

# Aspects of the float and temperature behaviour of lead-acid batteries in telecommunications applications

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## Abstract

**This paper reports on some results to date from a program of study to better understand the influence of factors which influence the long-term float behaviour of lead-acid batteries. Data from high resolution, long-term, real-time logging of the float performance of in-service VRLA batteries in the network is also presented.**

## Introduction

Battery integrity is integral to the stand-by power function, and for telecommunications applications, lead-acid batteries optimised for long-life on float duty are typically employed. The long-term float behaviour of lead-acid cells is therefore critical to both the energy storage and energy delivery function. The float condition is a compromise between the need to apply an over-voltage to ensure capacity retention, and the desire to minimise voltage-dependent grid corrosion and water loss for maximum service-life. For vented batteries in the relatively controlled environments of traditional centralised telecommunications power systems, this is well understood and reflected in operational procedures designed to ensure float conformance by minimising the degree of individual cell variations within a battery string [1-4].

The functionality of the stand-by duty battery is not diminished with the use of valve-regulated lead-acid (VRLA) battery technology, but the traditional knowledge and experience is less useful as a working formula to ensure float conformance. The service-life and reliability experience with VRLA batteries is varied [7,8,9], although generally accepted to be poorer than traditional vented cells [3,11]. The trend towards power systems distributed in uncontrolled thermal environments is expected to further exasperate field experience and service-life expectations of VRLA batteries. In Australia, ambient temperatures above 40 C are not uncommon and insolation and the heat generated by the telecommunications and power equipment can raise the temperature a further 15-20°C

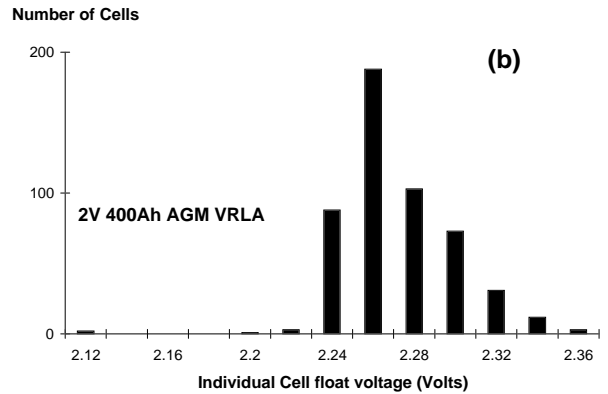
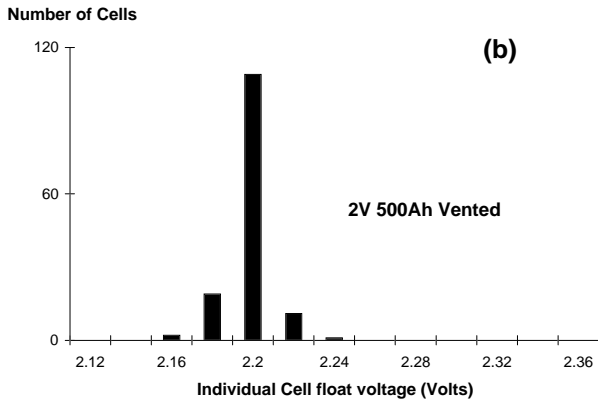
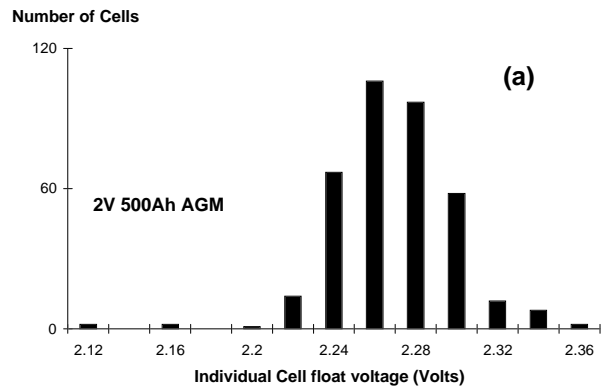
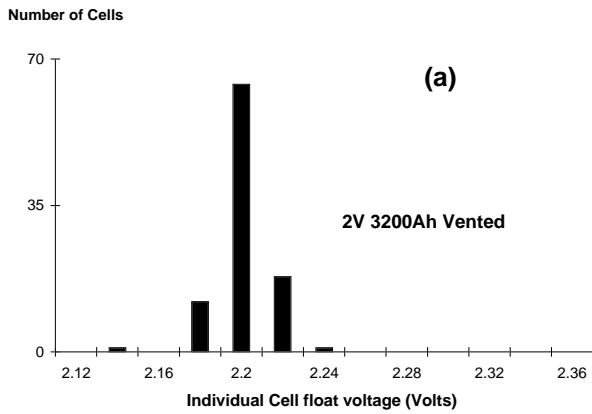
above ambient [5]. The accelerated degradation in service-life of some types of VRLA batteries in different types of network power equipment has been encountered. Yet the performance of other selected VRLA batteries in the shallow cycling regimes of Telstra's solar-powered network in outback Australia exceeds the benchmark performance of vented cells traditionally used in solar powered systems [6]. Clearly, a better understanding of the aspects of temperature influence on the real, in-service float behaviour of VRLA batteries is necessary.

Cell behaviour in a series-connected string is often different from the individual single cell studied in the laboratory. Telstra Research Laboratories has therefore embarked on a program to compare and correlate the long-term float behaviour and performance of in-service VRLA battery strings with laboratory studies where more complex determinations of float properties can be undertaken. This paper reports on some results to date in understanding the governing factors which influence the in-service behaviour of Telstra's VRLA batteries on stand-by duty.

## Float behaviour of in-service cells

The float behaviour of traditional vented lead-acid cells on stand-by duty in telecommunications applications is often used as the benchmark for float conformance [3,9]. The degree of float conformance in Telstra's battery banks can be gauged from cell and battery voltage recordings collected as part of routine battery maintenance procedures. *Figure 1* demonstrates the typical distribution of cell float potentials which can be expected for in-service vented battery banks in the network. Telstra uses flat-plate, Faure-type pure lead-positive cells, with acid density of 1.250 g/L, built to Australian Standard AS4029.3. The typical distribution is shown for the two most common size of vented cells used. A normal distribution is evident, and most cells float very close to the nominal 2.20 Vpc @ 25°C float control voltage. The typical spread of cell float potentials within a battery is no more than 40 mV, and often found to be better than 10-15 mV. The small deviation is not surprising given the performance standards of AS4029.3. This narrow distribution has

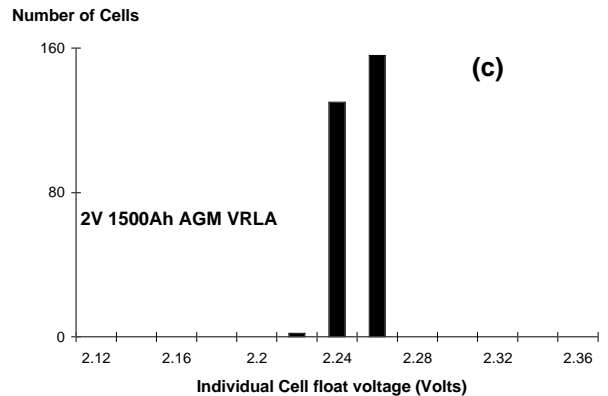
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**Figure 1:** Typical in-service float voltage distributions for two common sizes of vented cells used in the Telstra network - (a) 2V, 3200 Ah ( $C_{10}$ ) and (b) 2V, 500 Ah ( $C_{10}$ ).

not been observed to exhibit any significant aging trend or degradation as a function of operating temperatures over the range 20-45°C.

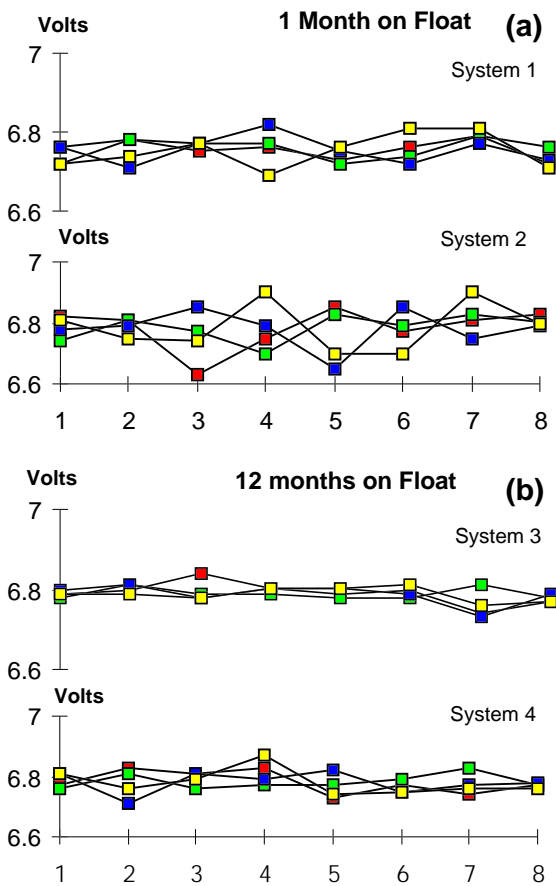
Similar float voltage distribution information is available for VRLA battery strings in the network. *Figures 2-5* show examples of the relatively wide variation in the float voltages of AGM VRLA cells within the same battery banks. *Figure 2* shows a typical "snapshot" of voltage distribution for three different sizes and types of AGM VRLA cells that have been under established float conditions for a long period of time. The batteries are all in stand-by power installations in air-conditioned environments and connected to similar rectifier equipment. Clearly evident is that for some types of VRLA batteries there is a very much wider range of cell float voltage distributions compared to that observed for vented batteries in the network. In *Figures 2a & 2b*, both types of batteries exhibit a float voltage distribution of about 140 mV. The population of cells shown in *Figure 2a* exhibits a normal distribution, and most of the cells are within 30 mV of the nominal float voltage (2.27 Vpc @ 25°C). On the other hand, *Figure 2b* exhibits a broader, "skewed" distribution and most of the cells are 60 mV from the nominal float voltage of 2.25 Vpc @ 25°C. This general variability in float conformance for VRLA batteries has been widely observed [3,8]. However, not all AGM VRLA batteries exhibit wide float



**Figure 2:** Typical in-service float voltage distributions for three common sizes of AGM VRLA cells used in the Telstra network.

voltage distributions. *Figure 2c* shows the distribution of float voltages for a significant number of large AGM cells. As can be seen, the distribution exhibits a variation similar to that expected for vented cells, indicating that expectation of "inherent" wide variations of the in-service float voltages may be inappropriate.

Often, significant differences in float behaviour of the same type of AGM VRLA in the same application are observed [7,9]. A comparative measure of "inherent" variability of AGM VRLA batteries on float in a battery string is shown in the series of plots in *Figure 3*. *Figure 3a* compares the float potentials of batteries in two identical stand-by power systems of the same age. Each power system has four parallel strings of eight,

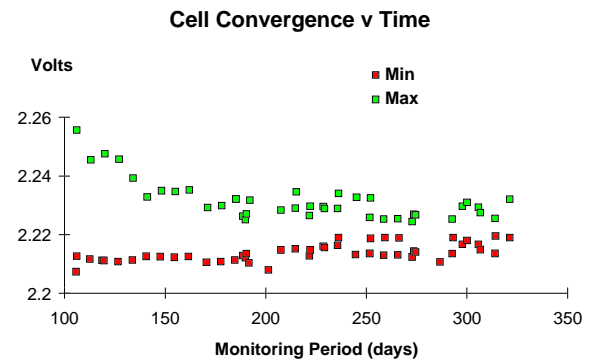


**Figure 3:** In-service float voltage distributions for new and aged 6V, 110 Ah AGM VRLA monoblocks in the same operating conditions.

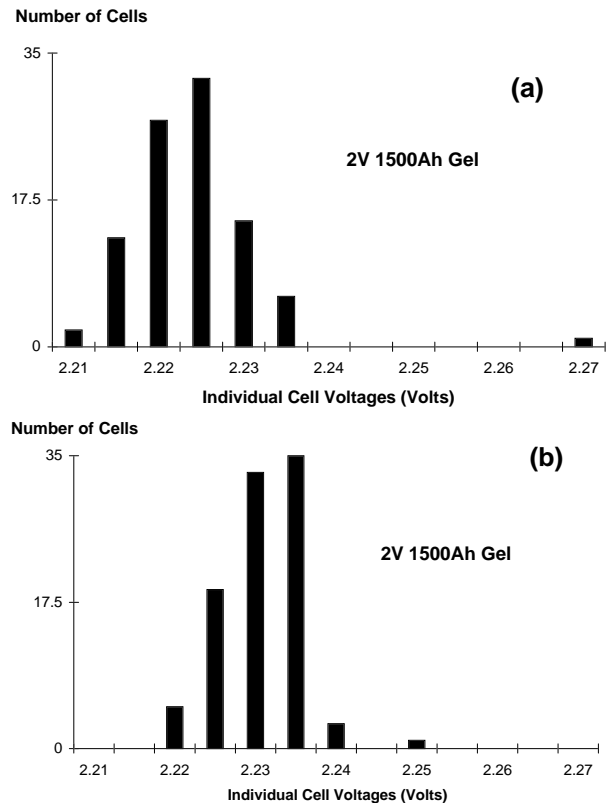
6V AGM VRLA monoblocks from the same production batch. The data was taken after two months of float under identical operating conditions and just prior to discharge testing which confirmed rated capacity in all batteries. One system displays good float conformance; the other does not. *Figure 3b* compares the float behaviour of the parallel strings of monoblocks for two identical systems after 2 years on full float, again just taken prior to discharge testing which confirmed rated capacity. The variation in the float conformance observed for the "young" systems is not too different from the aged units, and both good and poor float conformance is found. This type of behaviour is not uncommon. Recently, the scatter in cells voltages observed for AGM VRLA battery banks has been correlated with wide distribution of positive plate overpotentials [3]. The general conclusion is that there is a "generally inherent" greater scatter in individual VRLA cell voltages compared to vented batteries [8]. The extent to which this "inherent" scatter may be attributed to the "quality" of the VRLA cell is yet undetermined. However, work in this program has qualitatively correlated the general variability in float conformance of VRLA cells used in the Telstra network with battery characteristics such as variance in plate weights, pasting, separator quality and reproducibility in vent operation.

### Voltage-time behaviour on float.

The variation of cell float voltages within a string is known to be dynamic [8], and the distribution has been observed to diverge over time for some types of AGM VRLA batteries [8] and converge over time or with cycling for others [3]. The tendency for gelled VRLA batteries to converge on float is attributed to initial dryout. Valuable insight into the in-service behaviour of VRLA cells can be gained from real-time logging of battery float performance. *Figures 4&5* illustrate some of the battery float behaviour information collected during a long-term, continuous, high resolution monitoring and performance evaluation of a large



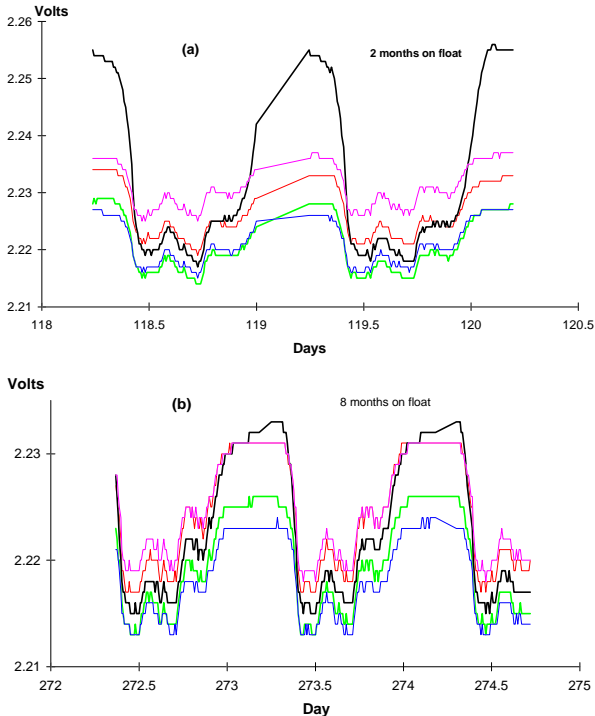
**Figure 4:** Long term time trend of 2V, 1500 Ah gelled VRLA on float service.



**Figure 5:** Float voltage distributions of 2V, 1500 Ah gelled VRLA batteries after (a) 3 months and (b) 11 months on continuous float at 2.23 Vpc.

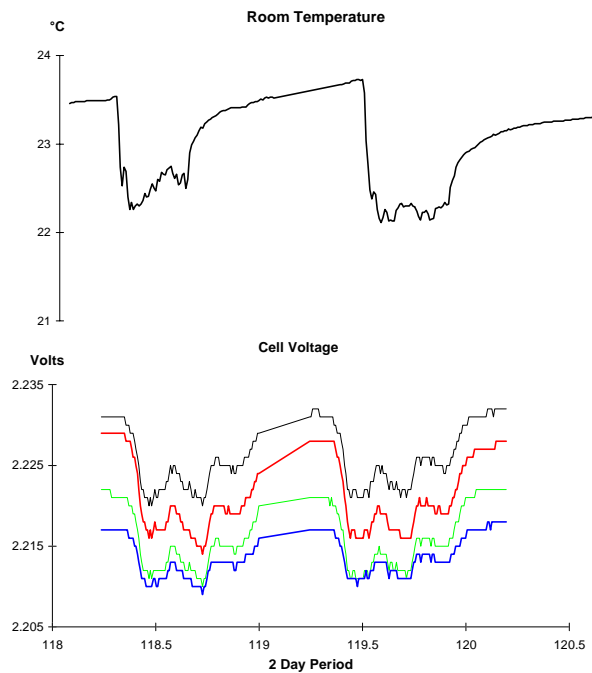
exchanged-based DC power system. [10]. The relative degree of float conformance achieved with four parallel 48 V banks of 2V, 1500 Ah gelled VRLA cells was real-time monitored over an extended period. *Figure 4* plots the envelope bound by the highest and lowest cell potentials over a monitoring period of approximately one year. Clearly, there is an overall convergence of cell float voltages over time. *Figure 5* shows two "snapshot" cell voltage distributions during the monitored period. *Figure 5a* shows the float voltage distribution after approximately 3 months of continuous float following a series of conditioning and commissioning discharge and charge cycles during which the capacity rating of each cell was verified. The nominal float condition was 2.23 Vpc @ 25°C. A relatively broad distribution spanning about 50 mV, centred at about 2.22 Vpc is observed. *Figure 5b* shows the situation after about 11 months at the same float voltage control. The voltage spread in the distribution has noticeably reduced to approximately 25 mV, and the distribution is centred very close to the float control voltage.

Real-time high resolution monitoring of the float behaviour allows quite detailed study of individual cell behaviour. *Figure 6* shows the 6 month change in the time trend of some selected VRLA cells on float in a stand-by installation in a basement battery room. The room does not have direct air-conditioning or other thermal environment control.



**Figure 6:** Comparison of the 2 day time trend of float voltages for the same cells in a VRLA battery over a 6 month (a) after 2 months on float and (b) after 8 months on float.

*Figure 6b* shows the behaviour of the same cells six months later. There are a number of interesting aspects. The cells all follow a background oscillatory cycle. *Figure 7* demonstrates how the cells in the string responded to changes in the ambient temperature over the same 2 day period. Clearly, the oscillatory behaviour can be attributed to temperature tracking. Further, there appears to be very little lag between room temperature and the change in cell voltage. In *Figure 6a*, one cell exhibits a comparatively large variation in float voltage compared to the other cells.

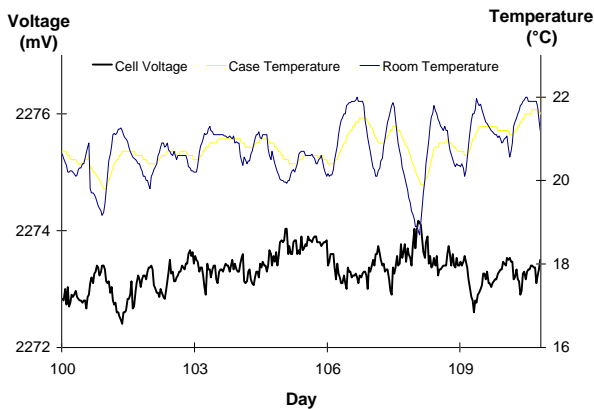


**Figure 7:** Effect of room temperature variations over a 2 day period on the float voltages of cells in the battery string

Further, over the 2 day period, the ordinal pattern of float voltage changes. In *Figure 6b*, the relatively large variation of the single cell is reduced and the distribution of float voltages is significantly smaller. However, there is considerably more changing of the ordinal pattern of float voltages over the same 2 day period. That is, both the general convergence and the shorter time, relative variation between cells appears to be linked to the temperature response. *Figure 7* indicates that even over relatively small temperature changes (22.3-23.5°C), individual cell float voltages vary by about 10 mV.

The apparent importance of the temperature influence on the float conformance has been observed in other high resolution experiments monitoring the in-service float behaviour of VRLA cells. The long-term, very detailed study of the individual float behaviour of cells in three, 48V parallel 48V banks of 2V, 3300 Ah AGM VRLA battery strings has recently been undertaken. The batteries are co-located with advanced switch-mode power supplies in a specifically refurbished power room fitted with high quality air-conditioning and thermal

environment control. *Figure 8* shows a typical example of the temperature behaviour of a cell float potential.

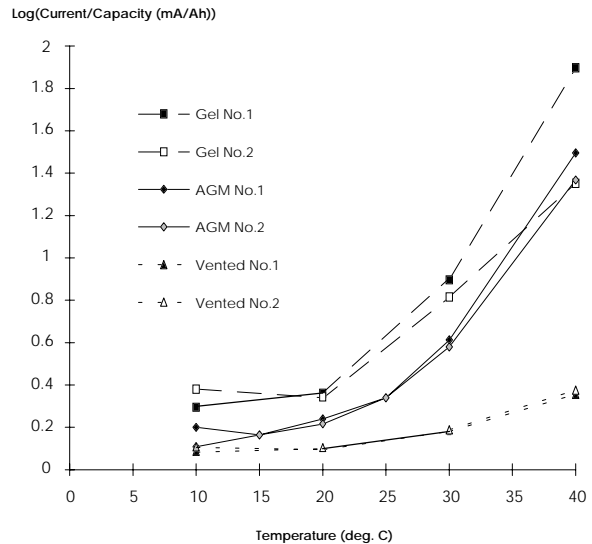


**Figure 8:** Comparison of changes in room temperature, battery case temperature and float voltage for an in-service 2V, 3300Ah AGM VRLA cell over a 10 day period.

Clearly evident is the way in which the float voltage tracks the room temperature. The lag between the room temperature and the battery temperature is small, but it is of interest to note that the range of variation of battery case temperatures is smaller than that for the room temperature excursions. This indicates that the cell bulk does afford some degree of thermal mass and insulation. There is considerably greater lag between the cell float voltage and either the room temperature or the battery case temperature. For approximately 5%-10% variations in room temperature, there are corresponding variations of about only 1-2 mV in the terminal float voltage of the cells. This is remarkably different than that observed in *Figures 6 & 7*. This observed temperature behaviour has ramifications for the practical implementation of temperature compensation strategies.

### Laboratory studies

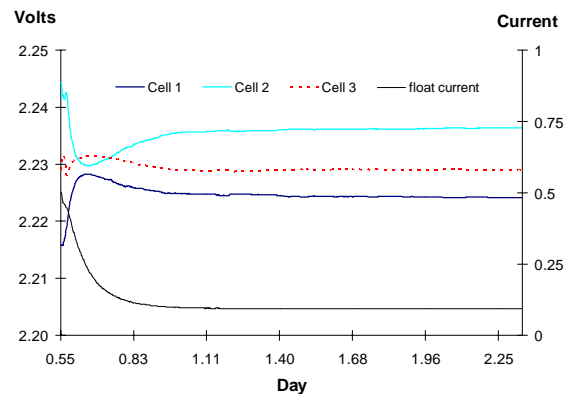
The real-time, high resolution studies of the float behaviour of in-service batteries is complemented by specific studies into the float characteristics under controlled laboratory conditions. Single cell float characteristics are often different from that observed with the in-series connection of the same type of cells. The study of the differences between the float characteristics of individual cells provides a means to assess the "inherent" variation of batteries. Three and six cell monoblocks provide a means to model the behaviour of series-connected cells which have nominally the same production quality and identical operating conditions.



**Figure 9:** Variation in float current with temperature for 3 different 2V batteries technologies. float voltage=2.250 Vpc. (C<sub>10</sub> capacities : - gelled, 250 Ah ; AGM 400 Ah; vented, 225 Ah)

*Figure 9* plots variation of the float current at 2.25 Vpc as a function of temperature for duplicate samples of three different types of battery technologies. Temperature compensation was not used. The graph shows that the duplicate cells have significantly different, and non-Arrhenius, float currents at the lower temperatures. The duplicate VRLA cells also exhibit significantly different float currents at 40°C. The difference in nominal float current at higher temperatures can be expected to have a direct influence on the in-service float conformance of batteries strings.

In series-connected batteries, float behaviour is governed and dictated by a single series string current. *Figure 10* shows a typical example of the behaviour of three cells in a 6V AGM VRLA monoblock under very accurate and controlled float voltage and temperature



**Figure 10:** Cell voltage behaviour as a function of time on float at 35°C for 3 series cells in a 6V, 110 Ah AGM VRLA monoblock. Float voltage 6.75 V. (2.23 Vpc)

conditions [12]. The temperature is 35°C and the float voltage set to 6.750 V (2.25 Vpc), which is considered an overcharging condition with respect to the manufacturer's recommended charging levels. As can be seen, the individual cell establish stable float voltage levels relatively quickly in which only one cell is at the nominal 2.230 Vpc. The voltage-time behaviour of the other two cells mirrors each other about the 2.230 V level. These two cells exhibit divergent trends, even though the float current remains extremely constant.

### Conclusions

A program to better understand the float behaviour of in-service VRLA cells has been established. The results and observations to date indicate that float conformance of cells in battery strings is often different to that expected from laboratory float measurements on single cells. The distribution of individual cell float voltages in battery strings is observed to be dynamic, and may converge or diverge with time. Individual behaviours appear to be strongly linked to both ambient temperature fluctuations and the variability in cells arising from both manufacture and a degree of "inherent" operation of the VRLA cells.

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