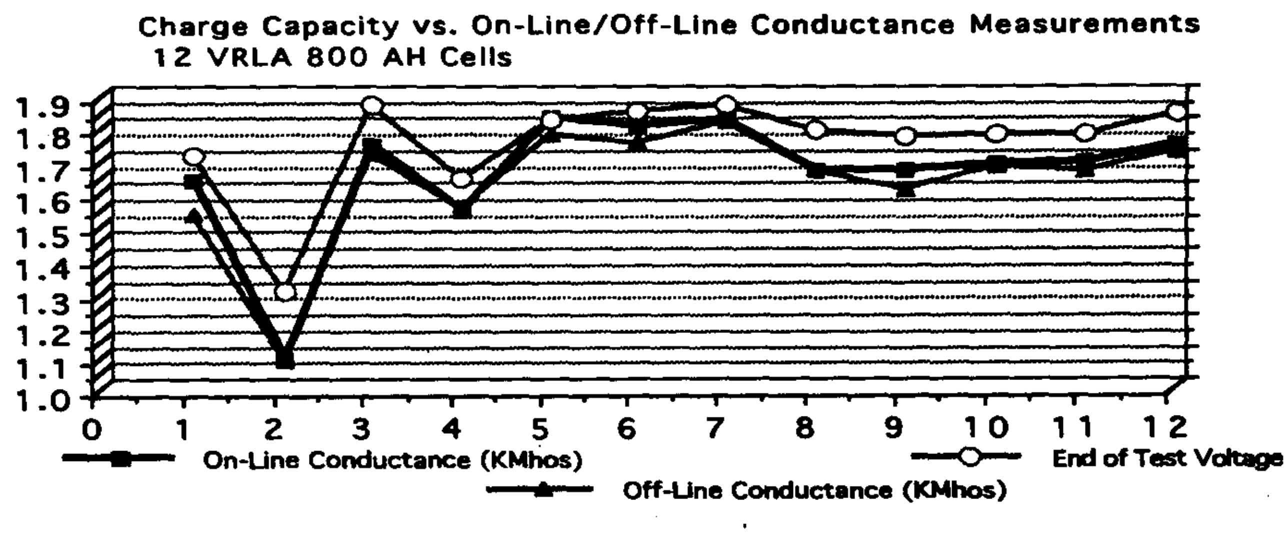


Figure 21

Railroad Signal System: AGM 200AH, Design B, Manufacture A

As reported in the previous Intelec publication (3). Field testing was performed in railroad signal site applications on VRLA 225 ampere hour cells. Typical ages for these cells were three to four years old. A sample of four cells exhibiting low, *medium* and high *conductance*, in addition to two new cells, were sent to Midtronics laboratory for capacity testing. **Figure 19** reveals the correlation of conductance and discharge capacity for the six cells. Three subsequent recharge and discharge tests were performed with no appreciable improvement in cell condition measured by either conductance or discharge capacity.

Post Morta Examination: Railroad Cells

Figure 20 shows the summarized results from measurements performed in the field, lab and after tear down. 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 the degree of positive grid corrosion.

Note particularly cell #2. When tested in the laboratory its conductance had *dropped from* 925 *Siemens Mhos* to 517 Siemens Mhos and its capacity measured 38%. Teardown analysis identified loose negative plates which appear to have lost sufficient contact to the buss, presumably during shipment, accounting for the drop in conductance and capacity. Cell #4 when tested in the field showed a *conductance which should have* resulted in a *capacity* of 35% to 40%. However, when measured in the lab its conductance had dropped to 281 Mhos and capacity was measured at only 9%. Tear down analysis showed dry out as the only obvious failure mode but provided no explanation for the decrease in conductance.

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

Experimental On-line Measurements

Results from on-line and off-line conductance testing, as well as, discharge results performed at a cellular transmission site on 12, 800 AH cells are shown. At the time of the test the AC noise current was measured at 2 amps peak-to-peak. **Figure 21** trend plot shows the difference in the off-line conductance measurement vs. the on-line measurements obtained with noise elimination. The differences observed from on-line and off-line conductance measurements are generally negligible, less than 5%. More importantly, the capacity and conductance correlation is shown to be unaffected when measurements are performed on-line with noise elimination. Testing performed at an independent test laboratory with a well filtered charging source have also shown conductance measurements performed on-line with no need for noise elimination. Similar results have been observed performing conductance measurements on-line, without noise elimination, where switch-mode power supplies are utilized for battery charging.

Flooded Battery Results and Discussion

As reported in recent publications {4,6}. Field tests were performed at several electric utility substation locations on flooded stationary batteries of various age and manufacture. Measurements of specific gravity, float voltage, conductance and discharge tests were performed. Results showed the conductance test as being more sensitive to actual cell performance than traditional measurements of cell specific gravity or float voltage. Results reported in one of the studies {6} showed 0 % accuracy of either float voltage or specific gravities in finding low capacity cells (<80%). By contrast, the conductance test accuracy was shown to be from 84% to 100% in finding the low capacity cells (<80%). These results, as well as results reported in references {2,3,5} again confirm the inability of either float voltage or specific gravity to identify capacity degradation while confirming that conductance measurements are effective in finding cells which have degraded to values just below the normally recommended 80% failure criteria.

Experimental Measurements with Nickel Cadmium Cells (NiCd)

In June of 1992 conductance measurements were performed on 13 year old NiCd 200 AH batteries. Prior to laboratory testing the cells were charged at a constant current rate of 48 amps for eight hours, rested for 10 hours and then discharged at the manufacturer's suggested one hour constant current rate to 1.0 volt per cell. New cells of similar size and construction were also tested in the laboratory. **Figure 22** shows the correlation plot of discharge capacity and conductance for the new and field returned cells with an R^2 correlation coefficient of 0.91. These preliminary results show that conductance testing may be used for determination of NiCad battery state-of-health.

Conductance vs. Impedance Measurements A Comparison Of Correlation Coefficients To Time Discharge Capacity

Figure 23 shows the relationship of R^2 correlation coefficients developed from both conductance, impedance measurements and discharge capacity. The correlations were developed from individual VRLA 1000 AH 24 cell strings, discharged at 269 amps. For these data the analysis indicate the correlation coefficients for conductance/capacity are significantly higher than for the impedance / capacity correlation. **Figure 24** shows the single string correlation coefficients of both conductance/impedance and discharge capacity as a function of end voltages of 1.88, 1.84, 1.80 and 1.75 volts. Although the conductance R^2 correlation coefficient is still higher than that of the impedance at these different end voltages, it is curious that the correlation coefficients appear to converge at lower end voltages. Analysis of the data for the other strings also show this convergence as the end of discharge voltage decreases. The data is being further analyzed to better understand these relationships.

Correlation of Plate Count to Conductance Measurements Performed on AGM VRLA Cells During Tear Down

During teardowns of several AGM, VRLA 1000 AH cells, conductance measurements were made at the cell terminals as each plate (positive or negative) were cut and removed from the respective strap. The cell was cut open, removed from the jar and placed down such that the weight of the element kept compressive contact of the mat on the plates. The dissection was done in such a way to keep the negative plate wet so as to minimize the oxidation (discharge) of

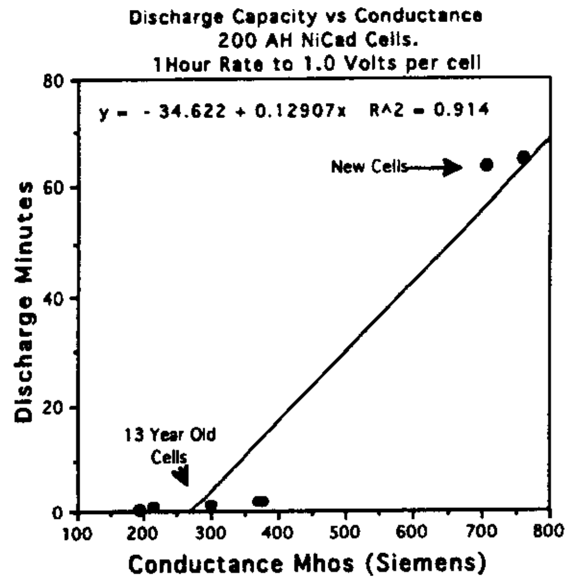


Figure 22

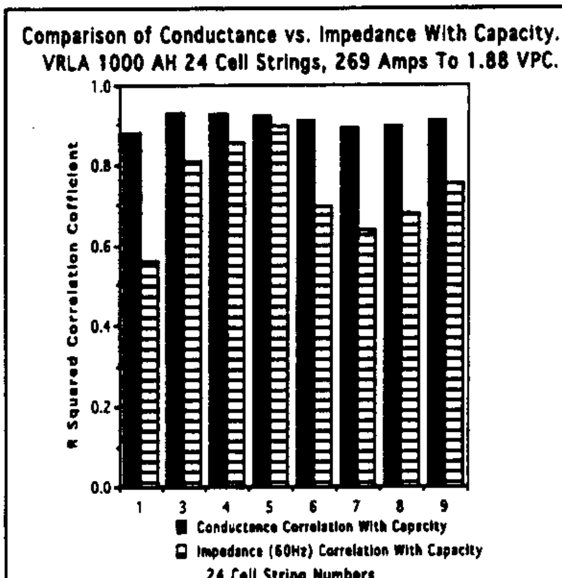


Figure 23

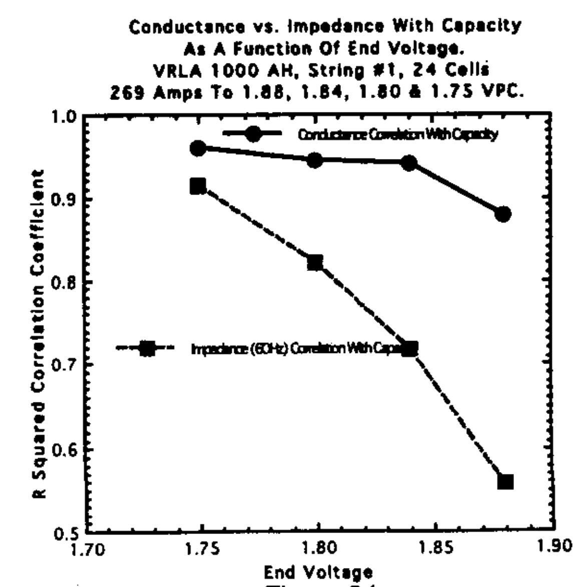


Figure 24

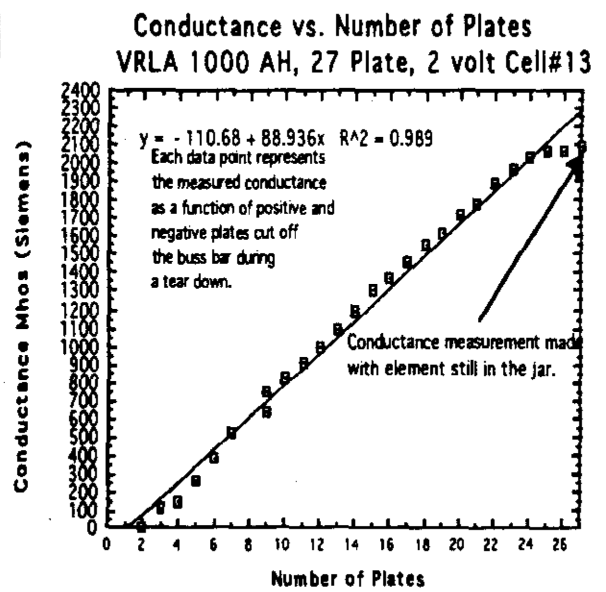


Figure 25

the plate. **Figure 25** shows the conductance vs number of plates and shows an R^2 correlation coefficient of 0.989. Measurements made during teardowns performed on other cells show the same results.

Temperature Effects On Conductance Measurements

Laboratory experiments were run over a wide temperature range from -40°C to 48.8°C. Conductance measurements obtained during the tests show a strong linear relationship of temperature and conductance with R^2 correlation coefficient generally greater than 0.95. However, the data also shows a noticeable slope difference between the AGM design 0.9%/°C (0.5% /F°) and GEL or flooded designs. Further analysis of data shows the conductance/temperature slope characteristics for the GEL 1.35%/°C (0.75% /F°)design closely resemble that of the flooded battery design 1.28%/°C (0.71% /F°).

Conclusions:

With the increasing use of lead acid batteries, especially VRLA designs, in 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 an excellent technique to do so. Based on the results of tests on more than 1200 VRLA cells, ranging in size from 25-1000 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 VRLA cell failure and provide little or no accuracy in detecting low capacity (<80%). Similar results have also been shown for tests performed on flooded stationary cells {4,6}.

2. In all cases tested, conductance measurements performed on VRLA cells correlate extremely well with cell discharge capacity and can provide early detection of premature capacity failures, without regard to application, design, size, specific manufacturer or specific failure mode of the particular VRLA cells involved. The accuracy in identifying low capacity (<80%) cell/batteries has been shown to be generally greater than 90%.

3. As reported in the previous Intelec paper {3}, and again demonstrated in this paper, VRLA cells tested showed a significant percent of premature capacity failures. Further studies are continuing to determine the extent of this condition.

4. The development of a proprietary design noise eliminator, allows conductance measurements to be made on-line without effecting the validity of the conductance/discharge capacity relationship.

5. Independent sources performing conductance and discharge tests on VRLA batteries also show *hard evidence* of the conductance/capacity correlation.

6. As reported in detail in recent publications {4,6,} conductance measurements performed on flooded stationary batteries correlate well with both serious capacity failures, and also 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.

7. For the limited number of NiCd cells tested, preliminary findings show good conductance and capacity correlation for the vented NiCd chemistry. Testing of a larger population of NiCd cells is in progress and should enhance and confirm these preliminary results.

8. Finally, this paper discusses the linear relationship of conductance and temperature for cell conductances measured over a temperature range from -40°C to 48.8°C

Acknowledgements:

The authors would like to acknowledge contributions of test data by Mr. D. Ogden, Ogden Power, Inc; Mr. S. R. Harrington, Ktech Corporation.; Mr. B. Jones, British Telecommunications.

References:

{1} K. S. Champlin: "Dynamic Method for Storage Battery Diagnostic Testing". Talk presented to 1975 SAE Off-Highway Vehicle Meeting, Milwaukee, Sept. 1975.

{2} D.O. Feder; T.G. Croda; K.S. Champlin; S.J. McShane; M.J. Hlavac: "Conductance Testing Compared to Traditional Methods of Evaluating the Capacity of Valve-Regulated Lead Acid Batteries and Predicting State-of-Health". Journal of Power Sources, 40 192. pp 235-250.

{3} D.O. Feder; T.G. Croda; K.S. Champlin; M.J. Hlavac: "Field and Laboratory Studies to Assess the State-of-Health of Valve Regulated Lead Acid Batteries: Part I: Conductance/Capacity Correlation Studies." Proceedings of the 1992 INTELEC Conference, pp 218-233.

{4} M.J. Hlavac; D.O. Feder; D.O. Ogden: "Field Application of Conductance Measurements used to Ascertain Cell/Battery State-of-Health and Inter-cell Connection Integrity in Electric Power Utility Applications". Proceedings of the American Power Conference 1993, Volume 1, pp 44-57.

{5} M.J. Hlavac; S.J. McShane: "Conductance Testing of Standby Batteries in Signaling and Communications Applications for the Purpose of Evaluating Battery State-of-Health". Proceedings of the 1993 Association of American Railroads.

{6} D.O. Feder; M.J. Hlavac; W. Koster: "Evaluating The State of Health of Lead Acid Flooded and Valve-Regulated Batteries: A Comparison of Conductance Testing vs. Traditional Methods". Proceedings of the 1993 International Conference on Lead-Acid Batteries, Varna, Bulgaria.

{7} B. Jones, British Telecommunications: "Conductance Monitoring Of Recombination Lead Acid Batteries", 1993 proceedings of the 11th International Lead Conference, Venice, Italy.