The Successful Use of VRLA Batteries in Solar Telecommunications Applications

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Abstract This paper reports on the results to date of a birth-to-death trial of selected VRLA batteries operating in 12V solar powered telecommunications systems in the harsh environment of outback Central Australia. The VRLA batteries in the trial have exhibited performance beyond expectation and appear to exceed the benchmark performance of the vented lead-acid battery traditionally used in this application.

Introduction

Telstra has an extensive solar-powered tele-communununications network which is used to deliver telephony services to thousands of rural and remotely located Australians. Due to large distances between rural customers and rural population centres and the sparsity of power reticulation, photovoltaic (PV) technology has proved to be an economic means to power telecommunications loads up to about 1000W. The PV systems use shallow cycling regimes designed for 8-10 day autonomy and typically employ vented lead-acid batteries for storage. The design and development of Telstra's solar-powered tele-communications networks over the past two decades has been previously described [1-3].

Provision of solar-powered plant is now considered a mature technology and is capable of providing the very robust and reliable performance needed to meet high level of service availability obligations. However, given the extensive geographical area involved, considerable operational support is required to maintain the solar plant, and now there is focus on life-cycle support strategies. Vented lead-acid batteries present a maintenance overhead which may be addressed with the use of VRLA battery technology. However, the reported performance of VRLA batteries under cycling applications, or in harsh operating conditions, is varied. [4,5]. Furthermore, very reasonable battery service life has been achieved under Telstra's shallow-cycling regimes with the standard, pure lead positive plate, faure vented battery traditionally used in Telstra's telephone exchanges. Any operational benefit in a shift to VRLA batteries in solar applications should not diminish established system performance. Therefore, a long-term performance monitoring project has been established to assess the potential benefits of using low maintenance VRLA batteries in solar applications. The behaviour and service-life performance of selected VRLA batteries in solar-powered Digital Radio Concentrator System (DRCS) repeaters operating in Central Australia has been studied and compared to the vented cell benchmark traditionally used in this application.

This paper provides an update of the previously reported comparison of performance between the batteries [6], and confirms earlier indications that the VRLA batteries have exceeded the benchmark performance of the flooded cells. Within the context of the trial, a level of confidence about the beneficial use of selected VRLA batteries in shallow-cycling PV applications is now possible.

Experimental

A comparison of the birth-to-death performance of selected VRLA batteries in Telstra's solar-powered applications was established in 1990. Real-time, high resolution remote monitoring has been used to characterise the battery and power system performance of four solar-powered DRCS repeaters along a communications route in Central Australia. Three of the sites are fitted with different types of VRLA cells while the fourth site has the vented lead-acid batteries traditionally used in this application to provide the benchmark performance.

The rationale behind the site selection and experimental methodology has been previously described [6]. Briefly, most of the DRCS network is solar powered and, as a variable load, is more demanding on the PV system design. The remoteness and environmental conditions typify most of the solar network. The ambient temperatures of the region range between 0°C in the winter and 45°C in the summer.

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The batteries are all housed in “thermally” transparent above-ground equipment housings, and thus the operating environment is considered harsh and uncontrolled. The selected sites are adjacent repeaters along the route, each separated from the next by about 50 Km. Therefore, each system can be assumed to experience similar operating and environmental conditions. The PV design, equipment and operating set-points at each site is essentially the same, so that general differences in system performance should primarily reflect differences in battery behaviour. Some general aspects of the solar-power system design used at the DRCS sites are listed in *Table 1*.

element	value
Nominal site power	100 W
System voltage	12V
Design autonomy	8-10 days
Load type	variable
typical average	4 - 5A
peak	8 - 10A
PV Array	
output	900W (peak)
technology	polycrystalline
configuration	13 x 35W panels & 8 x 58W panels
Storage	
nominal C_{10} capacity	1000 Ah to 1.80 Vpc
cell size	2V 500 Ah
configuration	2 banks of 6 x 2V cells
Regulation	
type	sequential switching
control	staggered set-point
configuration	6 regulators

Table 1 Some general design aspects of the solar-powered system used for DRCS repeaters.

Battery storage at 12V DRCS sites is typically configured as two parallel banks of 2V cells. The site location identifier and the main battery characteristics distinguishing the four different types of batteries in the trial are listed in *Table 2*.

Location	Sofa	Caroline	Oak Plain	Pakawindi
Battery	**Site A**	**Site B**	**Site C**	**Site D**
Technology Type	VRLA AGM	VRLA GEL	VRLA AGM	vented faure
grid geometry	flat plate	tubular	flat plate	flat plate
+ve plate alloy	Pb-Ca-Sn	Pb-Ca	Pb-Cd-Sb	pure Pb
-ve plate alloy	Pb-Ca-Sn	Pb-Ca	Pb-Ca	Pb-Sb
Acid Density	1260	1240	1300	1240
Orientation	vertical	vertical	horizontal	vertical

Table 2 Comparison of some battery details at each test site.

At Site B, each of the two battery strings consists of an “old” and a “new” sub-string of 6 series-connected 250 Ah, 2V cells (see *Figure 4*). This site therefore has a total of 24 cells. The “old” cells have about 18 months additional service life in this application. Site B results therefore also provide the basis of a performance model for “mixed” aged strings.

A simple on-off switching scheme for charge voltage regulation is typically used in Telstra's PV systems. Temperature compensation of the charge voltage regulation is not used at these sites. Operating set-points are usually standardised, and not subject to site-specific optimisation. The regulators used in Telstra are normally set to switch the array out at 2.35Vpc, and have a nominal 100 mV operating voltage hysteresis window. As a concession to charge requirements of VRLA batteries compared to vented cells, the voltage regulation at the test sites as been more precisely defined. The voltage regulation used at all the test sites has been set for staggered sequential switching in approximately 30 mV steps, beginning with the highest setting at 14.1V (2.35Vpc). The voltage hysteresis varies from 70mV to 100mV between the 6 regulators. This provides a deliberately tapered switching charge control.

Continuous, high resolution, real-time data logging has been used to characterise the complete operation and performance of the PV system at each site since commissioning. Conventional remote-logging methods using commercially available data loggers, suitably modified to accommodate the purposes of this experiment, have been used. A summary of the typical logging strategy is given in *Table 3*. Insolation data has been obtained from a calibrated solid-state pyranometer. System currents have been measured as voltage drops across calibrated precision shunts. Data has been automatically down-loaded daily from the loggers at each site via modem over the PSTN to a centralised computer for subsequent processing and analysis.

Parameter	Logging strategy
Insolation	1 sec samples summed over 3 min
Currents array, battery & load	3 min average of 1 sec samples
Voltages cells & bank	3 min sample
Temperatures ambient & cell	3 min samples
Ampere-hours charge & discharge	1 hour sum of 1 sec current samples

Table 3 Typical logging strategy used at all sites.

For most of the logging period, periodic intervention discharging and charging using a fixed procedure has been used to baseline reference the capacity of one of the two battery banks at each site [6]. In this approach, one of the two battery banks - *Bank 1* - at each site has been subject to periodic capacity testing. The time for these full discharge field tests has been varied to provide data on seasonal variations. The discharges provide a means to track and correlate the actual capacity of the batteries with the logged system performance data throughout the trial. The other battery bank at each site - *Bank 2* - has not been subject to regular intervention discharging. At each site, *Bank 2* has only been capacity tested twice throughout the logging period.

This approach provides a means to help gauge the effect of the more regular intervention discharging and charging of *Bank 1*.

Results & Discussion

The experiment has provided the most complete record of performance of a PV system yet obtained. Vast amounts of data, resolved in time to 3 minute intervals, fully describes the behaviour of the PV system, and allows assessment of performance at various levels of detail. Examples of the nature of the data and evidence that the sites generally experience the same operating conditions have been described [6].

Seasonal variations and longer-term trends over time are important in assessing PV system performance. The long-term seasonal variations in the daily insolation and daily average temperature for Site C is shown in *Figure 1*. The availability of such profiles provides a means to correct for seasonal effects and other operating conditions which might otherwise be reflected in the system performance estimates.

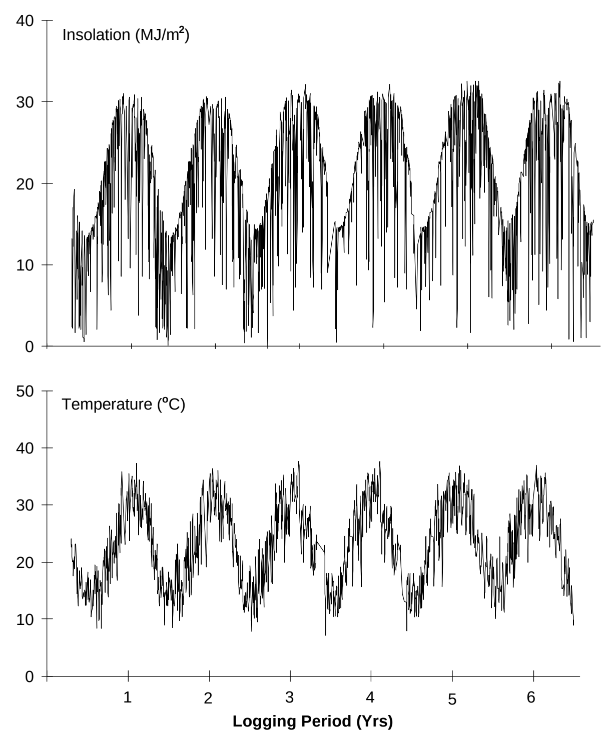
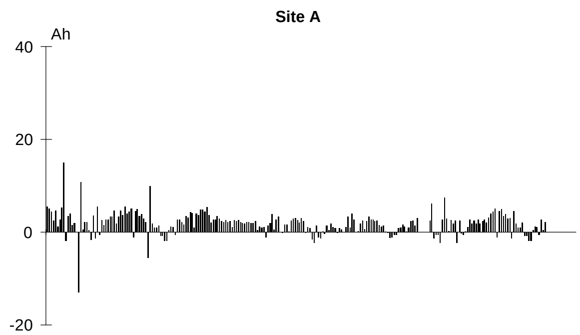


Figure 1 Seasonal variations in daily insolation and daily averaged ambient temperature for Site C.

Ampere-hour balance

Figure 2 shows the 10-day averaged daily ampere-hour charge and discharge balance over the logging period. Positive excursions in the plots indicate net battery charge, negative ones indicate net discharge. The low incidence of negative excursions in any of the plots indicates the effectiveness of the PV array sizing practice. Specific behaviour is influenced by seasonal variation in insolation, and is reflected in the 'oscillatory' characteristic superimposed to varying degrees on the charge profile for all 4 sites.

These profiles represent the generally different degree of overcharge, or excess capacity, taken by the batteries at the different sites. The degree of overcharging is governed by the regulation which is controlled by the terminal voltage of the battery.



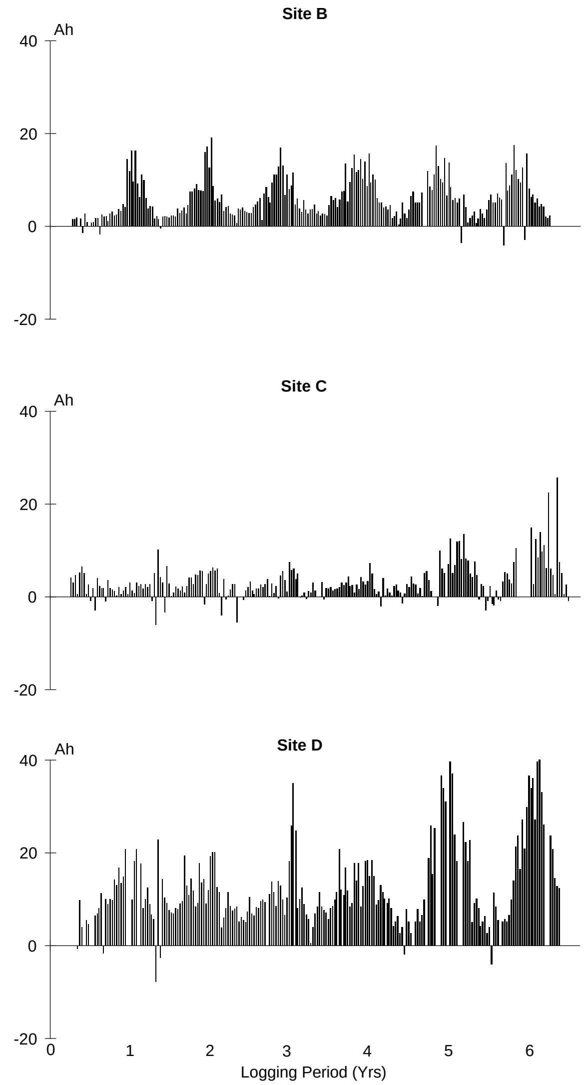


Figure 2 Ampere-hour balance for the 4 sites.

Since all sites have the same regulator settings, the profiles therefore directly reflect the charge efficiency of the batteries. Clearly, both types of AGM VRLA cells (Site A & C) require, or accept, less net over-charge than the Gel VRLA (Site C). All three VRLA battery types require substantially less overcharge than the benchmark vented cells.

The batteries at Site A appear to require a comparatively small degree of overcharge. The level of excess charge for the batteries at Site A & B batteries appears to be relatively stable over service-life. During mid-service life, Site C batteries had low levels of accepting overcharge similar to Site A batteries. However, for Site C & D batteries, the general level of excess charge appears to be increase later in service life.

Capacity Trends

The discharge and charge intervention program provides estimates of the "instantaneous", or available, battery capacity. In an active PV power system, the measured battery capacity is affected by both the load (energy demand) and the amount of solar radiation available to provide charging conditions (energy supply). The availability of highly resolved data tracking system parameters provides a means to correct for the seasonal variations which might affect the periodic capacity determination.

Figure 3 shows the trends in the normalised capacity determined for the batteries at each site. The normalised capacity is the ratio of the capacity measured during the periodic intervention discharging program, corrected for seasonal variations, to the rated capacity of the battery. The remnants of the seasonal variation is still evident as the small "oscillatory" profile which can still be superimposed on the plots. This gives the scatter about the decreasing capacity trend.

At all sites, the corrected battery capacity is observed to decrease over service-life. However, the rate of decrease in capacity is not the same at all sites. The batteries at Site D exhibit the greatest decrease in measured capacity over the logging period, while those at Site A exhibit the least. Sites B & C have very similar deterioration rates, intermediate between the other two. Interestingly, Site D batteries clearly appear to have a constant linear decrease in capacity over time. On the other hand, all the VRLA batteries seem to have a more complicated "two-stage" capacity deterioration profile, characterised by a more rapid fall-off, or, "knee", toward latter service-life. Site A batteries have the lowest rate of "fall-off" of all three types of VRLA batteries. This general "fall-off" characteristic may be important for network designers and maintenance purposes. Overall, the AGM VRLA batteries at Site A have exhibited the best performance. All the VRLA batteries appear to offer better performance compared to the benchmark behaviour of the vented cells. It should be noted that these capacity trends have been determined at relatively high discharge rates compared to the discharge rate encounted in the actual application. It is also important to acknowledge that there has been no attempt to optimise operating conditions for any particular battery technology. It is possible to optimise the PV system at each site to improve individual battery performance. However, in the context of an existing and extensive "standardarised" PV system infrastrucutre, introduction of VRLA batteries as direct replacements or alternatives to the traditonal vented cells must not invoke any significant site modification effort.

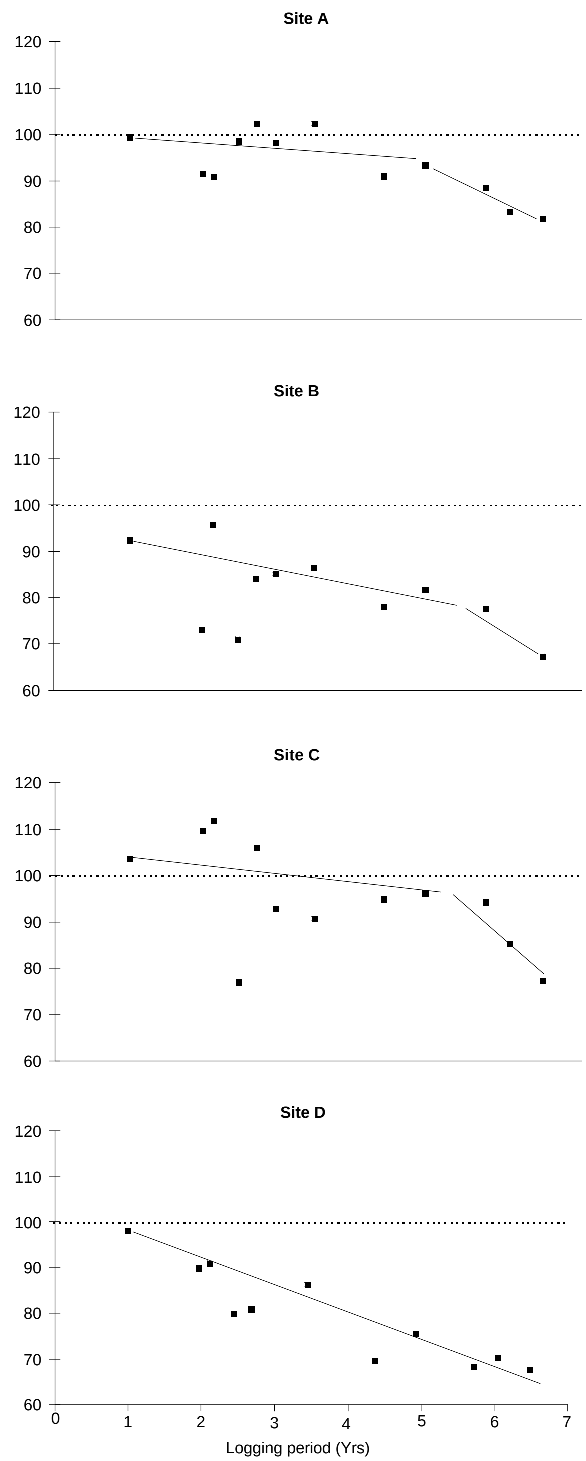


Figure 3 Normalised capacity vs time for the 4 sites.

Mixed Aged cells

There is much fine detail in the data, and Site B in particular carries interesting results. The configuration of the batteries at Site B is shown in *Figure 4*.

The "old" and "new" cells differ in service life by about 18-months and the results possibly reflect the effect of mixing of aged cells within the battery one installation.

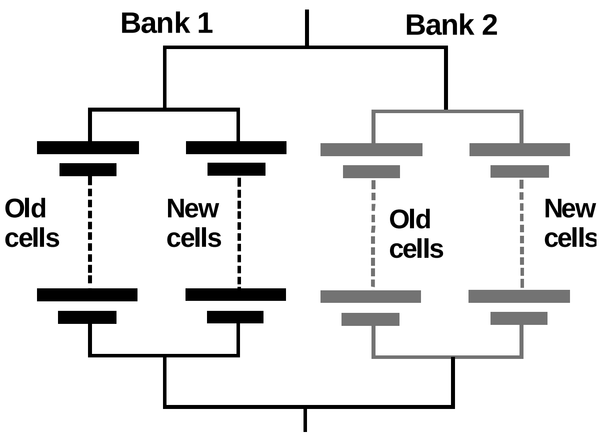


Figure 4 Site B battery bank arrangement.

Figure 5a shows the cell voltage profile of the weakest cell in each of the "Old" and "New" sub-strings in the tested *Bank 1* battery string at Site B during discharge early in the life of the system. *Figure 5b* shows the discharge current in each sub-string.

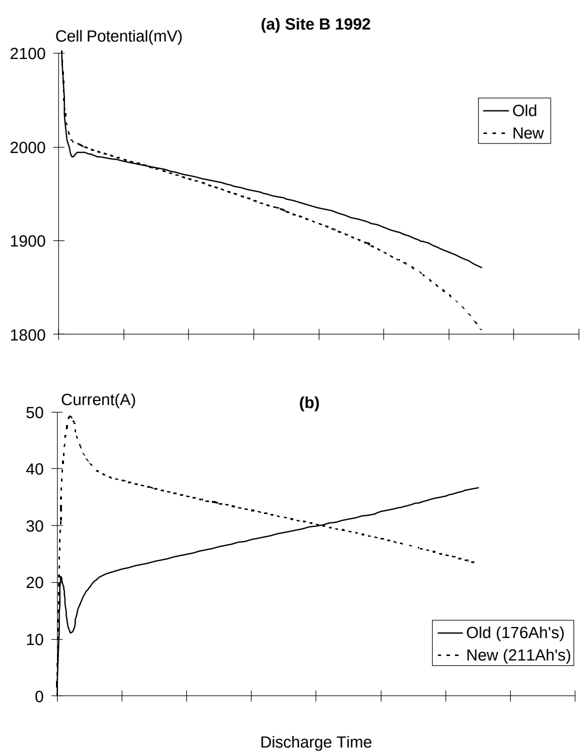


Figure 5 1992 Discharge Test for Site B, *Bank 1* (a) weakest cell behaviour and (b) sub-string discharge current.

The "New" cell limits the run-time of the discharge, yet delivers about 15% more capacity. The current profiles show considerable imbalance in supply of discharge current, and this must relate to differences in the effective plate polarisation during discharge between the "Old" and "New" cells. It can thus be concluded that the sub-string consisting of the "New" cells has a lower impedance than the sub-string of "Old" cells and hence dominate (and control) the bank discharge. The bank therefore effectively consists of two strings of different capacity cells. This is the reason why in *Figure 3* that the Site B battery does not initially achieve 100% rated capacity.

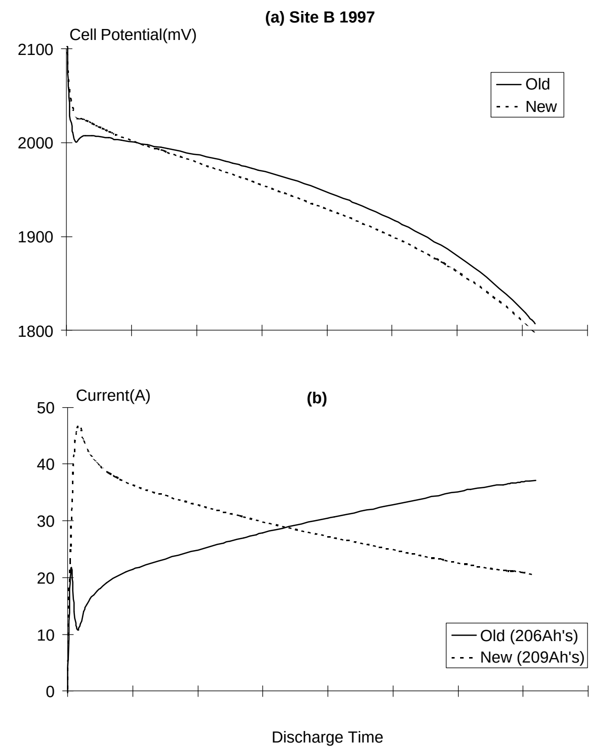


Figure 6 1997 Discharge Test for Site B, *Bank 1* (a) weakest cell behaviour and (b) sub-string discharge current.

Figure 6a and *6b* show the cell voltage profiles and current response respectively of the same cells (still the lowest capacity cells in each sub-string) during the most recent rated discharge test. The 'New' cell initially still dominates the start of the discharge, but now the delivered capacity of each cell is virtually the same. Compared to *Figure 5(b)*, the current profiles have become more non-linear during the latter part of the discharge, and the on-load polarisation of the "New" cell has clearly changed.

These observations can to be correlated with the ampere-hour balance for Site B. *Figure 7* shows the ampere-hour balance for Site B separated into "Old" and "New' sub-strings components for *Bank 1*. Clearly, there is a considerable difference in the excess charge taken by each sub-string. The "New" cells require significantly less overcharge than the "Old" cells. Further, over time, there appears to be a steady increase in excess charge taken by the younger cells. On the other hand, the excess charge taken by the older cells, which exhibit substantial overcharge requirements early in the logging period, decreases over time. This is consistent with the discharge current behaviour between the two sub-strings.

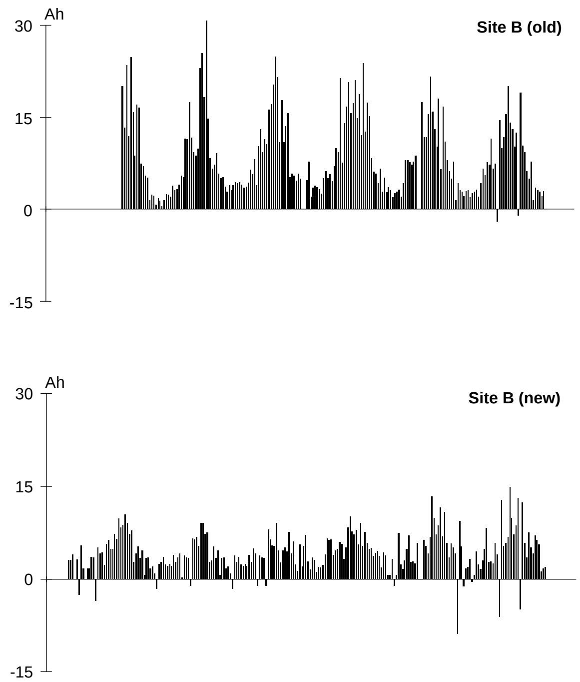


Figure 7 Ampere-hour balances for Site B, *Bank 1* "Old" & "New" sub-strings.

An interpretation of these observations is that in the case of active shallow cycling batteries, particularly VRLA batteries, any significant imbalance between parallel banks, may result in one bank effectively "doing all the work", and therefore effectively aging *(i.e.* losing capacity) relatively quicker than the other bank. This theme can be extrapolated to service-life considerations. In battery technology terms, it is not uncommon for a particular battery type or labelled range to evolve different cell characteristics such as internal impedance and plate polarisation behaviour as a result of minor changes to the battery design or new or improved manufacturing processes. Therefore, in an aged system, replacing only one battery bank may not be a good practice. While the new replacement cells may have improved rated performance, the in-service performance may be compromised by the aged cells retained in the system. In other words, the replacement batteries may be seen to achieve shorter service life than might have been expected.

Conclusions

It has been found that selected types of 2V VRLA batteries perform satisfactory in the shallow cycling regimes of 12V PV systems operating in the harsh environmental conditions of Central Australia. In this study, the VRLA batteries have all exceeded the capacity-life performance of vented cells traditionally used in this type of application.

In this context, the use of selected types of VRLA batteries in Telstra's solar powered telecommunications network may therefore represent considerable life-cycle cost savings. The results also indicate that in this type of shallow cycling application, caution may need to be exercised in the selective replacement of cells or banks as part of cyclic-life strategies. The results found in this work have been used as the basis to trial the use of selected VRLA batteries in larger 48V PV systems powering optical fibre repeaters [7].

Acknowledgment

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