Studies into the capacity retention behaviour of VRLA batteries used in telecommunications applications

J.M. Hawkins and R.G. Hand[†]
Telstra Research Laboratories
PO Box 249 Rosebank MDC
Clayton Victoria, 3169
Australia

Abstract This paper reports on the results to date of a study into differences in the float behaviour and capacity retention characteristics between 48V battery banks composed of 2V cells and 12V monoblocks. A comparison of the float voltage behaviour observed by continuous logging and capacity trends over time determined by annual intervention discharging is presented. Considerable differences in the capacity retention behaviour over the first 30% of rated service life between the two types of batteries have been observed.

Introduction

The VRLA battery is now generally the battery technology of choice in standby applications in Telstra. It should be noted that this probably is driven more by wider network issues than an acceptance of the claimed performance of VRLA battery technology. Telstra operates a diversity of standby applications. Customer and equipment compatibility requirements together with substantial reductions in traditional telepower network maintenance resources now demands the use of VRLA battery technology. This is even in the face adequate evidence of higher capital costs and shorter service-life compared to the traditional vented lead-acid battery. The widespread use of VRLA batteries in Telstra has been relatively recent compared to other tele-communications operators [1,2]. The average age of the current generation of in-service VRLA cells is now about 5 years. Yet, even for the "quality cells" in the current population operating in optimum environmental conditions, the predicted service-life is estimated to be at best 7-8 years. This is still considerably less than the claimed performance of some of these "quality cells".

More generally, the reported reliability and service life of VRLA cells on standby service is variable, and typically observed to be less consistent than that for vented cells [6]. Series-connected VRLA cells on standby service have been observed to exhibit wider distribution of float voltages compared to the benchmark behaviour of vented cells. Interest in float behaviour in relation to service life performance originates from the historical understanding and use of float conformance as a maintenance tool with vented cells. Expectations and explanations of float conformance of VRLA battery strings are varied [3-5]. However, it is important to understand the value of float voltages and float behaviour in developing productive maintenance routines for VRLA batteries. Often, recording terminal voltage measurements is the only routine maintenance activity carried out on battery strings. Indeed, many battery monitoring systems only automate the measurement of cell or monoblock terminal voltages. There is an assumption that float voltage measurements of VRLA cells alone is a valuable and productive activity in providing a degree of confidence about expected reserve times. However, this has not yet really been established.

The work presented in this paper is part of a previously reported program to better understand governing factors which influence the in-service float behaviour of VRLA batteries in the Telstra network [7]. In this paper, results from studies of the float conformance and capacity retention behaviour of two different types of battery installation are reported. The results to date support previous reports that the float voltage behaviour conveys little valuable information as to the capacity retention and state of charge of the cells within the battery strings. The results also lend support to the anecdotal evidence that better service life may be expected from a 2V cell than from a 6V or a 12V monoblock package.

Experimental

This study involves a comparison of the operational and capacity retention characteristics of two different standby battery installations strings operating under manufacturers' recommended conditions. The make of battery at the two installations is different, but both are AGM VRLA technology, marketed as quality 'telco' batteries with 10 or more years claimed design (service) life operating at 25°C. One type of battery is in the 2V footprint.

[†] Now with :-
Telepower Australia Pty Ltd
PO Box 49 Knoxfield MDC, 3180
Victoria, AUSTRALIA
e-mail: telepower@telepower.com.au

The other type is a 12V monoblock. Both types are similarly priced on a $/Ah basis.

One installation consists of 3 parallel 48V strings of 2V 3300 Ah cells and is part of an large, in-service 4000A centralised dc system, currently supporting a critical telecommunications load of 2400A. The 48V bus system is supplied from a suite of 200A switch-mode rectifiers fitted with active temperature compensation float control. The power system is housed in a high quality air-conditioned controlled environment operating at approximately 25°C. The batteries are floated at 54.0V (2.25Vpc), which the standardised float voltage applied to all Telstra's standby lead-acid batteries operating in controlled environments. This float voltage is slightly higher than the manufacturers recommended 2.23 Vpc for 25°C. The float control voltage is set at the rectifier suite. Remote sensing of the battery voltage is not used. All cells were purchased as new at the time of installation, but 9 of the 72 cells were from a more recent production batch and about 6 months younger in age. The younger cells were all placed as adjacent cells in the one string (*bank 3*).

Due to the critical nature of this particular installation, the characteristics of the power system and performance of the batteries are being closely monitored [7,8]. Continuous high-resolution remote monitoring using an advanced intelligent monitoring system is being used to trend and predict battery performance [9]. Annual C_3 string capacity tests are carried out to confirm the site reserve time and to provide capacity information to help in the development of predictive algorithms. For the capacity tests, each string is separately taken off-line and then discharged on-site (as a 48V series-connected string) at the C_3 rated current using portable resistive loads. The capacity discharge procedure is repeated identically in each test. The capacity performance of each of the 24 cells in the string is automatically logged by the monitoring equipment. The string is recharged to approximately 90% of discharge capacity before being returned to the system bus. The tested string attains a total of more than 105% recharge of the discharge capacity (*i.e*. fully charged) within 72 hours of float at the bus voltage.

The other battery installation in this study is laboratory-based and consists of three parallel 48V strings of 12V, 75 Ah monoblocks. The monoblocks were all supplied as new at the start of the study, but batching codes indicated that 4 monoblocks were 3 months older than the other monoblocks. The younger monoblocks were grouped together to form one of the strings *(Bank 3).* The batteries have been floated at 54.0V (2.25Vpc) by a single 50A switch-mode rectifier fitted with temperature compensation float control. This type of monoblock and rectifier are both commonly used in the Telstra network. Remote sensing has not been used, but the connection distance between the batteries and the rectifier is less than 2 meters. This battery bank has been floated under air-conditioned controlled laboratory conditions between 23-25°C. The float behaviour of the battery has been determined by continuous logging (using high-resolution data-loggers) of all monoblock terminal voltages, the string currents, all monoblock temperatures and the ambient temperatures. The C_3 constant current capacity of each of the individual monoblocks has been determined periodically using a very accurate automatic battery test facility [10]. Each monoblock has been recharged as per manufacturers' specification to approximately 107% of the discharged capacity before being returned into float service in the original battery string. Due to opportunities in the laboratory environment (which are not available at the 2V installation), the capacity determination of each monoblock have been confirmed by a repeat test discharge cycle.

Capacity measurement results in this paper are normalised to the manufacturer's claimed C_3 capacity at 25°C. The average of the two C_3 determinations for the monoblocks is reported

Results and Discussion

A considerable amount of data and information is available with continuous logging facilities. The focus of this report is on inspection of the extent of correlation with float behaviour and measured capacity.

Figure 1a tracks the float voltage behaviour of the highest and lowest floating cells in the 72 2V-cell

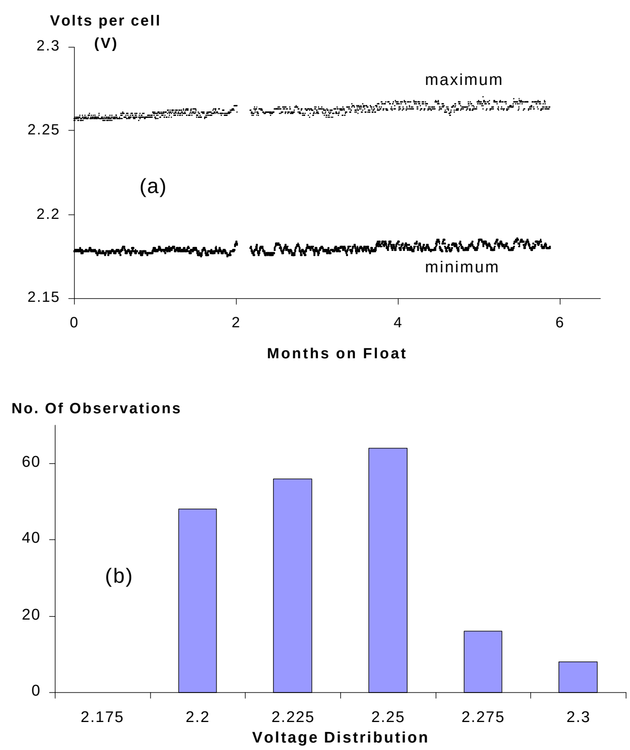

Figure 1 Float voltage behaviour of 2V cells in a 48V battery bank. *(a)* 6-month trend; *(b)* cell float potential distributions

population, over the 6 months prior to the most recent test discharge. The float potential of all the other cells in the installation fall within this "band". The band of float voltages is seen to slowly diverge over the six months prior to the discharge test. This type of trend was typical behaviour with the previous discharges. *Figure 1b* shows the distribution of the cell float potentials at the end of the float period just prior to the discharge test. It is of interest that the mean float voltage at the cells is approximately 2.23Vpc, significantly less than the 2.25Vpc set at the rectifiers. This is caused solely by the voltage drop in the extensive bus system and the lack of remote voltage sensing at the battery strings. The strings each experience different physical bus lengths from the rectifiers. Two of the three strings are approximately the same distance from the rectifiers, while the third is "closer". This is reflected in the "skewed" normal distribution characteristic caused by having a greater number of cells floating less than 2.25Vpc. Nevertheless, all cells are within ±75mV of the nominal bus voltage. This range is not exceptionally high but coupled with the divergent trend, these cells may be expected "to float better."

The float behaviour of the monoblocks in the other battery installation in this study is shown in *Figure 2*. The voltage trend of the highest and lowest floating monoblocks in the monoblock population over the 6 month period prior to the most recent test discharge can be seen in *Figure 2a*. The trend is clearly convergent. The range between highest and lowest float voltages

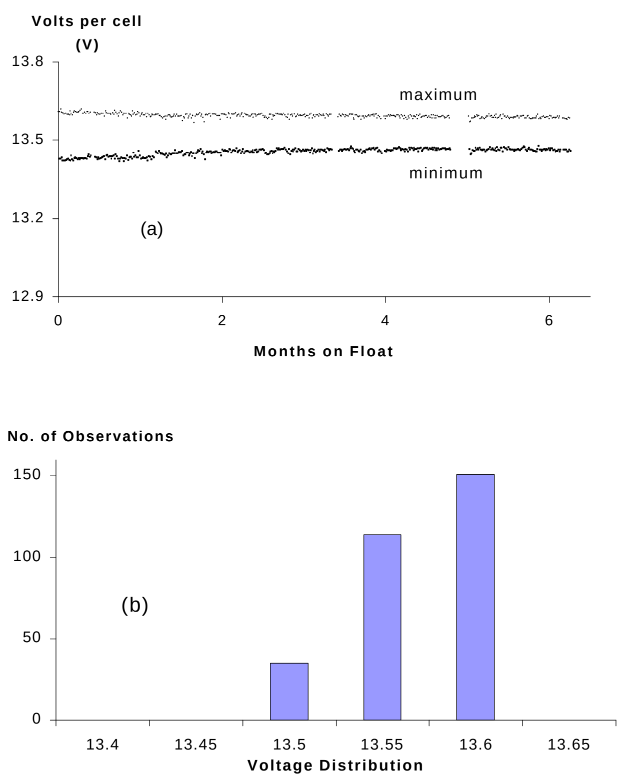

Figure 2 Float voltage behaviour of the 12V monoblocks in a 48V battery bank. *(a)* 6-month trend; *(b)* cell float potential distributions

towards the end of the trend period is a remarkably small 100mV, implying an average cell float range of less than 20 mV. This float behaviour is consistent with some previously reported expectations following time on float after a discharge cycle [5]. Such behaviour alone may lead to the conclusion that the monoblocks are floating exceptionally well and thus underpin expectations that the monoblock strings should deliver rated capacity. The distribution of monoblock voltages within each battery string is shown in *Figure 2b*. The distribution is clearly not normal as might be expected. In comparison with the distributions in the 2V, 3300 Ah battery installation, it may not be valid to conclude that all is well with these monoblocks.

Capacity trends

Figure 3 shows the capacity determinations of the 2V-cell installation since the commissioning of the battery. The distribution of measured capacities of the 72-cell population is shown in *Figure 4*. For comparison, the capacity trend over nearly 4 years of periodic capacity determinations on the laboratory-based 12V monoblock battery strings is shown in *Figure 5*. The distribution of the capacities of each of the individual monoblocks for each of the test discharges are shown in *Figure 6*.

As can be seen there is considerable difference in the performance between the 2V-cell system and the 12V monoblock system. For the 2V-cell system, the bench-mark commissioning capacity (first discharge) is about 10% above the rated capacity of the battery, and is remarkably consistent for all three strings. However, the distribution between individual capacities (*Figure 4a*) at commissioning is wider than indicated by the very narrow spread in the overall string capacities. Some of the wide distribution is attributable to the 9 (younger) cells in *Bank 3*.

The capacity of each of the three 2V-cell strings has increased by nearly 10% from the commissioned capacity within the first year of float service (*Figure 4b*). Moreover, the range of individual cell capacities after the first year or so on float has converged and all cells in the installation have capacities within about 5% of the mean capacity. This increase in capacity within the first 12 months or so of float operation is expected behaviour for AGM VRLA batteries, but such a decrease in the distribution of capacities is not always observed [3,5].

It is particularly pleasing that the shift observed here has applied to the entire 72-cell population. At the third discharge, there is a small decrease in the average string capacity compared to the previous year, and the capacity of one of the strings (*Bank 2*) appears to be emerging as slightly lower than the other two. However, the distribution of individual capacities (*Figure 4c*) has again improved, albeit slightly, and the installation is characterised as consisting of cells with remarkably similar capacities. Indeed, the float voltage range of the 2V cells prior to the most recent discharge test
(*i.e. Figure 1*) might have been expected to have more

in common with the relatively wide discharge capacities at commissioning (*Figure 4a*) than with the very narrow range of capacities measured on the third discharge. The point is, that for these particular cells, there does not appear to be any correlation at all between float voltage behaviour and the cell capacity. But clearly, this is a very healthy battery installation.

For the 12V monoblock results, the situation is quite different. Any sense of comfort that might have been taken from the narrow distribution and convergent behaviour of the monoblock float voltages (*ie Figure 2a*) is shattered by the capacity results.

As can be seen from *Figure 5*, while the monoblock string capacities were above rated performance at commissioning, the capacities of all three strings quickly fall off. At the third discharge at about 3.5 years age, there is considerable difference between string capacities, and the average string capacity has failed the standard 80% capacity end-of service life. While the

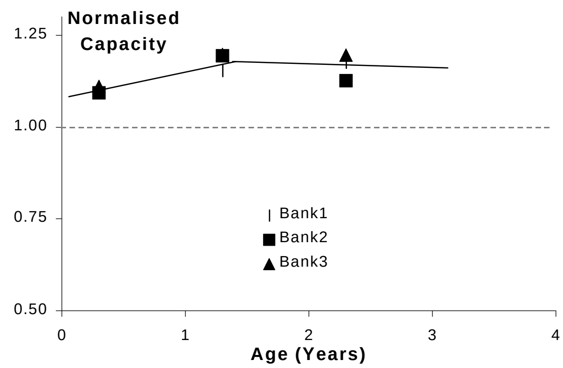

Figure 3 Capacity trend for the 2V cell battery banks

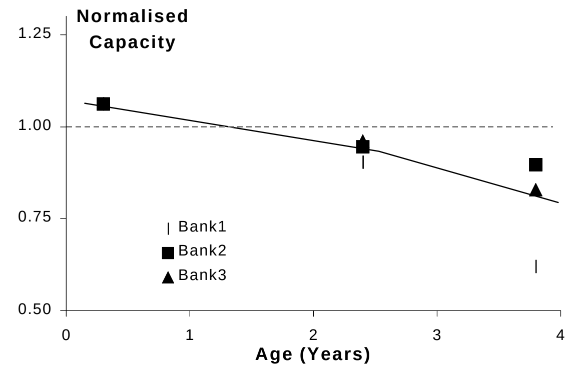

Figure 5 Capacity trend for the 12V monoblock battery banks

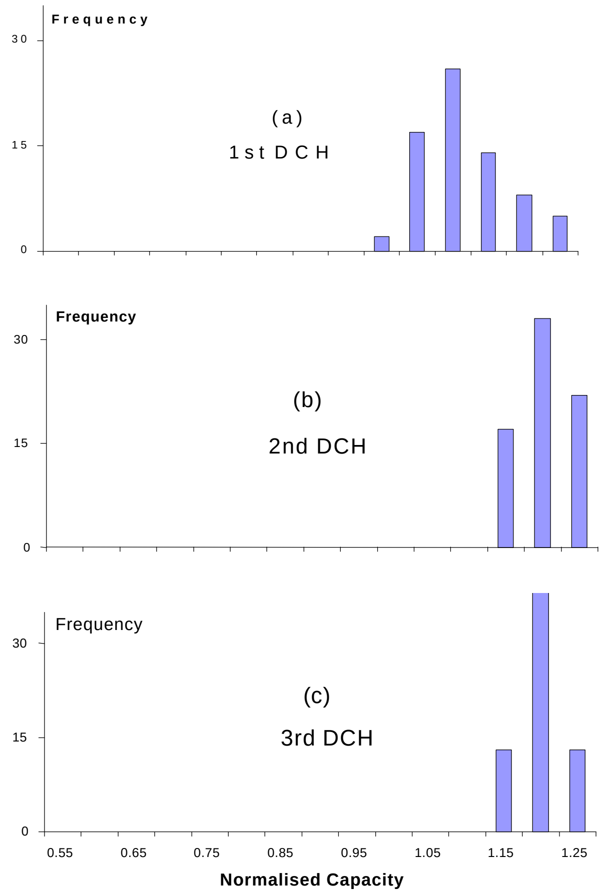

Figure 4 2V cells capacity distribution with each annual discharge.

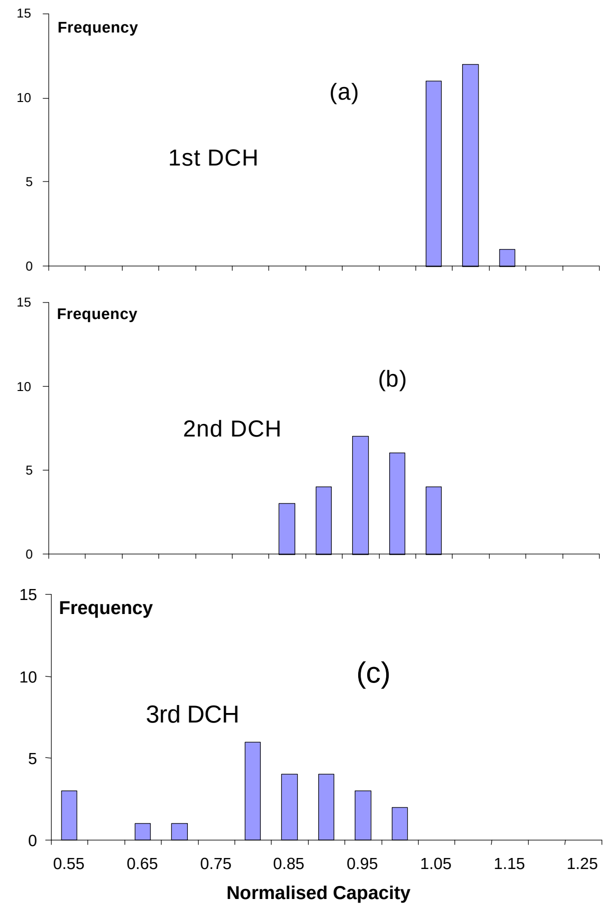

Figure 6 12V monoblocks capacity distribution for

each of the discharge tests.

differences in string capacities within the battery installation is itself of concern, the real telling and disappointing, information is in the distribution of individual monoblock capacities within the total population (*Figure 6*). Initially, at commissioning, the distribution of monoblock capacities is very narrow, and, as in the case with the 2V cells, the monoblock capacities were all about 10% above the rated capacities. At the first discharge test, after about two years on float under controlled laboratory conditions, the distribution has widened significantly, and there is about a 20% range in capacities about the now average, or mean of 90-95% of rated capacity. The repeated capacity test did not improve the spread. For a battery expected to exhibit a long term capacity loss of 20% over ten years, a fall of 5% or so over the first two years would not be unexpected if a linear degradation of capacity with time is assumed. However, the typical behaviour for AGM VRLA batteries is to sustain or increase rated capacity over the first 12-18 months, as observed with the 2V cells. Further, the distribution shown in *Figure 6b* indicates that about half of the population had repeated capacity determinations below the average, and about 25% had capacities below 85% rated capacity. *Figure 6c* shows that after just over an additional year on float, during the period of monoblock float behaviour plotted in *Figure 2*, the monoblock capacities have collapsed. There is no evidence of this in the float voltages.

Conclusion

A detailed study of the float conformance and capacity retention of two 48V battery installations has shown considerable difference in service-life behaviour. In the content of maintenance and service operations, there appears to be very little basis for drawing a degree of confidence about the capacity retention, and hence reserve time, based on terminal voltage measurements alone. However, scrutiny of the dynamic changes in the *distribution* of cell float voltages over time may be more productive.

The results also suggest that there may be greater risk of undetected poor float performance of battery strings composed with monoblock batteries than with individual 2V cells. The results found in this work support previously reported observations of the poor, or unpredictable, capacity performance of 6V and 12V VRLA monoblocks used in series-connected strings in telecommunications standby applications [6,7].

Acknowledgment

The authors wish to thank the Director of Research, Telstra Research Laboratories, for permission to publish this work.

References

[1] B.A. Wittey, “Sealed lead-acid batteries: operational experience in a telecommunication service application”, *Proc. Conf.* INTELEC 85, 1985, pp 133-137.

[2] M. Grossoni and G. Clerici, “Experience and considerations on maintenance-free batteries in Italian telecommunication systems”, *Proc. Conf.* INTELEC 87, 1987, pp 623-629.

[3] A.I. Harrison and R.P. Bullough, “Float voltage characteristics of valve regulated lead-acid batteries”, *Proc. Conf.* INTELEC 90, 1990, pp 213-218.

[4] D.O. Feder and G. Carosella, “The never ending pursuit of float voltage uniformity in stationary reserve battery plants”, *Proc. Conf.* INTELEC 94, 1994, pp 609-617.

[5] S.S. Misra, T.M. Noveske, and A.J. Williamson, “Maintenance and reliability of standby battery systems: flooded vs valve regulated lead acid battery”, *Proc. Conf.* INTELEC 94, 1994, pp 250-255.

[6] D.O. Feder, “Performance measurement and reliability of VRLA batteries”, *Proc. Conf.* INTELEC 95, 1995, pp 22-28.

[7] J.M. Hawkins, L.E.E. Moore, and L. O. Barling, “Aspects of the float and temperature behaviour of lead-acid batteries in telecommunications applications”, in *Proc. Conf.* INTELEC 95, 1995, pp 372-374.

[8] J.M. Hawkins, L.O. Barling, R. Hand and B.K. Hawkins, Telstra Research Laboratories Report, in preparation.

[9] J.M. Hawkins, L.O. Barling, and N.J. Whitaker, “Automated and cost effective maintenance tools”, in *Proc. Conf.* INTELEC 95, 1995, pp 648-652.

[10] J.M. Hawkins, *J. Power Sources*, **35**, (1991), 417.