

# The operation of VRLA lead acid batteries in parallel strings of dissimilar capacity or Can we now sin?

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**Abstract** – The operation of a 24V VRLA battery formed by two strings of dissimilar cells and monoblocs in a 100% d.o.d C<sub>3</sub> discharge/charge cycle service has revealed not unexpectedly that an asymmetric current flow from the strings occurs but that its implication on ultimate cycle service life is less significant than the strict rule of “do-not parallel dissimilar strings” would indicate.

## I. Introduction

### **The lead acid cell, an assembly of plates of opposite polarity in parallel and series connection.**

Lead acid batteries are the choice power back-up systems for telecom service providers for bridging power outages in the range of minutes to several hours. Lead acid batteries are formed by an assembly of serially connected individual cells giving, in this case with 24 cells, the nominal system voltage of 48V DC.

Each cell itself is an assembly of positive and negative plates consisting of the lead alloy current collector, a grid or spine in a tubular fabric, and the solid active materials lead dioxide and lead. It is the general rule in cell design to build up the cell capacity by assembling at least two or more ( $n \oplus$ ) positive plates with at least  $n \oplus + 1$  negative plates with each plate type connected electrically and electrochemically in parallel within the cell container. The plates are connected in parallel with the plate group bar or strap which carries the discharge or charge current load through the plate lug to the plates and then to the individual reaction sites in the active material. The current flow to or from the individual plates is governed by the ohmic resistance of the strap, lug, grid and active mass together with electrochemical polarization phenomena at the interface active material and electrolyte and the electrical resistance of the electrolyte and separator.

The number of plates in parallel in a cell is a compromise in terms of manufacturability (small vs. large size plates) and cost of handling (few vs. many plates) and may range typically from 2 to 20.

### **The operation of parallel strings of lead acid batteries**

The extensive operation of lead acid batteries in parallel strings stems mainly from the desire of enhancing the redundancy of the supply of power from the battery. By paralleling physically two or more strings of cells or monoblocs it is inferred that a failure of one cell in one of the strings would still allow a certain amount of backup time to be achieved with the “n-1” remaining “healthy” strings. Another reason for using parallel strings is the urge to reduce the size or weight of each cell or monobloc so to enhances their “man-handling” friendliness.

In the now very competitive environment of the telecom service providers a further reason of using parallel strings is the desire to reduce the types of cells or monoblocs in operation to very few and to install the battery back-up capacity in a “just-enough-fashion” to meet the load requirements at network start-up and to expand as need arises.

It has been an established rule in the battery community that a particular and added attention has to be given to the proper selection and design of cells, monoblocs, electrical connections and stands when they are to be used in batteries with parallel strings. In a recent paper by Migliaro [1] the “Do not’s” in such cases have been vividly described.

A key tenet of this rule is also the requirement that the connection of strings with different cells or monoblocs capacities in parallel shall be avoided (the “no dissimilar string” rule).

However a rapid expansion of telecommunication traffic and/or the installation of new equipment can quickly require battery power back-up beyond that initially installed. An additional and new battery may be therefore needed before the OEM battery has reached its end-of-life or because a significant expansion of the power back-up requirements cannot be met economically by simply multiplying parallel strings of the original battery.

In such cases the temptation to parallel an old and a new battery or batteries with the same string voltage requirements but with different individual capacities proved sometimes irresistible.

The desire to explain the implications of the softening of the “no dissimilar string” rule has led to the presentation of J. Szyborski et al. at Intelec 1998 [2]. The authors presented test results supporting the notion that the operation of batteries with dissimilar strings may not be so unacceptable as traditionally stated. In the framework of the continuous expansion of the installation and operation planning database for users of Compact-Power™ VRLA cells and monoblocs, a battery comprising two extremely dissimilar strings where operated throughout 1998 in a float charge - repetitive discharge mode.

## II. Experimental

For the purpose of testing a battery with parallel strings significantly differing in capacity and layout, two 24V strings were assembled with 4 units of 6V VRLA monoblocs of the type Compact-Power™ 6CP100 (100Ah  $C_{10}$  to 1.80Vpc @ 20°C) and 12 units 2V VRLA cells of the type Compact-Power™ 2CP550 (550Ah  $C_{10}$  to 1.80Vpc @ 20°C) as shown in Fig. 1 below.



Figure 1: View of the Compact-Power™ VRLA 6V/100Ah monobloc (left) and the 2V/550Ah cell (right).

The monobloc and cells used have the following characteristics.

Property/Type	6CP100	2CP550
Unit voltage/cells	6V/3	2V/1
Capacity $C_{10}$ 1.80Vpc @ 20°C	100	552
Capacity $C_3$ 1.80Vpc @ 20°C	83.4	456
$C_3$ to $C_{10}$ ratio	0.834	0.826
Number of $\oplus$ plates	5	11
Plate size in $\text{cm}^2$	538	1254
Total $\oplus$ plate area per cell in $\text{cm}^2$	2690	13794

Table 1: Key characteristics of the 2CP550 cell and 6CP100 monobloc.

The 4 monoblocs and 12 cells were operated in a such a position that the plates were in a horizontal or dish-like position.

The connection hardware consisted in rigid tin plated copper connectors of either  $2 \times 90\text{mm}^2$  or  $1 \times 90\text{mm}^2$  cross-section between the cells and monoblocs and with the two strings joined to the automatic charge and discharge unit via  $75\text{mm}^2$  cables of suitable but uneven length.

The current to and from the two strings was monitored via in-line shunts and the capacity, delivered or absorbed, by Ampere hour meters. The string currents were also recorded with a strip chart recorder.



Figure 2: View of the 24V VRLA battery with one string with 12 cells 2V/550Ah (left) and one string with 4 monoblocs 6V/100Ah (background right).

The discharge and charge cycle routine, carried out at room temperature, consisted a) in a discharge with the combined  $C_3$  rate current of  $27.8\text{A}$  (6CP100) +  $152\text{A}$  (2CP550) =  $180\text{A}$  to 1.80Vpc or 21.60V and b) in a recharge under constant current-constant voltage conditions with 100A starting current and a charge voltage of 2.25Vpc (float charge voltage). The charge time was limited to 21h and one full discharge/charge cycle was carried out per day. The internal impedance of the cells and monobloc strings was measured with an AC Milliohmeter, model 3550 made by Hioki Japan.

## III. Results

The results of the operation of this 24V battery with two parallel strings of dissimilar Compact-Power™ VRLA cells and monoblocs and submitted to a daily 100% d.o.d. discharge at the  $C_3$  rate are presented as follows:

- Individual string discharge currents
- Internal impedance of the strings  
vs. current delivered
- Individual string charge currents
- Evolution of residual capacity with 100%  
d.o.d  $C_3$  cycling
- String utilization vs. depth of discharge

### i) Individual string discharge currents

The battery was discharged with 180A (the sum of the two  $C_3$  rate currents). Not unexpectedly, significantly different string currents were observed.

The current flow from the 6CP100 string started with 44A, peaked within two minutes at 53.2A or 1.91 times the  $I_3$  current (27.8A), and then decayed in approximately 100 minutes to the  $I_3$  current. At the end of the discharge (battery voltage 21.60V), the current amounted to 0.77 times the  $I_3$  current.

During this discharge the 6CP100 string delivered 94.5Ah or 113% of its rated  $C_3$  capacity of 83.4Ah.

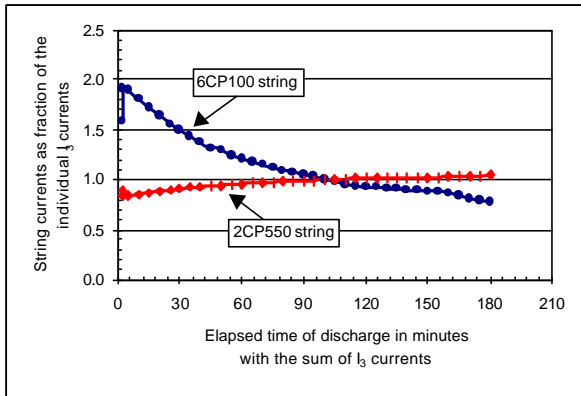


Figure 3: Plot of the individual string discharge currents as fraction of the rated  $I_3$  current at cycle # 28 of the life test.

During this same discharge the string with the 2CP550 cells started with a current flow of 136A or 0.89 times the  $I_3$  current, reached its rated  $I_3$  current also after 100 minutes elapsed discharge time and finished with 1.04 times the  $I_3$  current. During the discharge a total of 445Ah or 97.5% of the rated  $C_3$  capacity were furnished by this string.

The obtained data indicates that during discharge the “low-capacity” string (6CP100/100Ah) showed an over-proportionally high contribution to the total discharge current, “protecting” for approximately 55% of the discharge duration the “high-capacity” string (2CP550/550Ah) from an elevated current demand.

The differential current sharing is related to the internal impedance of the two strings which, when measured with the Milliohmmeter, amounted to 3.46mOhm for the 4 monobloc 6CP100 string and 6.36mOhm for the 12 cell 2CP550 string.

### ii) Internal impedance of the strings vs. current delivered.

During the above discharge cycle #28 the impedance of the two strings, in parallel and connected to the load, was followed by direct measurements with the Milliohmmeter. The evolution of these impedances is shown in Fig. 4.

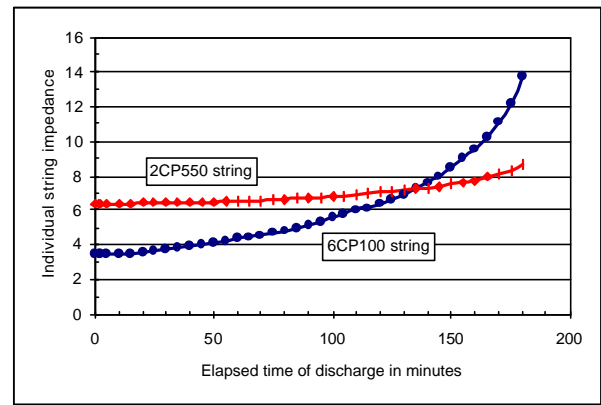


Figure 4: Evolution of the internal impedance of the two strings during the  $C_3$  discharge.

Plots of the current flowing from each string against the individual string impedance are displayed in Fig. 5 and Fig. 6.

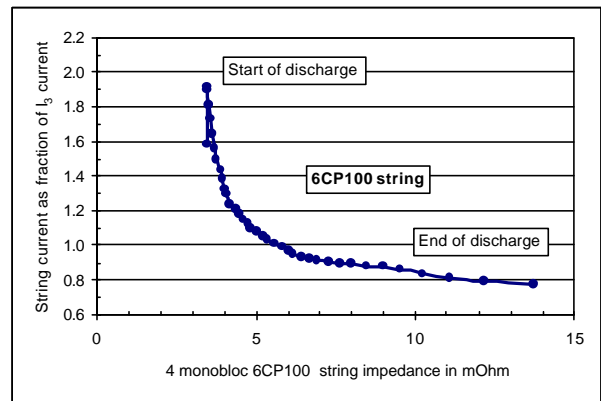


Figure 5: Correlation of string discharge current with the impedance of the 4 monobloc 6CP100 string.

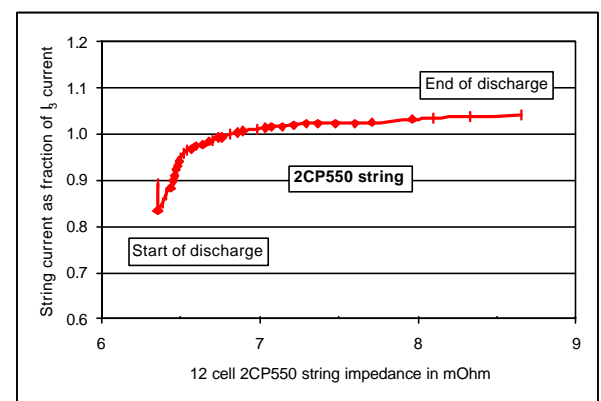


Figure 6: Correlation of string discharge current with the impedance of the 12 cell 2CP550 string.

The data of Fig. 4 to 6 show that no direct and simple correlation exists between the two string impedances and the current delivered into the load circuit but that qualitatively a low string impedance equates with high

current delivery capability independently of the installed Ah capacity.

### iii) Individual string charge currents

During a short period of time ( $\approx 2$  minutes) between the end of discharge and the start of charge, the battery was in open circuit and a flow of an exchange current between the two strings was noted.

It was observed that the string with the 2CP550 cells delivered a charging current of approximately 5A into the 6CP100 string until the external charger was switched on.

The battery was recharged under constant current – constant voltage conditions with 100A starting current and a charge voltage limited to 2.25Vpc (float voltage). Also in this recharge phase a differential current flow was noticeable with again a over-proportional higher current ( $\approx 3 \times I_{10}$ ) flowing initially into the lower impedance 6CP100 monobloc string when compared to the  $\approx 1.3 \times I_{10}$  current flowing into the 2CP550 string. The evolution of current flow into both strings is shown in Fig. 7.

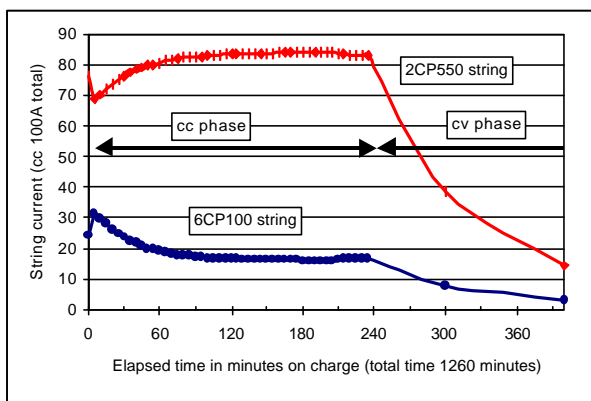


Figure 7: String charge current during the first 400 minutes of the cc – cv charge.

Both strings accepted charge quite well and reached after  $\approx 235$  minutes (at the end of the constant current phase) a recharge status (Ah in/Ah out) of 76% for the 6CP100 and 71% for the 2CP550 string.

At the end of the 21h charge period and with a maximum charge voltage of 2.25Vpc, a recharge status of 102% for the 6CP100 string and 101% for the 2CP550 string was achieved.

### iv) Evolution of the residual capacity with 100% d.o.d. $C_3$ cycling

In order to evaluate how the repetitive discharges of the “dissimilar string battery” influence the capacity evolution, the above described 100% d.o.d.  $C_3$  charge/discharge cycles were repeated on daily basis.

The residual capacity of each string was determined every 50 to 100 cycles with  $C_{10}$  discharges and without any prior equalization charge.

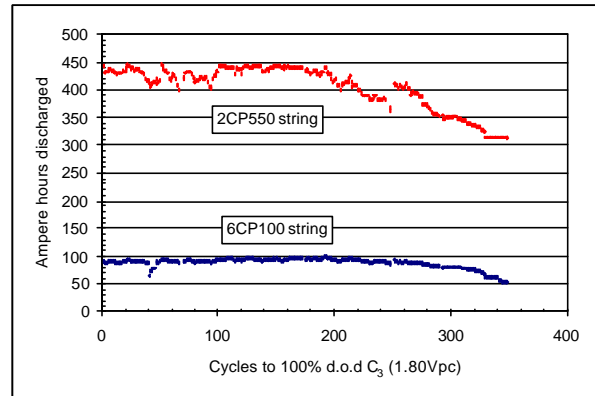


Figure 8: Evolution of the delivered capacity from each string during the 100% d.o.d  $C_3$  discharge cycles.

The evolution of the daily capacities, shown in Fig. 8, reveals that the “lower” capacity and impedance string formed of 6CP100 monoblocs does not age prematurely notwithstanding the severe discharge duty imposed and did reach its planned life of  $\geq 30000$  discharged Ah throughput.

The 2CP550 string did not fully reach its planned  $\geq 165000$  discharged Ah throughput before reaching a residual capacity of less than 80%. As this string was running with an minimal overcharge of only 1% insufficient recharge was expected and also confirmed at the end of the test as repetitive boost charges were able to restore a significant amount of the missing residual capacity.

The “dissimilar string battery” however performed quite well also in this repetitive discharge/charge regime when compared to requirements of typical telecom cycle life specifications ( $\approx 3 C_3, C_5, C_8$  discharges per service year).

### v) String utilization vs. depth of discharge

The previous data have shown that an asymmetric current flow occurs when such a “dissimilar string battery” is discharged i.e. when it satisfies a power demand from the telecom equipment.

As the current and Ah flow balances out during a full or 100% d.o.d discharge, each of such a discharge event would equally count as a discharge cycle from each string. If however the power outage duration does not result in a “deep” but only in a “shallow” discharge then the current flow imbalance will result in the fact that one string will deliver more Ah than the duration of the discharge or the accumulated cycle counter will reveal. Such hidden overuse of one string could result in premature aging and power back-up time loss.

In order to evaluate the effect of “shallow” discharges on the possible service life of “dissimilar string batteries” the experimental current flow data obtained with the above battery were utilized for a numerical evaluation of such effects.

For this purpose it was assumed that each string had a fixed aggregate amount of Ah which could be discharged during its life before active mass aging or other discharge related effects would reduce the available capacity to a value below 80% of the nominal capacity.

By fixing this aggregate value at an Ah throughput of  $\geq 300$  times the nominal  $C_{10}$  capacity, the 6CP100 string would have an Ah throughput capability of  $\geq 30000$  Ah and the 2CP550 string one of  $\geq 165000$  Ah. As the 6CP100 string discharges initially with nearly 2x the  $I_3$  current, shallow and short duration discharges will significantly eat into the cycle life capital of this string.

The expected cycle life under such <100% d.o.d conditions is shown in Fig. 9.

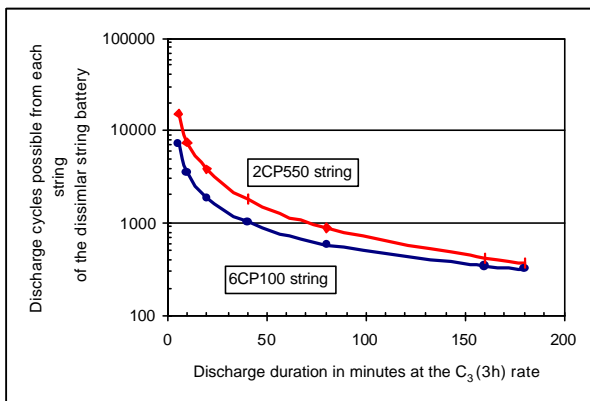


Figure 9: Number of discharge cycles possible in function of the discharge depth of the dissimilar string battery.

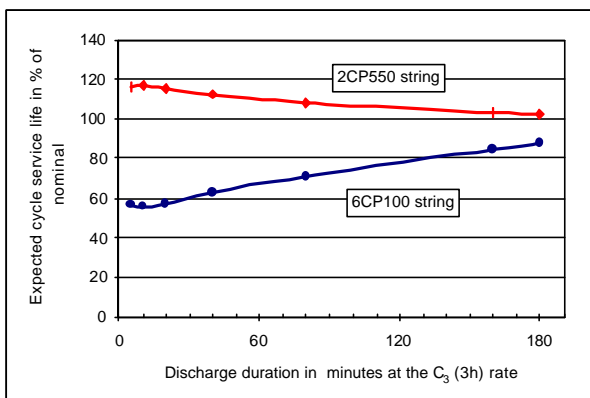


Figure 10: Expected cycle life of the individual strings with less than 100% d.o.d discharge depths as % of the nominal one (real  $I_3$  load current).

The calculated percentage of cycle life, based on the above assumption, is shown in Fig. 10 and reveals the results of discharge stresses on the “low” impedance 6CP100 string and the resulting discharge protection of the “high” impedance 2CP550 string.

## IV. Summary

The charge-discharge testing of a 24V battery with two very dissimilar strings formed by 4 monoblocs 6CP100 (6V/100Ah  $C_{10}$ ) and 12 cells 2CP550(2V/550Ah  $C_{10}$ ) showed that the currents flowing from and to the individual strings are principally governed by the string impedance and independent of the installed string capacity.

Such “asymmetrical” batteries can be operated quite successfully and yield nearly their complete cycle life potential when deep discharges to 100% d.o.d  $C_3$  are carried out.

If power outages cause only shallow discharges then the “low” impedance string furnishes an over-proportional share of the Ah discharged and may thus suffer in terms of achievable cycle life.

However if these shallow discharges are infrequent ( $\approx 50$  to 100/year) then the ultimate battery life will be governed mostly by calendar or elapsed service time considerations and not by exhaustion of its cycle life capital.

### Can we now sin?

The test results presented show that a prudent use of dissimilar string VRLA battery operation can be supported if the battery plant operator recognizes eventual drawbacks in terms of ultimate cycle life and strictly observes the fact that only strings with the same float voltage requirements and behavior should be considered for such parallel operation.

## V. Acknowledgements

The author wishes to thank Mr. G.Karlsson of Ericsson AB Sweden for formulating in 1997 the framework of this “far-out” test and the Innovation & Test laboratory of Oerlikon Stationary Batteries in Aesch for carrying out the experimental work.

## VI. References

- [1] M.W.Migliaro, Parallel strings-Haven't we learned our lesson? in Batteries International, January 1998.
- [2] J.Symborski et al., Operational characteristics of VRLA batteries configured in parallel strings, in Intelec 1998 Proceedings Paper 16-1, p 356.