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Evaluating the state-of-health of flooded and valve-regulated lead/acid batteries. A comparison of conductance testing with traditional methods

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Abstract

In a previous series of studies, field and laboratory examinations were made of the relationship of both traditional cell-testing parameters and conductance testing with actual capacity testing for approximately 500 valve-regulated lead/acid (VRLA) cells of various sizes and designs, and in various applications. It was concluded that a significant number of VRLA cells had suffered premature capacity loss, that was not detected satisfactorily by the individual cell float-voltage or by specific-gravity (calculated) measurements. In contrast, the data showed a high degree of correlation between cell capacity and cell conductance. This study provides additional evidence of the extent of premature capacity degradation of VRLA cells, and includes cells of newer designs. It quantifies, more explicitly, the inability of cell float-voltages or specific gravity to provide early warning of these significant failures in capacity. It provides additional data that demonstrate the high degree of correlation between conductance and capacity, and presents striking evidence of the ability of conductance testing to provide early warning of premature capacity failure of VRLA cells. Additional data are given on teardown postmortum analyses of a series of cells that exhibit a wide range of measured capacities. Although the established failure modes among these cells are significantly varied, it is extremely encouraging to report that cell performance is accurately predicted by the conductance values obtained. A report is also given of the results of initial tests of conductance/capacity relationships in flooded lead/acid cells, i.e., of the type used by both electric power utilities and telecommunications organizations to provide stand-by reserve power. The accuracy of conductance data to predict, correctly, cell capacity behaviour is contrasted with predictions that result from the conventional test parameters of cell float-voltages and measured specific gravities. Again, with flooded cells, the data indicate a significantly improved capability to detect low-capacity cells, based on conductance, than would be obtained from either cell float-voltage or specific-gravity measurements.

Application background

Electric utilities, telecommunications companies and railroads typically have hundreds of large battery systems located in their respective plants, central/transmission

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offices and signaling/crossing locations. The batteries can represent several million dollars of investment and may help to protect billions of dollars in assets.

Traditionally, maintenance practices for flooded batteries 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. Measurements of float voltage and specific gravities, as well as scheduled service tests, have been the primary methods that have been utilized for determining battery state-of-health in these industries. Most have good intentions of implementing battery maintenance programs. Several companies 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 that each has to maintain. Because of the work load and manpower cuts, all that can be done 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 voltages in plants containing several thousand individual VRLA cells in a single location, while at the same site, no plan exists for scheduled capacity testing. Other sites utilize carefully scheduled periodic tests of capacity. The majority of users, however, 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 unit of mho, or in the SI unit of siemens. The a.c. conductance test is performed by applying a low-frequency a.c. voltage signal of known frequency and amplitude across a cell/battery, and then observing the a.c. current that flows in response to it. The a.c. conductance is the ratio of the a.c. current component that is in phase with the a.c. voltage, to the amplitude of the a.c. voltage that produces 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 Champlin [1]. In recent years, several studies have utilized conductance technology to ascertain the relative condition of batteries. Successful attempts have been made to correlate the conductance results to timed discharge tests [2–5]. Other measurements of cell impedance have also been actively pursued as possible methods for evaluating cell/battery condition [6–9]. 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. Furthermore, conductance measurements can provide the user with critical information on battery condition that 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 the maintenance of VRLA cells.

Two types of Midtronics industrial conductance testers have been utilized in performing field tests. The first type is the 'Celltron' tester. This is a self-contained, fully portable tester that is designed to measure the conductance of a single cell, or a three-cell battery, over a wide range of sizes from 10 to 8000 Ah. The second type of tester is the 'Midtron' tester. Again, this is a self-contained, fully portable tester that can measure the conductance of three- and six-cell batteries over a wide range of sizes from 2 to 600 Ah.

VRLA usage in electric power, railroad and telecommunications applications

Over the last ten years, VRLA batteries have been rapidly deployed into many different applications, especially where their 'maintenance-free' promise appears attractive. Both GEL (gelled-electrolyte) and AGM (absorptive glass mat) designs are available. These cover a wide range of sizes and capacities, and are now available for deployment in wholly new types of applications and for replacement of ageing 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. It should be pointed out, however, that 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 susceptible to a significantly longer list of possible 'fatal' problems, for example: dryout by post-seal or jar-cover leakage and by valve malfunction; grid corrosion and growth, that also cause dry out in addition to loss of grid/paste contact; loss of plate/separator/electrolyte compressive contact; internal corrosion and loss of contact between post/strap/plate lugs. 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 that conductance measurements should provide indications of potential cell/battery failure.

Field and laboratory testing has revealed [2, 3] the relationships of traditional testing parameters with conductance testing on ~500 VRLA cells. It was concluded that a significant number of the cells had suffered serious premature capacity loss that was not detected satisfactorily by either individual cell specific gravity (calculated from open-circuit voltage after 36 h) or individual cell float voltage. By 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. These early studies emphasized the utility of conductance testing in detecting VRLA cells that show premature capacity loss. The correlation is found to be equally high for VRLA cells ranging form 200 to 1000 Ah in size, in series strings of 48 to 360 V, and in battery plants that contain from 3 to 15 strings in parallel.

Tests of VRLA cell/batteries

In 1992 and 1993, a series of tests was performed on more than 700 VRLA cells in telecommunications, UPS and railroad-signalling 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. For more than 26 battery strings tested using Alber discharge equipment, data typical of individual string results are shown in this section, together with 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) telecommunications transmission plant (design A) typical single-string 24-cell float-voltage distribution data are shown in Fig. 1. Combined float-voltage distribution for 7 strings (168 cells) are shown in

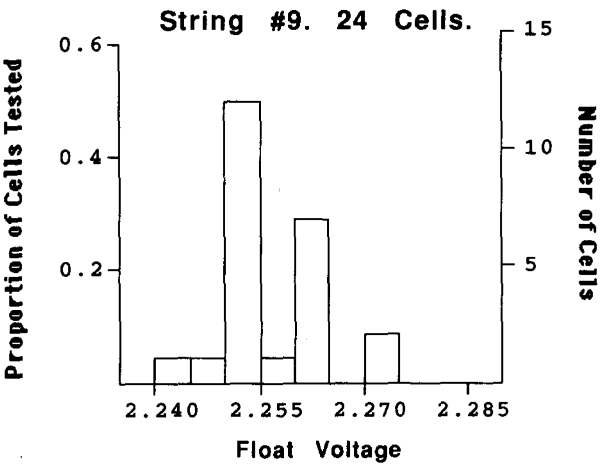


Fig. 1. Design A. Float-voltage distribution for 1 string (24 1000-Ah cells); string no. 9.

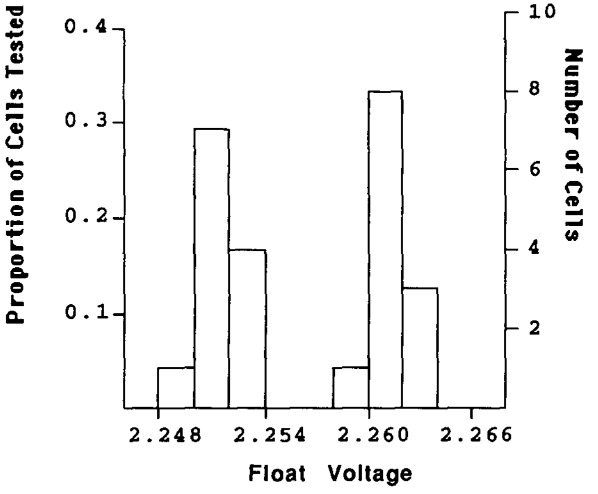


Fig. 2. Design A. Combined float-voltage distribution for 7 strings (168 1000-Ah cells); strings nos. 9–15.

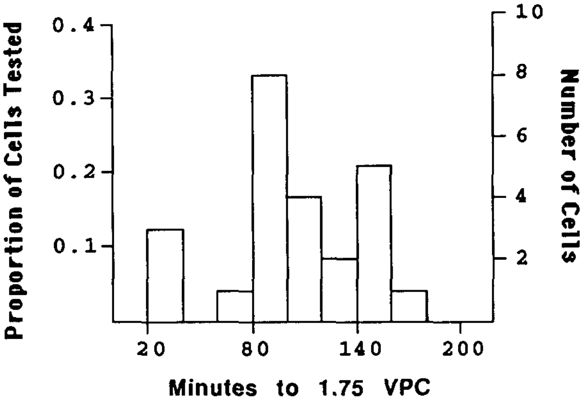


Fig. 3. Design A. Capacity distribution data for 1 string (24 1000-Ah cells); string no. 9; VPC= V per cell.

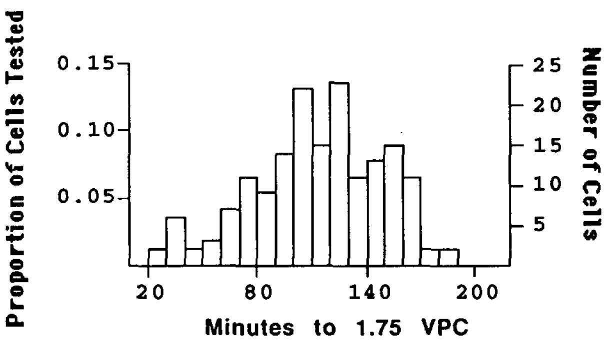


Fig. 4. Design A. Combined capacity distribution for 7 strings (168 1000-Ah cells); strings nos. 9–15; VPC=V per cell.

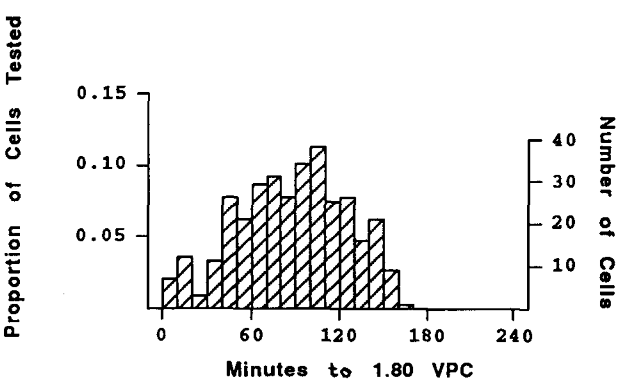


Fig. 5. Design A. Combined capacity distribution data 14 strings (336 1000-Ah cells); strings nos. 9–15; VPC=V per cell.

Fig. 2. In all cases, float voltages are within the manufacturer's accepted range. Capacity distribution data for the same string are given in Fig. 3, and for the same 7 strings are shown in Fig. 4. The capacity distribution data for the 14 strings tested in this office are presented in Fig. 5. 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, i.e., from 0 to 180 min. Most of the cells display capacities below their rated value (150 min to 1.80 V) and a majority fall below the 80% failure rating of 120 min at this discharge rate. It should be noted that these cells have been in stand-by service for only 25% of their rated lifetime. For these same cells, there was a total lack of correlation between the float voltage and the capacity for the single string (Fig. 6). The results, summarized in the box score of Fig. 7, indicate that float

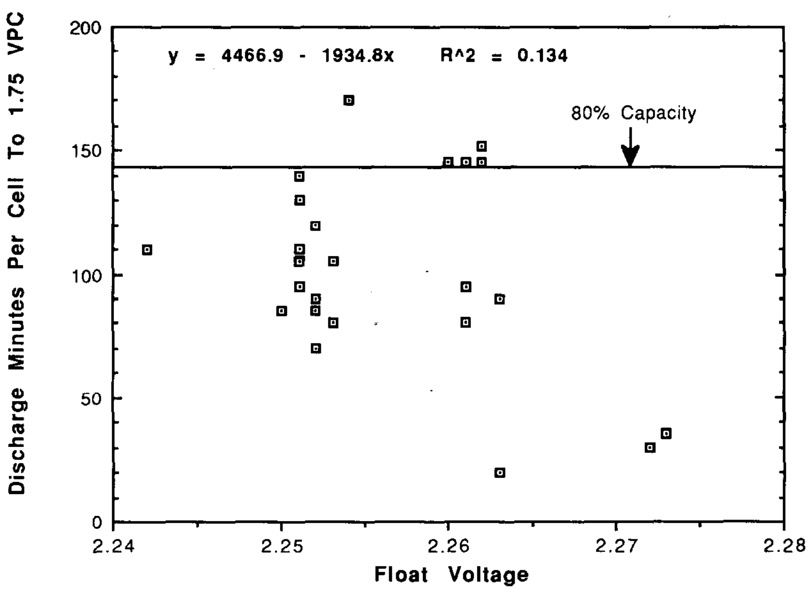


Fig. 6. Design A. Discharge capacity vs. float voltage for 1 string (24 1000-Ah cells); string no. 9; 263 A to 1.75 V per cell.

Float Voltage Test Outcome

Capacity Test Outcome	Bad	Good	
Good	0	6	Correct Assessment Overall: 6/24 = 25%
Bad	0	18	Correct Assessment of Failures: 0/18 =0%

Total 24 Cells

Fig. 7. Box score of float voltage vs. capacity outcome for 24 1000-Ah cells.

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 the same string. Here again, the box score (Fig. 9) shows an overall successful prediction of 13%, but 0% prediction of low capacity cells. The same results are shown for the 7 strings taken as a group in Figs. 10 and 11, and in the box scores of Figs. 12 and 13. By contrast, Figs. 14 and 15 show an excellent correlation between conductance and capacity, with a correlation coefficient of 0.897 for the single string and 0.825 for the 7 strings taken as a group. Figure 16 reveals a bar-graph of conductance and capacity for the single string. The results are summarized in Fig. 17 and show that 21 of the 24 cells meet both conductance and capacity criteria. Clearly 18 cells have failed both conductance and capacity criteria, while only 2 cells that failed conductance did not also fail capacity, and only 1 cell that failed capacity

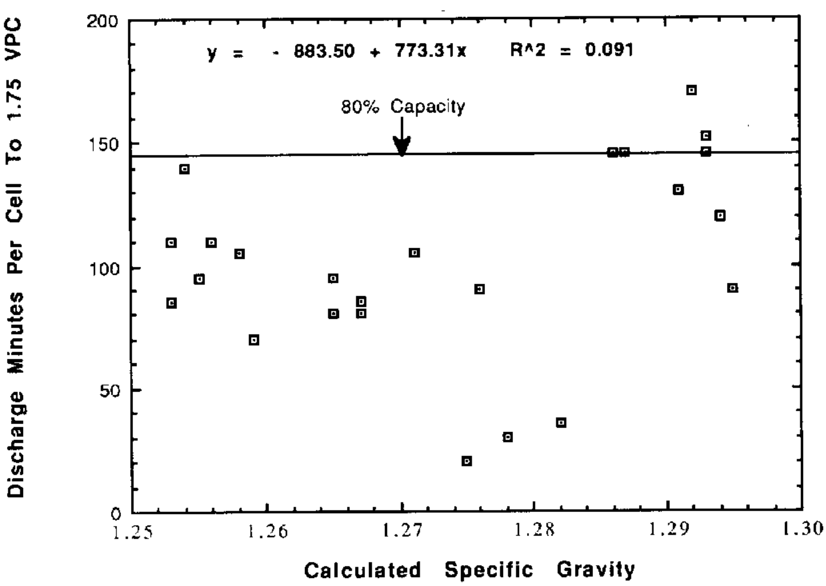


Fig. 8. Design A. Discharge capacity vs. calculated specific gravity for 1 string (24 1000-Ah cells); string no. 9; 263 A to 1.75 V per cell.

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%

Fig. 9. Box scores of float voltage vs. calculated specific gravity for 24 1000-Ah cells.

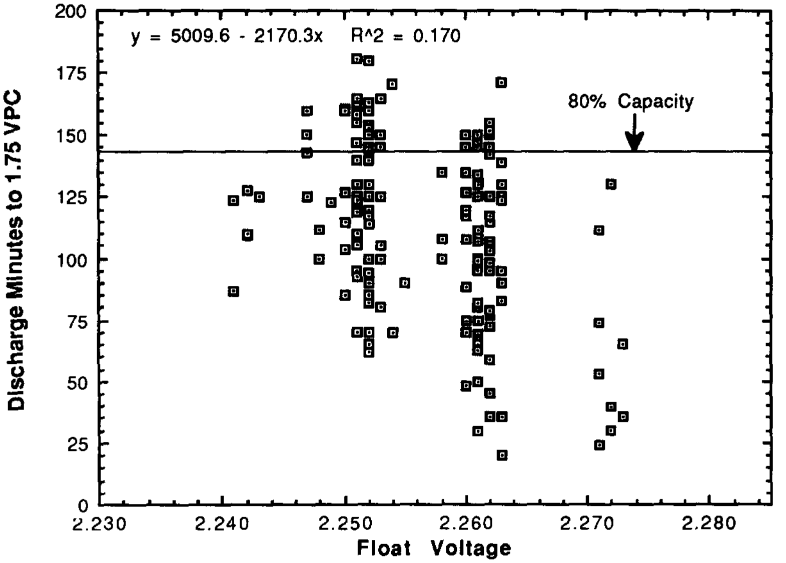


Fig. 10. Design A. Discharge capacity vs. float voltage for 7 strings (168 1000-Ah cells); strings nos. 9–15; 263 A to 1.75 V per cell.

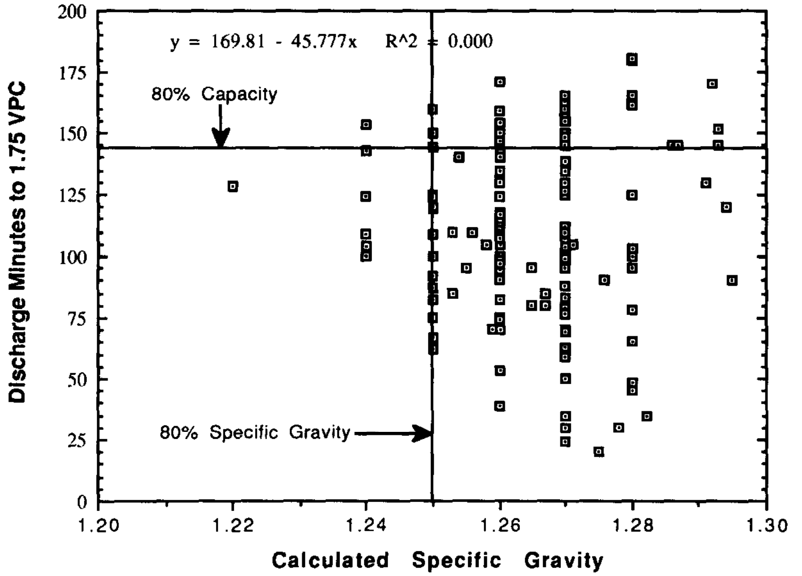
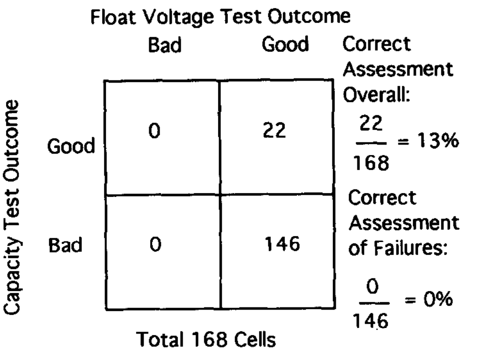


Fig. 11. Design A. Discharge capacity vs. calculated specific gravity for 7 strings (168 1000-Ah) cells); strings nos. 9–15; 263 A to 1.75 V per cell.

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 Fig. 18, for the 168 cells, shows 88% overall accuracy, and 98% accuracy in detecting bad cells. Figure 19 gives the correlation of conductance versus capacity for 336 cells of the



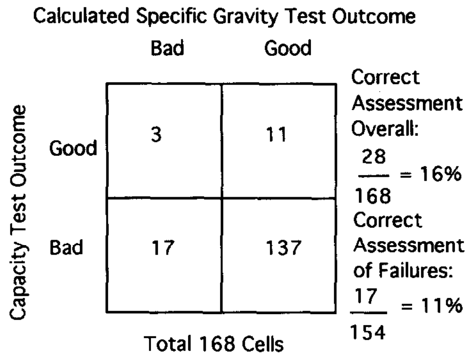


Fig. 12. Design A. Box score of discharge capacity vs. float voltage for 7 strings (168 1000-Ah cells); strings nos. 9–15; 263 A to 1.75 V per cell.

Fig. 13. Design A. Box score of discharge capacity vs. calculated specific gravity for 7 strings (168 1000-Ah cells); strings nos. 9–15; 263 A to 1.75 V per cell.

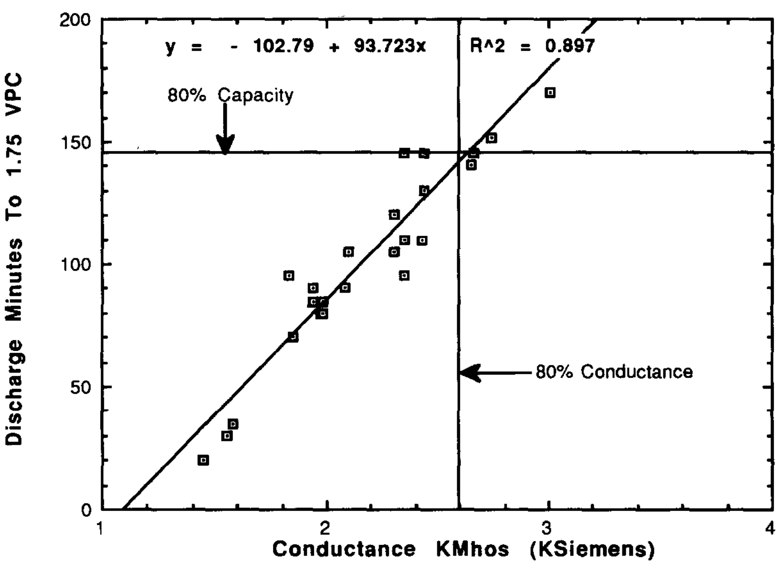


Fig. 14. Design A. Discharge capacity vs. conductance for 1 string (24 1000-Ah cell); string no. 9; 263 A to 1.75 V per cell.

entire plant; a R^2 correlation coefficient of 0.86 was obtained. Figure 20 reveals an overall accuracy of 88%, with an accuracy of 98% in detecting low-capacity cells (<80%).

In a more recent test of telecommunications VRLA (1000 Ah cell) cells of the same size but of a newer design (design B) in a different transmission plant, 192 cells arranged in 8 parallel strings were evaluated. There was a wide capacity distribution of these newer cells (see Fig. 21), with many well below both their rated (120 min) and 80% failure (96 min) values. Again conductance/capacity measurements for these cells indicated excellent correlation (Fig. 22). For these cells, the box score (Fig. 23) gave an overall prediction accuracy of 88% and low-capacity cells were predicted with

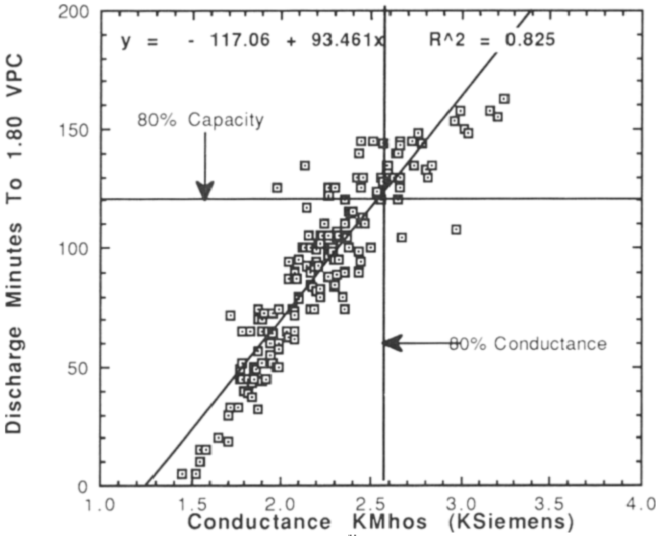


Fig. 15. Design A. Discharge capacity vs. conductance for 7 strings (168 1000-Ah cells); strings nos. 9–15; 263 A to 1.80 V per cell.

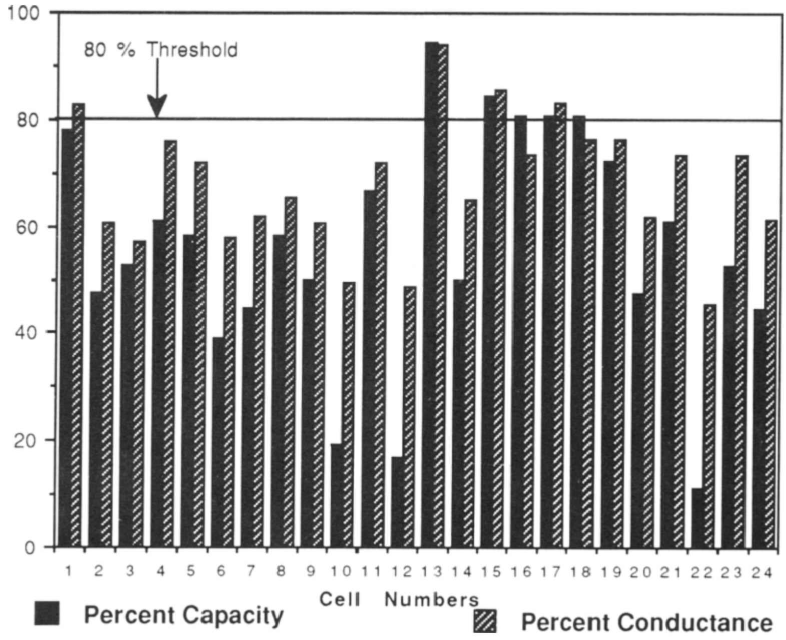


Fig. 16. Design A. Percent capacity and conductance for 7 string (24 1000-Ah cells); string no. 9; 263 A to 1.75 V per cell.

an accuracy of 96%. These results demonstrate again the effectiveness of conductance both in characterizing the capacity distribution among VRLA cells in a given power plant and in detecting premature capacity failure.

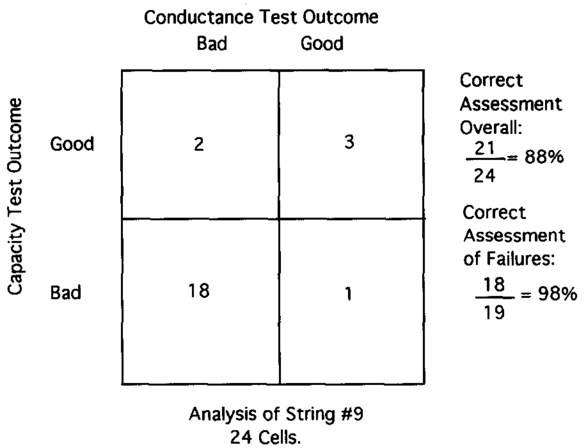


Fig. 17. Design A. Box score of conductance vs. capacity outcome for 1 string (24 1000-Ah cells); string no. 9.

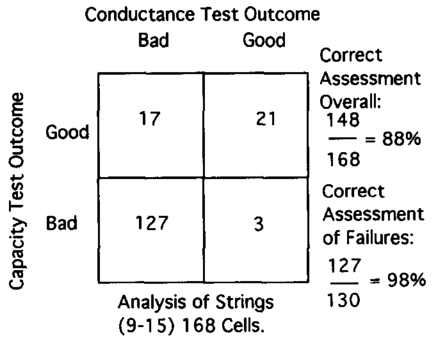


Fig. 18. Design A. Box score of conductance vs. capacity outcome for 7 strings (168 1000-Ah cells); strings nos. 9–15.

Another series of tests (design C) were performed in a UPS application containing 180, 6-year old, 6-V VRLA monoblocs of 200 Ah design. On of the three parallel strings was taken off-line to perform both conductance and discharge testing. Figure 24 shows the poor correlation of float-voltage measurements as compared with the discharge capacity results. By contrast, the correlation of battery conductance to discharge capacity again revealed excellent correlation (Fig. 25).

Field testing was also performed in railroad signal applications of VRLA 225 Ah cells. Typical ages for these cells were three to four years. A sample of 4 cells exhibiting low, medium and high conductance, together with two new cells, were sent to the Midtronics laboratory for capacity testing (design D). The correlation of conductance and discharge capacity for the six cells is presented in Fig. 26. The discharge curves for the four cells removed from the field are given in Fig. 27. Three subsequent recharge and discharge tests were performed with no appreciable improvement in cell condition, as measured by either conductance or discharge capacity.

Subsequent postmortem examination indicated subtle differences in dry-out that accounted for the difference in capacity between the lowest capacity (26 min/9%

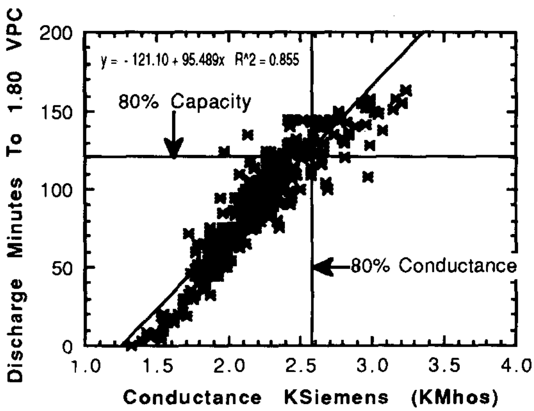


Fig. 19. Design A. Discharge capacity vs. conductance for 14 strings (336 1000-Ah cells); strings nos. 2–15; 263 A to 1.80 V per cell.

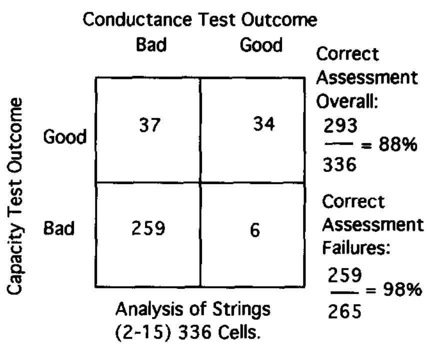


Fig. 20. Design A. Box score of conductance vs. capacity outcome for 14 strings (336 1000-Ah cells); strings nos. 2–15.

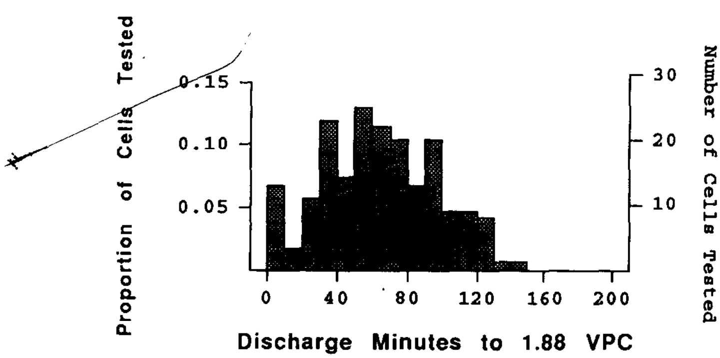


Fig. 21. Design B. Capacity distribution for 8 parallel strings (192 1000-Ah cells); VPC = V per cell.

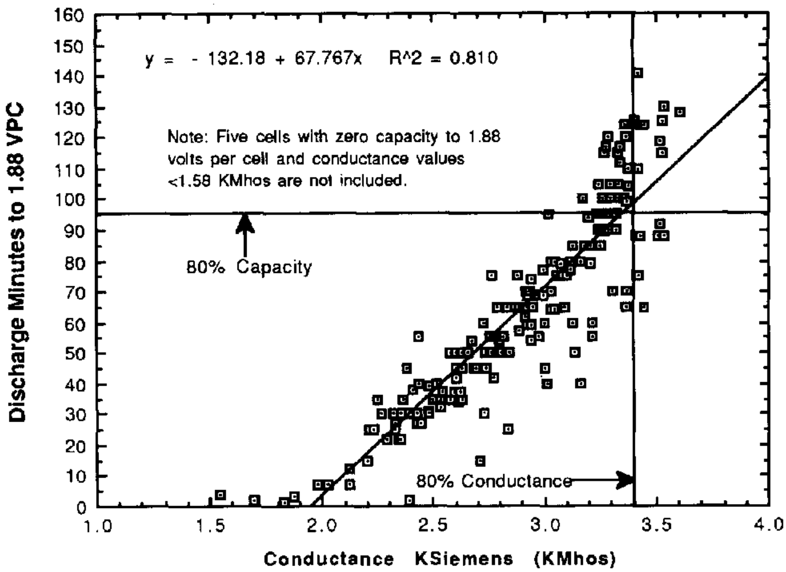


Fig. 22. Design B. Discharge capacity vs. conductance for 186 1000-Ah cells; 269 A to 1.88 V per cell.

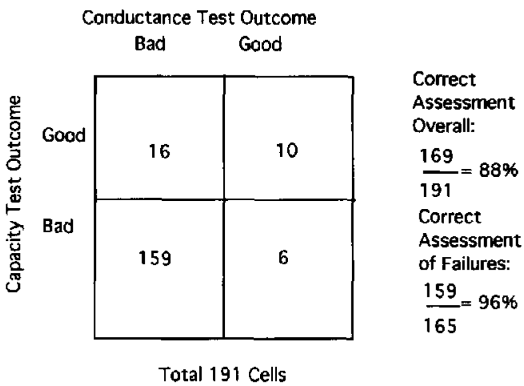


Fig. 23. Design B. Box score of conductance vs. capacity outcome; 191 1000-Ah cells.

capacity) cell and the cell that achieved (112 min/38% capacity). The differences in performance between the best (270 min/91% capacity) cell and the second worst (105 min/35% capacity) cell resulted from differences in the 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 the above studies represent only a small sample of the data collected to date on VRLA cells in a variety of applications they clearly demonstrate that: (i) VRLA cells exhibit a significant incidence of premature capacity failures (further studies are underway to determine the extent of this behaviour); (ii) neither individual

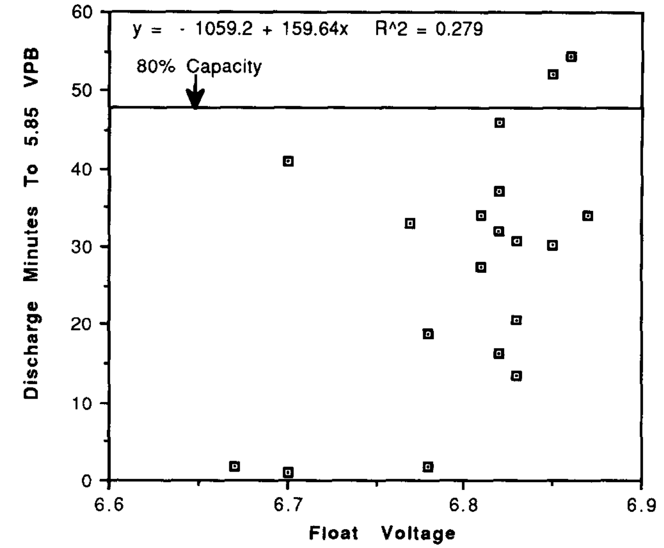


Fig. 24. Design C. Discharge capacity vs. float voltage for 180 6-year-old, 6-V VRLA monoblocs of 200 Ah; 100 A to 3.85 V per battery.

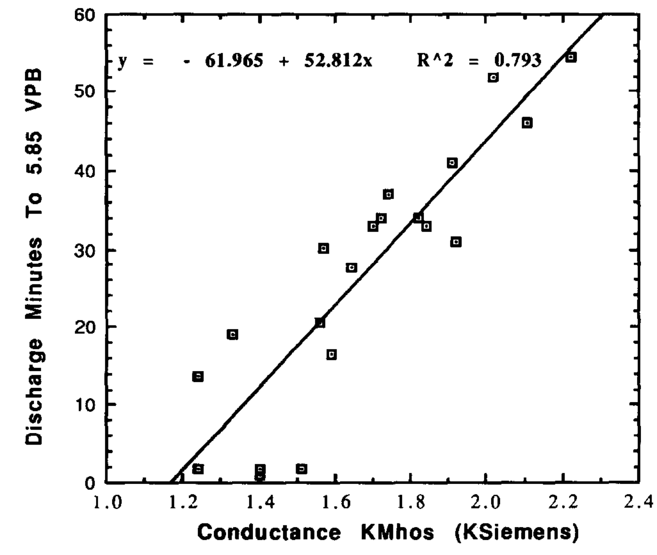


Fig. 25. Design C. Discharge capacity vs. conductance for 180 6-year-old, 6-V VRLA monoblocs of 200 Ah; 100 A to 5.85 V per battery.

cell float voltage or specific gravity can give significant early warning of cell failures; (iii) conductance measurements correlate extremely well with cell capacity and can provide early detection of premature capacity failure.

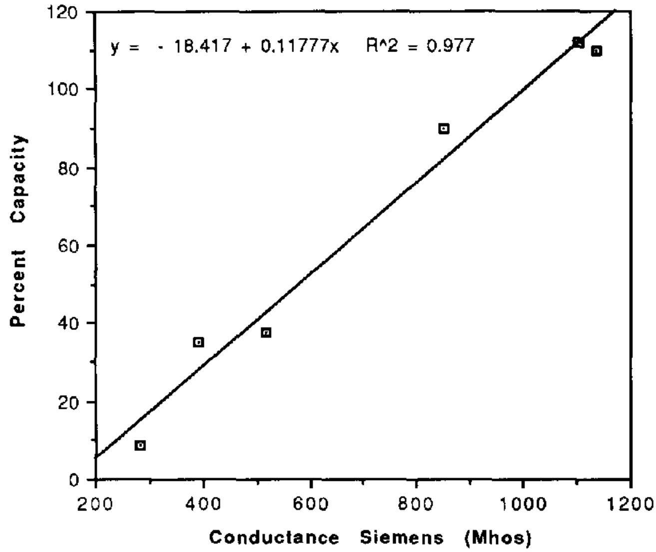


Fig. 26. Design D. Discharge capacity vs. conductance for 6 VRLA cells of 225 Ah; *C*/5 to 1.75 V per cell.

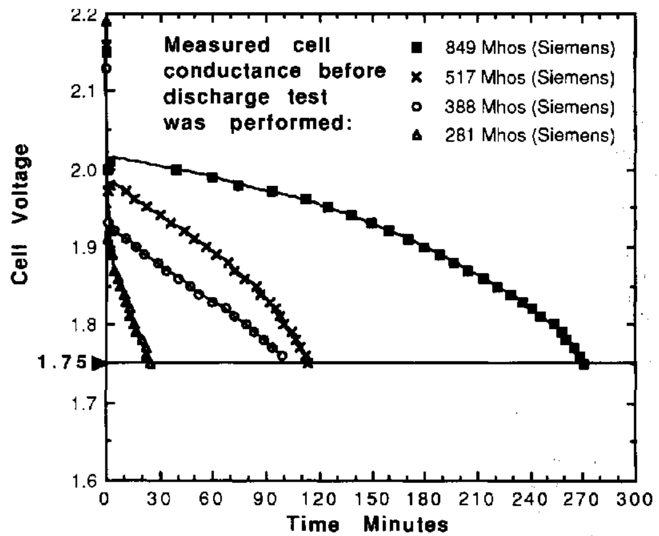


Fig. 27. Design D. Discharge curves of 225-Ah cells with various initial conductance readings; *C*/5 to 1.75 V per cell.

Tests on flooded batteries

Initial field tests were conducted in several electric utility substations on flooded batteries. Measurements of specific gravity, float voltage, conductance and discharge testing were performed. Thus far, the limited amount of data show significant correlation of conductance and capacity. The results also reveal that conductance is more sensitive to actual cell performance than traditional measurements of cell specific gravity or

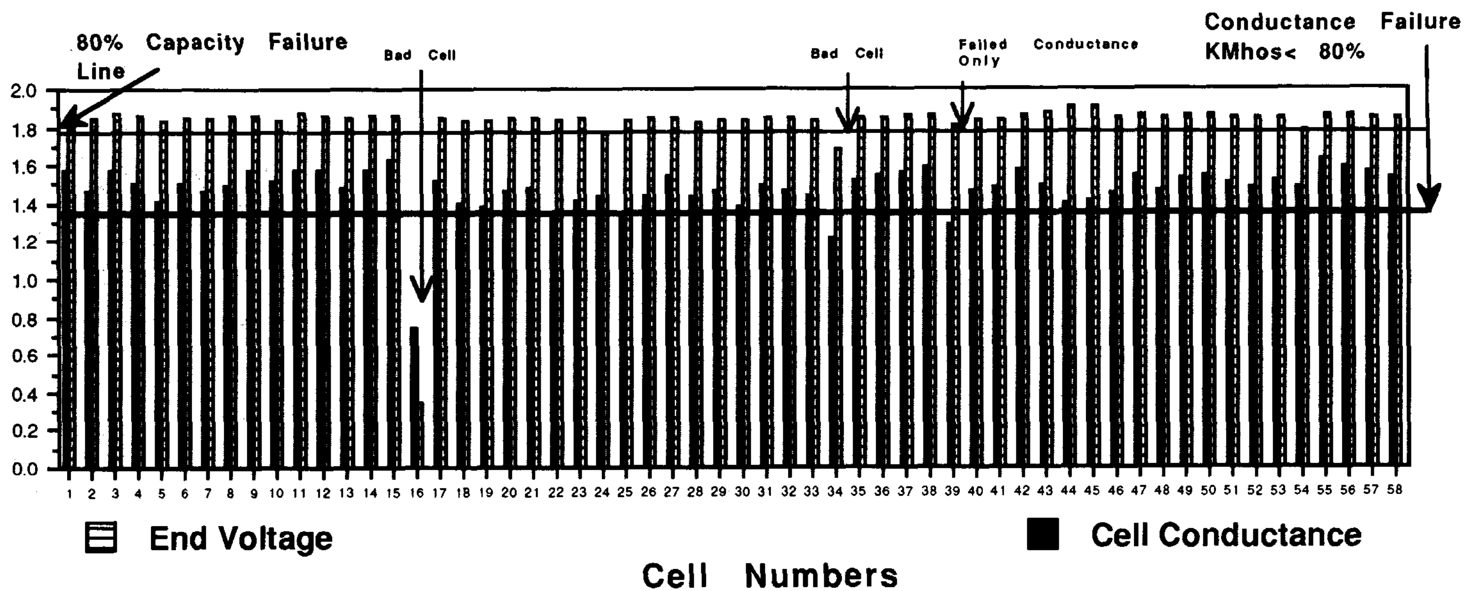


Fig. 28. Trend plot end-of-discharge voltage vs. conductance for substation no. 1 (58 flooded 200-Ah Pb–Ca cells); 98 A to 1.81 V per cell.

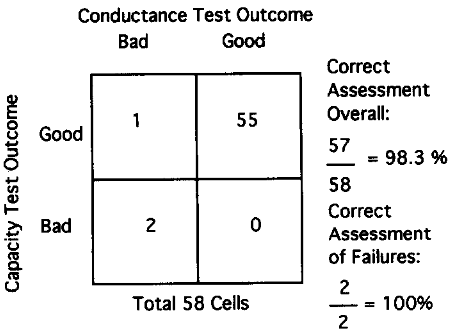


Fig. 29. Box score of conductance vs. capacity outcome of substation no. 1 (58 flooded 200-Ah Pb–Ca cells).

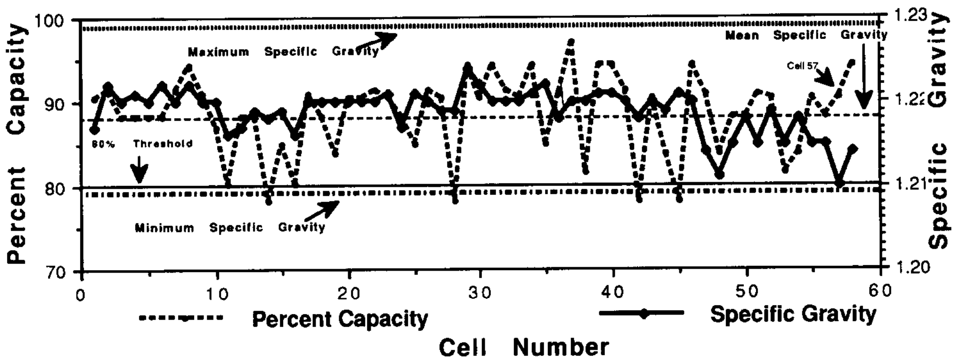


Fig. 30. Trend percentage capacity and specific gravity for substation no. 2 (58 flooded 200-Ah Pb–Ca cells).

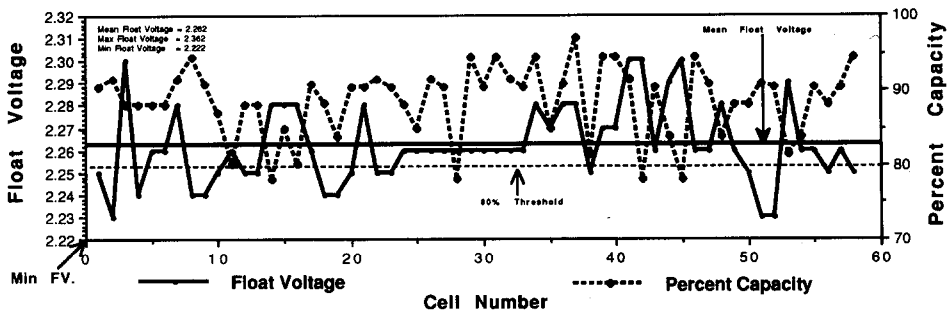


Fig. 31. Trend plot percentage capacity and float voltage for substation no. 2 (58 flooded 200-Ah Pb–Ca cells).

float voltage. The conductance measurement has been found to be an indicator of cell/battery performance and it detects cells that vary significantly in capacity from the rest of the population. 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 Ah capacity. The battery string was approximately 20 years old and of a lead–calcium grid alloy design. The test was performed at a 98 A load for 60 min to an end voltage of 1.81 V/cell. Figure 28 gives a bar graph of conductance versus end voltage at 60 min for substation no. 1. Since the end voltage at a specific time is not linear, it is difficult to draw a perfect correlation between this voltage and conductance. Nevertheless, the end voltage and conductance do exhibit close trends in behaviour. Figure 29 shows that 57 of the 58 cells meet both the conductance and 80% end-of-discharge voltage criteria. Clearly, 2 cells are shown to be poor performers by both conductance and capacity tests. One cell that failed conductance did not fail the capacity criteria. The accuracy of the resultant conductance test is extremely good at 98.3% overall and is 100% correct in the detection of poorly performing cells.

A second series of tests were conducted at substation no. 2. This battery was less than one year old and was a 200 Ah, lead–calcium design. Discharge testing was performed on the 58-cell battery at the 30 min rate to 1.75 V/cell. These data reveal the results of several measurement parameters (e.g., 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 discharged capacity, a trend analysis plot for each technique is presented. Figure 30 shows 6 cells at, or slightly below, the 80% capacity limit. For these 6 cells, specific gravity gives no indication of capacity loss. It is curious that the only specific gravity value at the low limit (cell no. 57) corresponds to a 91% capacity. For the same 6 cells (at slightly below 80% capacity) the float voltages are either at the mean or well within ± 40 mV of the mean and therefore give no indication of low capacity cells (Fig. 31). The trend analysis of conductance and percent capacity is given in Fig. 32. Both capacity and conductance are in agreement for the 6 failed cells as indicated by the arrows. While 12 cells appear to have failed conductance but not the capacity criteria, it should be noted that 8 of the 12 cells only failed conductance by 1%. Figure 33 presents the same data set as a bar graph. The results are summarized in Fig. 34 and show an overall accuracy of 80% for the conductance test and, again, 100% accuracy in detecting the bad cells. The conductance results represent a significant improvement in battery diagnostic sensitivity when compared with traditional measurements and would provide early warning to the user of poor cell/battery state-of-health.

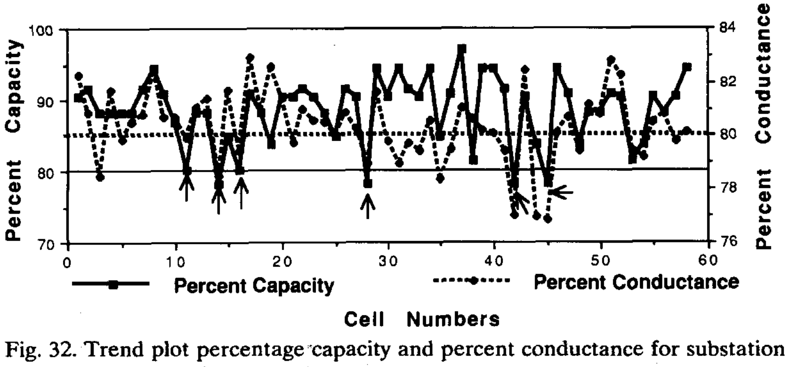


Fig. 32. Trend plot percentage capacity and percent conductance for substation no. 2 (58 flooded 200-Ah Pb–Ca cells).

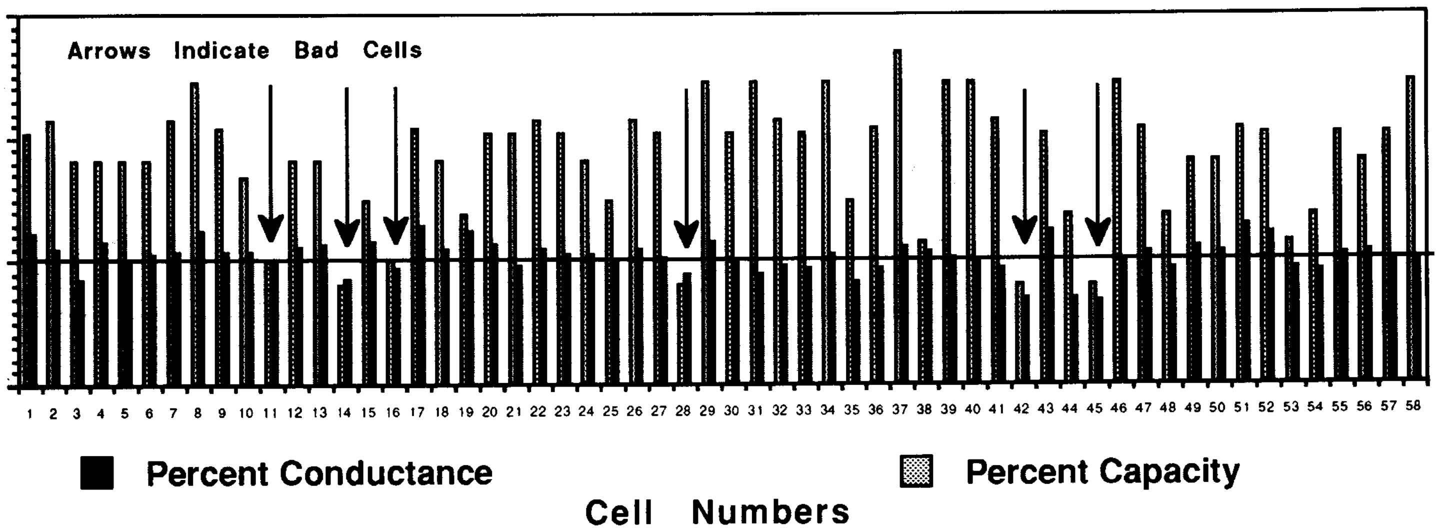


Fig. 33. Percent conductance vs. percent capacity for substation no. 2 (58 flooded 200-Ah Pb–Ca cells).

Capacity Test Outcome	Conductance Test Outcome: Bad	Conductance Test Outcome: Good
Good	12	40
Bad	6	0

Total 58 Cells

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

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

Fig. 34. Box score of conductance vs. capacity outcome for substation no. 2 (58 flooded 200-Ah Pb–Ca cells).

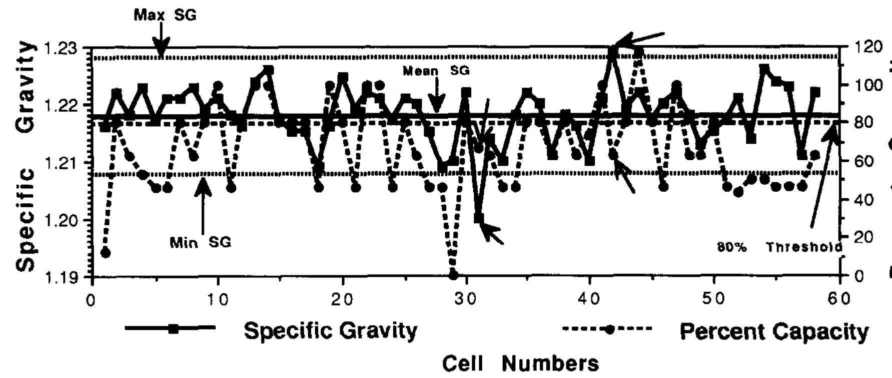


Fig. 35. Trend plot percentage capacity and specific gravity for substation no. 3 (58 flooded 100-Ah Pb–Ca cells).

The third study (substation no. 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 lead–calcium 100 Ah design. The battery was discharged at the 30 min rate (59 A) to an end voltage of 1.84 V/cell. The results are similar to those reported above. Several more cells are in poor health, however, as indicated by both timed discharge capacity and conductance. The specific gravity and percent capacity relationship is given in Fig. 35. Of the 38 low-capacity cells, only one cell displays low specific gravity, while one cell has a specific gravity above the high limit that would normally indicate high capacity. Only one low-capacity cell had a voltage below the manufacturer's recommended minimum, while one cell had a voltage above the maximum (Fig. 36). All other low-capacity cells are well within the manufacturer's recommended float-voltage range. It is curious that one cell (cell no. 19), which is below the low-voltage limit, yields one of the highest capacities. Clearly, it is very difficult to predict how each cell would perform using either measurement. By contrast, Fig. 37 shows the trend relationship of conductance and capacity and Fig. 38 shows the same data as a bar graph. The results are summarized in Fig. 39. It can be seen that 47 of the 58 cells meet both the conductance/capacity criteria. By contrast, 32 cells failed both conductance and capacity criteria, while only 6 cells that failed capacity did not also fail conductance, and 5 cells that failed conductance did not also fail capacity. The overall accuracy of the conductance test

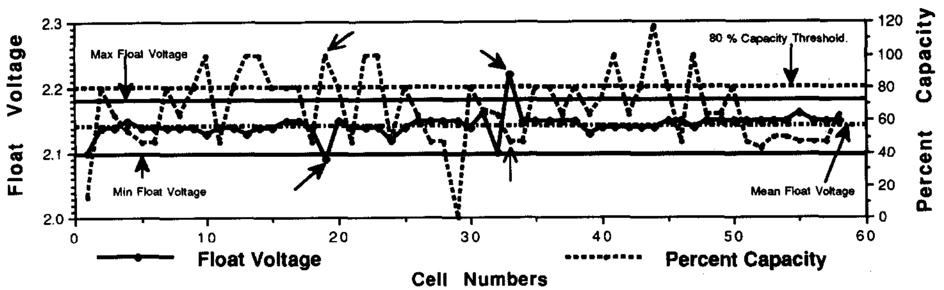


Fig. 36. Trend plot percent capacity and float voltage for substation no. 3 (58 flooded 100-Ah Pb–Ca cells).

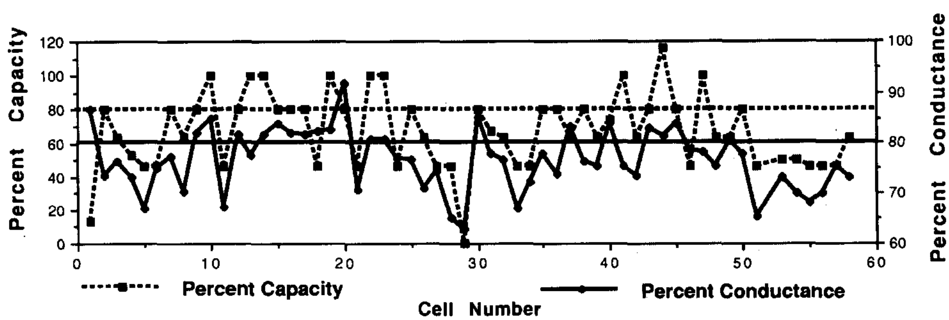


Fig. 37. Trend plot percent capacity and percent conductance for substation no. 3 (58 flooded 100-Ah Pb–Ca cells).

was 81%, and there was 84% accuracy in detecting 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.

Temperature data analysis

Temperature data revealed a strong linear relationship with a R^2 correlation coefficient greater than 0.95 for conductance and temperature (Fig. 40). The data listed is representative for a temperature range of −40 to 120 °F (−40 to 48.8 °C).

The differences in the temperature/conductance slopes of AGM, GEL and flooded cell designs are listed in Table 1. 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 resemble closely those for the flooded battery design.

While variations are observed among the 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 designs, and 0.75% per °F (1.35% per °C) for flooded and GEL designs.

Conclusions

Valve-regulated lead/acid cells

With the ever increasing usage of VRLA cells in electric utility and telecommunications stand-by service, the results of this study, and those reported elsewhere,

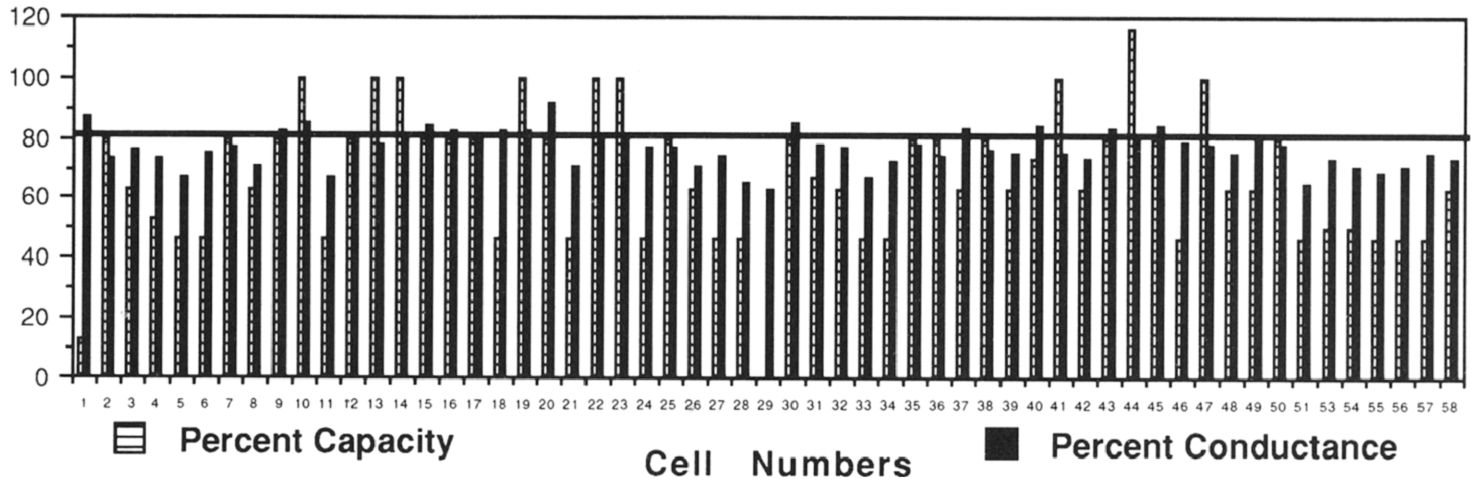
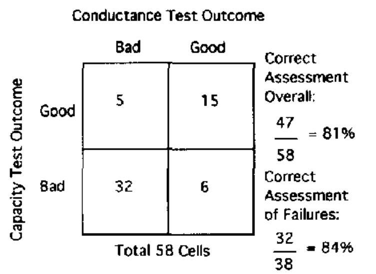


Fig. 38. Percent conductance vs. percent capacity for substation no. 3 (58 flooded 100-Ah Pb–Ca cells).



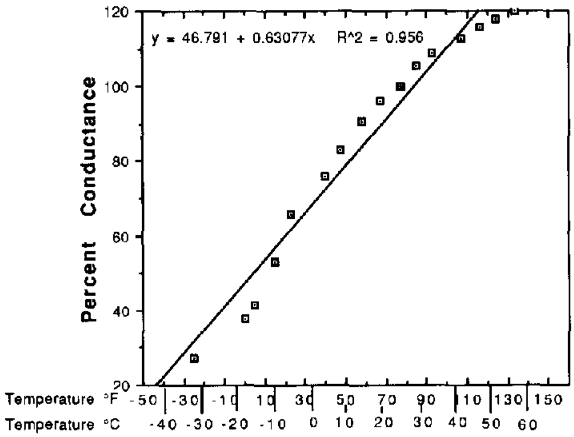


Fig. 39. Box score of conductance vs. capacity outcome for substation no. 3 (58 flooded 100-Ah Pb–Ca cells).

Fig. 40. Percent conductance vs. temperature Celltron conductance tester; flooded 100-Ah Pb–Ca battery.

indicate quite clearly that an effort is necessary to monitor their state-of-health and that conductance measurements provide the user with an appropriate technique for this purpose. Based on the results of tests on more than 700 VRLA cells that range in size from 200 to 1000 Ah, in battery strings of 24 to 360 V, and are used in a wide variety of battery plant applications that contain as many as 15 strings in parallel, the following conclusions can be drawn.

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

(ii) 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.

(iii) VRLA cells tested in this situation show a significant incidence of premature capacity failures. Further studies are currently underway to determine the extent of this condition.

Flooded 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 VRLA cells, the following observations have been made with the vented cells tested to date.

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

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

(iii) Studies of vented cell capacity/conductance correlations are continuing and will add significantly to the limited database that has been established to date.

TABLE 1

Temperature/conductance slopes for various battery designs

a) Battery design type: VRLA–AGM (Absorptive glass mat design)
Temperature bandwidth: −40 to 120 °F (−40 to 48.8 °C) used for slope characterization

Battery type/Mfg	Correction (%/°F)	Correction (%/°C)
Battery Mfg A 6 V 200 Ah	0.50	0.90
Battery Mfg B 12 V 225 Ah	0.40	0.72
Battery Mfg B 12 V 300 Ah	0.47	0.85
Battery Mfg B 12 V 95 Ah	0.51	0.92
Battery Mfg B 12 V 95 Ah	0.50	0.90
Battery Mfg B 12 V 95 Ah	0.51	0.92

b) Battery design type: VRLA–GEL (gelled-electrolyte design)
Temperature bandwidth: −40 to 120 °F (−40 to 48.8 °C) used for slope characterization

Battery type/Mfg	Correction (%/°F)	Correction (%/°C)
Battery Mfg B 12 V 100 Ah	0.73	1.31
Battery Mfg B 6 V 200 Ah	0.67	1.21
Battery Mfg B 12 V 31 Ah	0.75	1.35
Battery Mfg B 12 V 31 Ah	0.74	1.33

c) Battery design type: flooded lead–calcium, 1.215 sp.gr.
Temperature bandwidth: −40 to 120 °F (−40 to 48.8 °C) used for slope characterization

Battery type/Mfg	Correction (%/°F)	Correction (%/°C)
Battery Mfg C 6 V 100 Ah	0.712	1.28

Measurement techniques

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

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