Impedance/Conductance Measurements as an Aid to Determining Replacement Strategies

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Abstract - When to replace your battery is a critical and inevitable decision for the battery user. Replace too late and reliability of the battery and the systems they serve to protect will be degraded resulting in the inevitable service failure. Replacement too early increases costs unnecessarily, and with typical VRLA battery life being between 4-8 years, depending on operational temperature, even a short time period can be a significant percentage of whole life costs.

For the manufacturer, replacement decisions also present a dilemma: The replacement business would certainly be appreciated whilst on the other hand, repeat business may well depend upon customer satisfaction in achieving reasonable life and reliability in the first instance.

This paper describes the importance of modern battery monitoring techniques and the interpretation of data that can assist the battery User in determining a coherent and cost effective battery replacement strategy.

I INTRODUCTION

The subject of Impedance and/or Conductance measurements has attracted controversial debate for more than 10 years. The instrument manufacturers have extolled the virtues of this technique as a "fuel gauge", whereas the battery manufacturers have had grave doubts about the capability of the technique to measure battery performance to the nearest 20 percentage points. In the middle of this debate, is the User who needs some quantitative method of appraising his V.R.L.A. battery stock, but is unable to find a solution to his problem.

BT have been studying the "A.C. Characteristic" (Impedance and/or Conductance) of V.R.L.A. batteries since the late 1980's [1,2,]. In this work, attention was drawn to the obvious lack of definition between recorded capacity and the measured "AC Characteristic". A typical example of this feature is reproduced in Fig.1 where it can be seen that a variation about the mean of 30% exists for conductance and 25% for time.

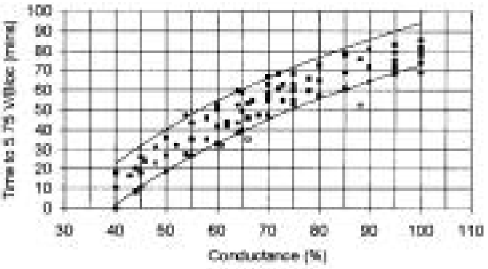

Figure 1. Depreciation of performance with Conductance during Battery Service

It was however a very useful technique to use in a qualitative manner, and as a consequence, in joint investigations with their suppliers, and an update of this work was published [3] at Intelec 94. In this work, a comparison was made between the "AC *Characteristic" measured on a series of V.R.L.A.* blocs and using three different types of instrument.

This information is reproduced in Fig. 2.

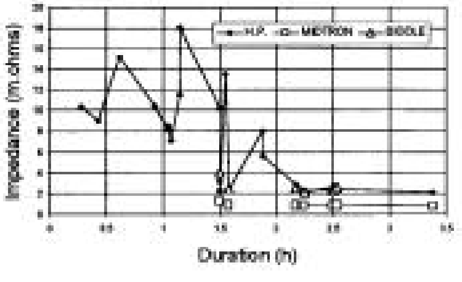

Figure 2. Comparison of Instruments.
Intelec 94

In addition, attention was drawn to the effects of "State of Charge" in relation to the measured "AC

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Characteristic", and this information is reproduced in Fig.3.

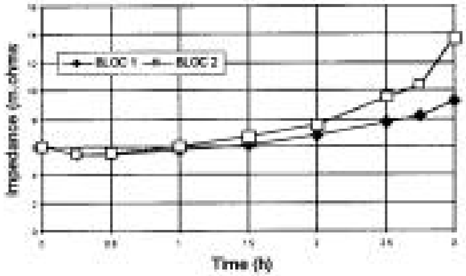

Figure 3. State of Charge of Blocs. Intelec 94

From this work it was concluded from the results in Fig. 2 that :-

If all instruments were appraised on a common basis, then their indicated measured values were comparable in relation to the measured capacity of the battery.

and from the results in Fig. 3 it was concluded that :-

Enormous errors could be made if the measurement of the "AC Characteristic" was carried out in any condition other than the fully charged state.

Investigations have continued on a joint basis for the past four years and this paper provides an update on the developments that have taken place in the use of "AC Characteristic" techniques, and their consequent use in the formulation of Replacement Strategies.

II MEASUREMENT PROCEDURES

The quality of the "AC Characteristic" measurement is fundamental to the development of a relationship between it and the battery performance, which in turn is one of the principal issues supporting a replacement strategy.

Where portable measuring instruments are used to measure the "AC Characteristic" measurement is influenced by the effectiveness of the "clip on" connector and the location at which the measurement is made.

In order to quantify the quality of this measurement, an experiment was arranged using 8 blocs of each of two different V.R.L.A. products but using the same pillar arrangement as required by the BT type approval. Two types of instrument were used in the exercise, one of the "conductance" type and the other of the "impedance" type.

The pillar connecting nuts on all the blocs were "torqued" to manufacturer's requirements, and the location of the measurement was across the "flats" of the connector nut. In all cases the measurements were made by the same person, in a laboratory environment. A set of six measurements was made on each bloc of eight blocs for both types of V.R.L.A. battery.

The average value, standard deviation, and range (6 x standard deviation), were calculated for each set of measurements 1 to 6 for each bloc. Similar values were calculated for each series of blocs 1 to 8 at all readings 1 to 6 in turn. The most important factor in this evaluation is the "Range" and the value for the "Range" has been expressed as a % of the relevant average value, in order to eliminate natural differences in values arising from different instrument technologies. These values are shown in Table 1 for the sets of repeat readings per bloc; Table 2 for the series of readings per 8 blocs; and Table 3 for the combined population of sets and series readings.

Table 1 Ranges arising from sets

Product Type	Range - % of the mean			
	Conductance Instrument		Impedance Instrument	
	Max	Min	Max	Min
VRLA1	4.9	0	13.0	1.6
VRLA2	8.8	0	11.2	4.0

Table 2 Ranges arising from series

Product Type	Range - % of the mean			
	Conductance Instrument		Impedance Instrument	
	Max	Min	Max	Min
VRLA1	12.0	11.3	14.6	9.0
VRLA2	14.5	10.6	11.4	2.7

Table 3 Ranges arising from all data

Product Type	Range - % of the mean	
	Conductance Instrument	Impedance Instrument
VRLA1	11.1	10.7
VRLA2	11.4	9.4

From this exercise, Table 1 would indicate that from a repeatability of measurement view point the conductance instrument would be preferred in comparison to the impedance instrument. However, in Table 3, the overall results show a fairly close comparison between both instruments. The difference between the Max Min range % values in Table 2 would indicate a little more consistency in favour of the conductance instrument in comparison to the impedance instrument.

It should be noted however that for portable "clip on" type instruments the smallest range of the mean values for the "AC Characteristic" , obtained under ideal conditions is of the order 10.5%.

As a separate exercise, 30 different blocs were measured for conductance in laboratory conditions by three different personnel, and the results showed that average values agreed to within ± 0.33% and the range of the results expressed as a % of the average values agreed to within ± 1.5%.

This would indicate that under ideal conditions the smallest % range of the mean value for the "AC Characteristic" would increase from 10.5% for one person measurements to 11.0% for multi-person measurements.

The quality of measurements has so far been determined under ideal laboratory conditions. However, under operational conditions, where it is often difficult to achieve the recommended "clip on" location, the smallest % range of the mean value of 11.0% can no longer be sustained. A recent exercise involving six fairly new batteries of eight blocs per battery, indicated that the smallest % range of the mean value could be between 12% and 18%. It should be noted however that the batteries were between one and three years old, and the wider % range values do reflect the condition of the older batteries.

Reference has already be made to the use of average % values to eliminate natural differences in instrument technologies and this has to be considered as part of the "Quality of Measurement" issue, particularly when measurements have to be taken over the replacement cycle of the product life. The actual value for the "AC Characteristic" is known to depend upon the following parameters:

- The frequency of operation.
- The level of AC current injected into the bloc/battery.
- The level of current discharged from the bloc/battery. (For those instruments using the test sample as a source of power).

All these parameters should remain constant throughout the product service life, otherwise the quality of measurements will be impaired to the extent that both average and % values will depart from the relationship between "Performance" and "AC Characteristic" to the extent that defining limits for a "Replacement Strategy" could become impracticable.

III DEFINING LIMITS

Given the conclusions of the "Quality of Measurements" review it would appear that there may be possibilities of accommodating the wide variation in bloc characteristics in terms of the average bloc value, and allowing this value to be related to the electrical performance of the battery.

It was therefore necessary to establish whether or not there was an acceptable relationship between Average bloc duration; Battery duration; "AC Characteristic"; over the service life of the battery.

As during the first two years of BT operational service there is little change in the battery characteristics, batteries were selected representing commencement of service in 1995, 1994, 1993 and two batteries in 1992. Each battery consisted of eight blocs and prior to any discharge testing it was established that the battery was at the "Top of Charge" condition and individual conductance measurements were taken of each bloc in the battery. The discharge was performed at the BT rate of discharge of 50A to an end voltage of 5.25 V. per bloc (42 volts per battery). The battery duration was recorded to 42V and the individual bloc durations were recorded to 5.25 V. per bloc. Average values were then calculated for bloc duration and conductance and these results together with the battery duration, and relevant battery service are shown in Table 4.

Table 4. Performance – Conductance and Life

Service	Battery	Bloc Performance	
(Months)	Duration (mins)	Conductance AVG (%)	Duration AVG (mins)
39	100.2	99	104.69
49	100.5	106.13	103.50
61	90.5	88.43	93.63
70	80.5	74.88	81.50
74	78.0	68.13	79.25

The same data is shown in Fig.4 where it can be seen that a usable relationship exists between battery duration, average bloc duration and conductance.

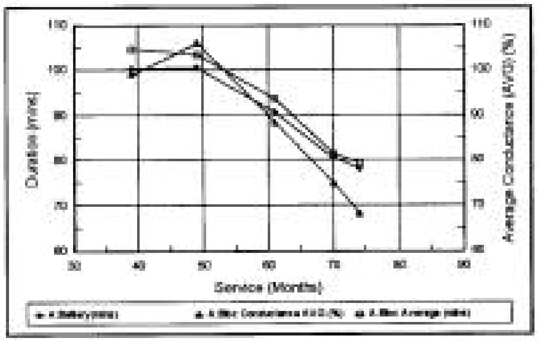

Figure 4. Performance and Conductance with Battery Service in BT Operation

It should be noted however that the service values reflect BT operational service which means that battery temperatures can vary between 25°C and 35°C.

In conclusion therefore it would appear possible to arrive at acceptance/rejection limits suitable for BT operation, which can be used to support a Replacement Strategy.

IV OPERATIONAL ENVIRONMENT

Having reviewed the quality of measurements and described a technique for the determination of acceptance/rejection limits, the outstanding issue is their application to operational service. This requires the definition of a typical operational service life from which replacement strategies can be deduced. As the most important factor affecting operational service life is operational temperature, which is variable throughout any one year, a method of defining a typical operational temperature is essential.

Because battery service life is reduced by one half for every 10°C rise, a "typical operational temperature" cannot be defined as the arithmetic mean between the maximum and minimum operating temperatures observed over a 12 month period. The whole of the temperature/time profile has to be considered for the 12 month period and the "typical operational temperature" is based upon the temperature (T)/life factors (F) shown in Table 5.

Table 5. Temperature (T)/Life Factors (F)

(T) °C	F	(T) °C	F	(T) °C	F
20	1.00	27	0.62	34	0.38
21	0.53	28	0.57	35	0.35
22	0.87	29	0.53	36	0.33
23	0.82	30	0.50	37	0.31
24	0.76	31	0.47	38	0.29
25	0.71	32	0.44	39	0.27
26	0.66	33	0.41	40	0.25

From operational temperature/time profiles generated from 12 month field data a "typical operational life factor" F_{typ}, for that profile is:

$$F_{typ} = F_{T=20,} + \sum_{t=20}^{t=40} \frac{t}{F}$$

where (t) is the proportion of time at temperatures (T) °C, between 20°C and 40°C and (F) is the relevant life factor obtained from Table 5.

Having deduced the typical operational life factor F_{typ} this value can then be used to determine the typical operational temperature F_{typ} by back reference to Table 5, or, to calculate the product replacement period by multiplication of the product "Design Life" by F_{typ}. Given this information, it is now possible to develop a product "replacement strategy".

V REPLACEMENT STRATEGIES

The proceeding sections have identified the quality required of the measurement procedures, and a method has been given to define operational limits. Most importantly, we have quantitatively defined the operating temperature conditions that adversely affects battery life. These are the essential ingredients to formulate a battery replacement strategy.

One extreme strategy could be to replace individual battery systems as and when they fail the prescribed criteria. At the other extreme, automatic replacement on a fixed time basis may be a more suitable option. BT along with other users operates a combination of these extremes but common to both is the essential need for an accurate battery inventory. Such an inventory should contain essential data such as battery make, type, age and location so that financial and logistical management is possible.

The proposals in this paper assume that "normal" corrosion deterioration with service life is taking place. This should not be confused with the use of the conductance/impedance instrument as a diagnostic tester for which other methods of analysis are more appropriate.

However, it is possible to enhance V.R.L.A. battery reliability by monitoring conductance/impedance data, together with an appreciation of environmental conditions and the corresponding limits on V.R.L.A. technology that dictate when replacement is required.

VI CONCLUSIONS

This paper has shown that two particular parameters, namely conductance/impedance monitoring and temperature/time/life factors can be effective in forecasting battery replacement timescales. Users are advised to interpret conductance/impedance data carefully, paying particular attention to the "battery state-of-charge" the variability of instrument readings and the effectiveness of the method of connection onto the battery terminals.

The use of temperature time factors has been explained in a way that users can anticipate expected life, by doing so they can formulate budgets for a timely and cost effective battery replacement programme that maintains and protects their vital networks.

ACKNOWLEDGEMENTS

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