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Batteries in standby applications: comparison of alternate mode versus floating

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Abstract

Experimental procedures are exposed that allow quantitative conclusions about the use of alternate mode (alternation of constant current charge and open-circuit periods) instead of floating mode (constant voltage condition) in standby applications of VRLA batteries. The level of capacity and the rate of a recharge following a discharge period are particularly studied. The influence of the three parameters of an alternate mode, that is to say the charging current, the maximum and minimum voltages, is especially discussed, with regard to the previously described responses. © 2001 Elsevier Science B.V. All rights reserved.

Keywords: VRLA batteries; Standby applications; Float charging; Alternate mode; Current-interrupt

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1. Introduction

Standby applications of batteries result in peculiar requests of the electrochemical system. Very few cycles are made (about once a month). However, the battery should always be at his maximum capacity. Since batteries without any self-discharge do not yet exist, this request is usually achieved by maintaining the battery in a slight overcharge.

VRLA batteries are often used in those conditions because they can undergo a large overcharge without big damages [1]. For example, if a VRLA battery which shows an open-circuit voltage (where self-discharge occurs) of 2.15 V is forced to an overcharge voltage of 2.30 V, a stabilized overcharge current of about a few 0.1 mA/Ah constantly flows through the battery. In these conditions, called float ones, the battery is really maintained in his maximum of capacity. However, the floating current represents an overcharge of about 10 times the nominal capacity of the battery, for 10 years of service-life [2]. Most of this overcharge corresponds to the oxygen cycle (during overcharge oxygen is produced at the positive electrode and reduced at the negative one), which does not consume any materials in ideal conditions [3,4]. Nevertheless, a few percents correspond to the grid corrosion of the positive electrode and generally lead to the end of live of the battery around 5–10 years of service-life [1–4].

New modes of charging could increase the service-life. For example, Lam et al. use pulsed-current charging in order to improve the cycling properties [5]. High charging currents could actually be used during very short times (a few milliseconds) followed by short times in open-circuit state.

Nelson et al. recently use the same idea with longer pulse duration (a few seconds) [6]. This "current-interrupt" charging method also allows improvement of cycling performances.

Although the same idea was already described for standby applications [7,8], very few corresponding studies could be found. This work deals with the use of current-interrupt algorithm for standby applications. Opposite to former studies for cycling applications, the different step's duration is not imposed. The voltage is kept in a small interval. A charging current (called I_c) is actually imposed until the voltage reaches U_{max} (the duration of this period is called t_{on}) and the battery is left in open-circuit conditions until the voltage decreases up to U_{min} (the duration of this period is called t_{off}).

Preliminary data of accelerated aging tests with alternate mode show that the average overcharge current is lower in alternate mode than in floating one, with suitable

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parameters. The aging of the batteries seems also to be slowed down.[1] However, the aim of this work has nothing to do with aging performances.

We propose a method to characterize quantitatively the functionality of the new mode, the alternate mode, compared to the previous one, the floating mode. In other words, this work will describe how the new mode will meet the specifications for standby applications of new batteries:

- Maintenance of the maximum capacity of the battery.
- Recovery of the maximum capacity after a discharge (monthly use of the emergency battery), and time required.

2. Experimental

2.1. Batteries

The different experiments have been performed on new VRLA batteries from Exide (reference S312/7, i.e. 7 Ah/12 V batteries with $C_{10} = 6.3$ Ah). In order to study only one individual element (2 V), these batteries were short-circuited on five elements during the manufacture by CEAC. Connecting wires between positive and negative terminals of the same element were installed on five elements just before closing the battery.

2.2. Electrochemical testing

Chronoamperometric and chronopotentiometric data are obtained with an Arbin battery testing system associated with the ABTS 4.0 software. First of all, the batteries are submitted to at least three charge/discharge cycles.

The discharging procedure for all tests corresponds to a constant current discharge (at a $C_{10}/1.34$ regime) until 3.8 Ah is reached (that is to say about 50 min).

The usual recharging procedure (unless otherwise specified) includes a first constant current recharging step at $C_{10}/10$ up to a cut-off voltage of 2.27 V, followed by a constant voltage step at 2.27 V.

2.3. Experimental parameters choice

The alternate mode is made up of constant current and open-circuit periods. The duration of each period, respectively, called t_{on} and t_{off} is not fixed. Only the voltage interval (U_{min} and U_{max}) and the current value (I_c) are set.

The selected voltage and current values are reported in the Table 1. The voltage interval is chosen in order to include the usual floating voltage (around 2.27 V at room temperature). U_{min} is chosen near the usual open-circuit voltage of a fully charged battery in order to keep the battery in a high state-of-charge. Finally, relatively high currents are chosen in order to avoid an insufficient charge of the negative plates because of the oxygen cycle [9,10].

Table 1
Parameters in alternate mode

Alternate conditions	U_{min} (V)	U_{max} (V)	Charging current (mA/Ah)
MMM	2.16	2.34	23.8
− + −	2.14	2.40	14.3
− + +	2.14	2.40	33.3
− − −	2.14	2.28	14.3
− − +	2.14	2.28	33.3
+ + −	2.18	2.40	14.3
+ + +	2.18	2.40	33.3
+ − −	2.18	2.28	14.3
+ − +	2.18	2.28	33.3

3. Results and discussion

3.1. Charge maintenance

When stabilized floating conditions (voltage of 2.27 V at ambient temperature and constant current of about 0.2 mA/Ah) are achieved (usually within a week), the battery could be considered as kept at his maximum capacity. Measurement of the charge required for returning to these stabilized conditions after an interruption of any nature allows the quantitative estimation of the loss of charge caused by this interruption. This principle is first used to estimate the possible loss of charge during an alternate period, as sketched in Fig. 1.

Following stabilized floating conditions, an alternate period directly results, as shown in Fig. 2, in immediately stabilized responses (except during few cycles around the 100th cycle because of external perturbations). The value of t_{on} is 6 s and that of t_{off} is around 1100 s and thereby the average current is around 0.13 mA/Ah (which represents for the 6.3 Ah battery a measured average current of 0.8 mA).

The average current in alternate mode is found smaller than the floating current (see Fig. 3): with MMM parameters the average current in alternate mode is around 65% of the floating current of the same battery. But quantitative conclusions on ageing could not be drawn from this result, as the current is composed of at least two phenomena: the oxygen cycle and the grid corrosion [3,4]. The first one does not cause damage whereas the second causes irreversible one for the battery. The lowering of the measured current is expected to be concomitant with the lowering of irreversible part of the current.

The important conclusion of this experiment is the negligibility (not measurable in our conditions, which means $\Delta Q < 1$ mAh) of the charge necessary to return in stabilized float conditions after almost 1 week in alternate mode. The alternate mode (with MMM parameters) is an efficient way

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[1] MGE UPS Systems preliminary results of aging tests at 45°C with floating and alternate mode on new VRLA batteries.

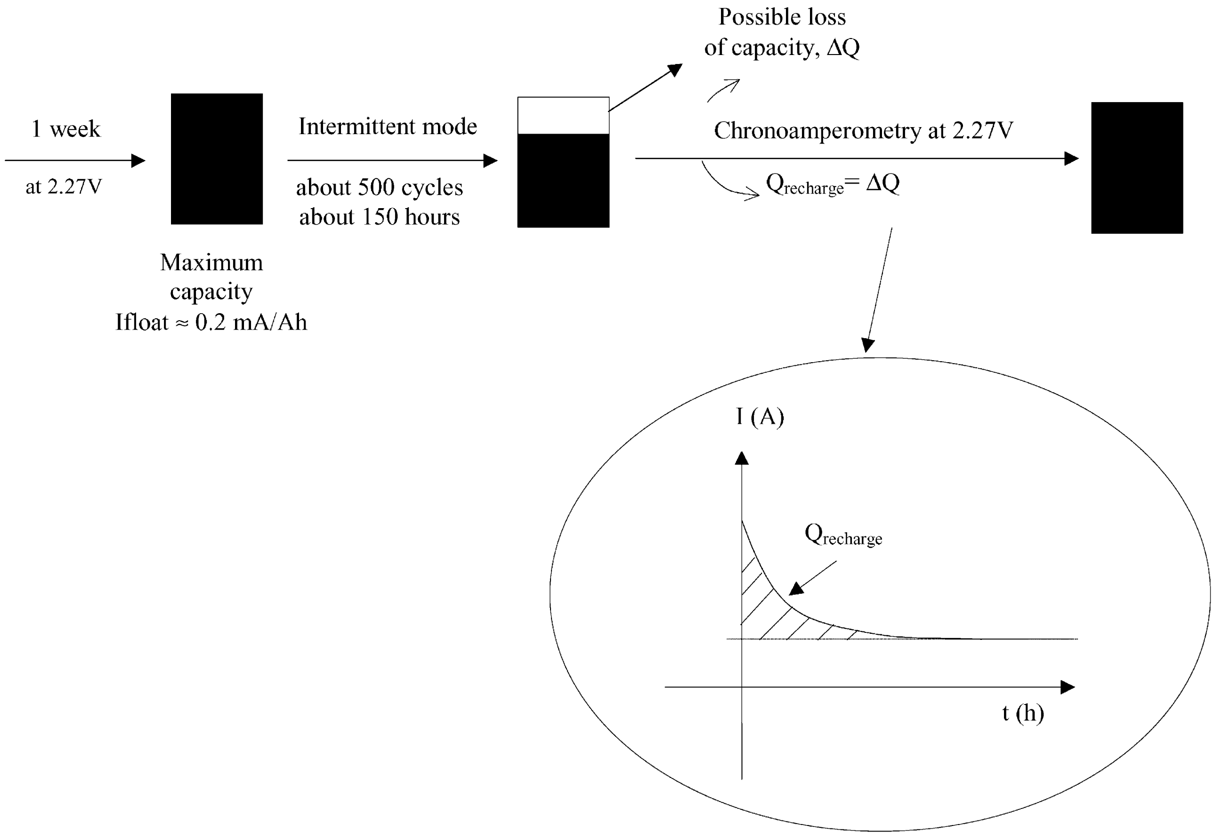

Fig. 1. Principle of the estimation of the possible loss of charge in alternate mode. The total rectangular surface represents the maximum capacity of the battery and the black part the available capacity, or the charged ratio.

to maintain the maximum capacity of the VRLA batteries, with a lower average current rate.

3.2. Recharging

Another important question that must be asked before giving up the floating mode for standby applications is the way the recharge of the battery could be achieved. With the conventional floating mode, a discharged battery is first recharged with a constant current mode (at a *C*/10 regime) until the floating voltage is achieved. The recharge is then finished in a constant voltage mode at the floating voltage.

The recharging characteristics that are tested in the following experiments are also composed of a first step in constant current mode (at a *C*/10 regime). However, the cut-off voltage is the maximum voltage parameters of the

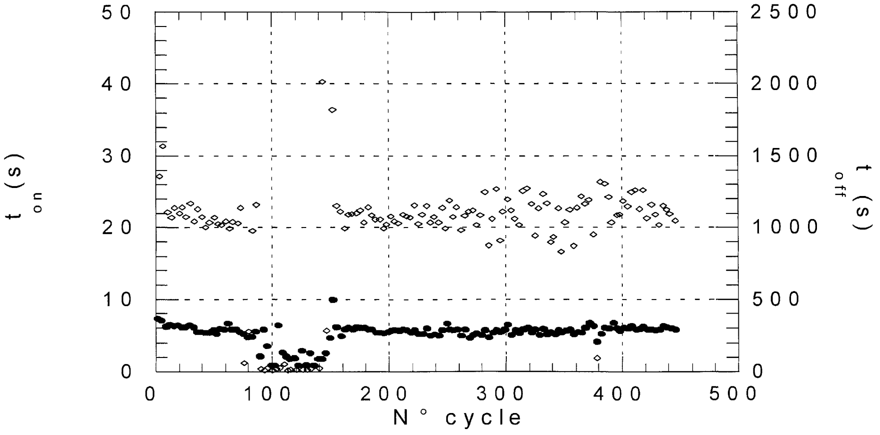

Fig. 2. The t_{on} (●) and t_{off} (○) values during an alternate period (with parameters MMM, see Section 2) following an 1 week floating period.

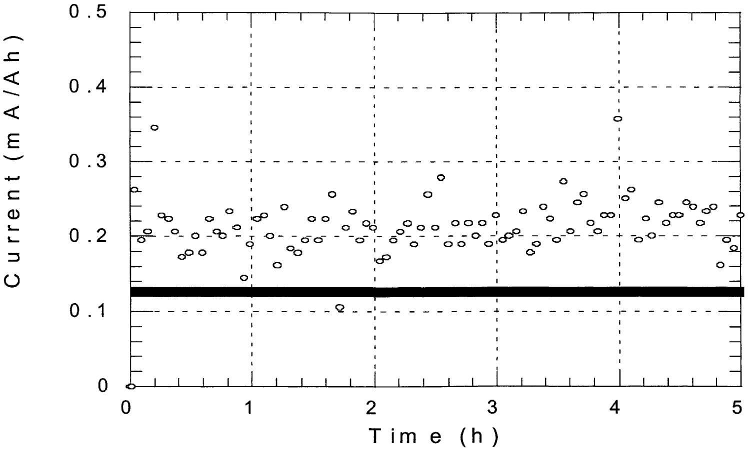

Fig. 3. Evolution of current with time in the final floating period following the alternate one (○). The straight line represents the level of the constant average current during the alternate period.

alternate mode that will immediately follow (beginning with an off period).

The measurement of the charge ($\Delta Q'$) required for the return to stabilized floating conditions after about 1000 cycles in alternate mode allows a quantitative estimation of the level of capacity achieved when recharging the battery is accomplished with constant current followed by alternate conditions. This principle is sketched in Fig. 4.

The first conclusion of this experiment is the negligibility (not measurable in our conditions, which means

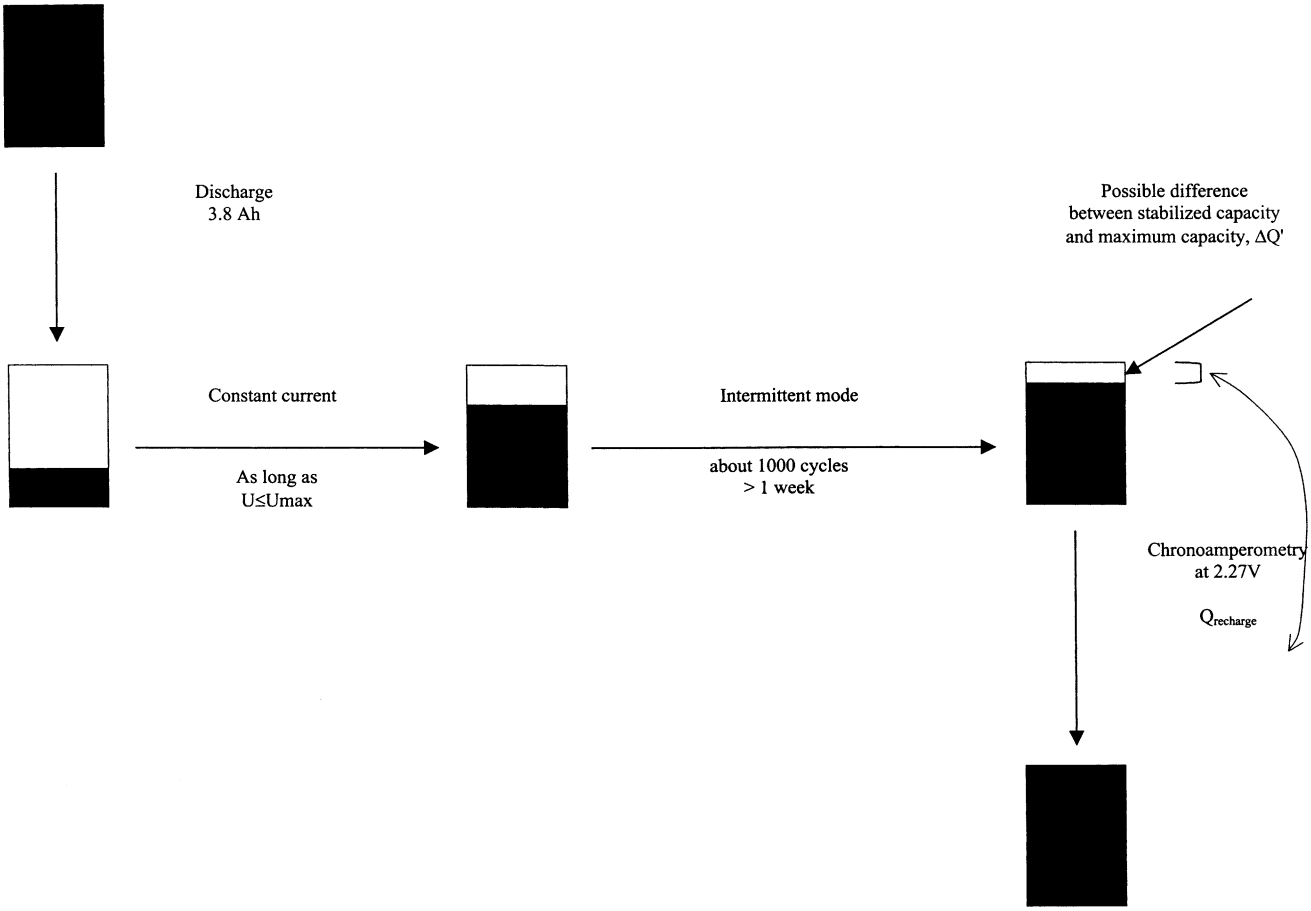

Fig. 4. Principle of the estimation of the level of capacity achieved with recharging conditions using alternate mode. The total rectangular surface represents the maximum capacity of the battery and the black part the available capacity, or the charged ratio.

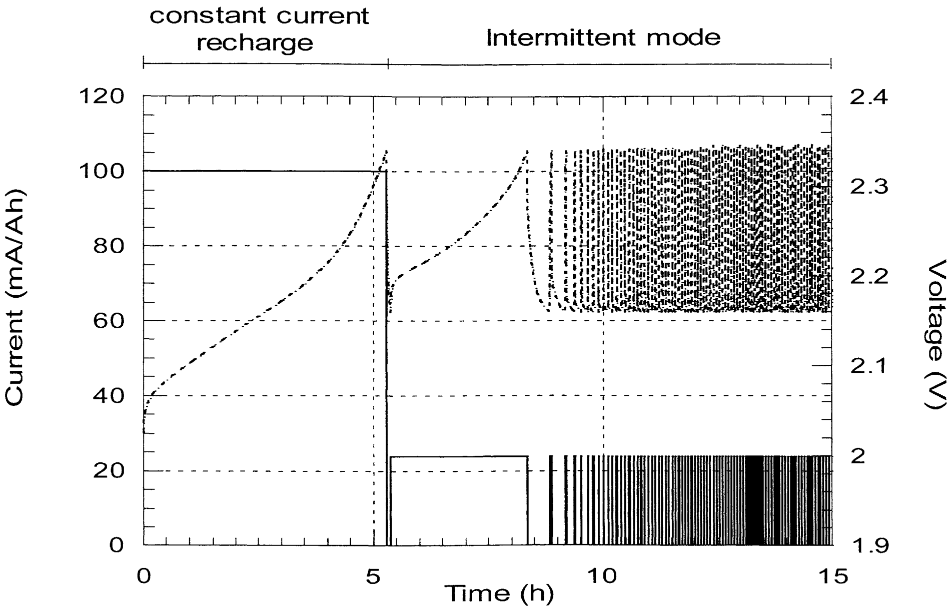

Fig. 5. Evolution of current (continuous line) and voltage (dotted line) with the recharging time following a 3.8 Ah discharge. The exact procedure of recharge is described in the text (constant current at $C/10$ regime followed by an alternate period).

$\Delta Q' < 1$ mAh) of the charge necessary to return in stabilized float conditions. The previously described procedure using alternate mode (with MMM parameters) following constant current period is an efficient way to obtain the maximum capacity of the VRLA batteries after a discharge.

Another data that are interesting to analyze is the beginning of the recharging procedure, as shown in Fig. 5. At the beginning of the alternate period, the current and voltage responses display a first very large value of t_{on} (about 3 h instead of 6 s in maintaining conditions, see Section 3.1) and a first low value of t_{off} (around 340 s instead of around 1100 s in maintaining conditions, see Section 3.1). Those characteristics are directly linked to the fact that the battery is not completely charged when the alternate period begins: alternate mode allows, like the floating one, the achievement of full recharge.

The evolution of the level of capacity with recharging time in both recharging modes, as shown in Fig. 6, allows the comparison of the time needed to reach different levels of recharge. The important information extracted from these data is that the time needed to reach 98% of the maximum capacity after a discharge is exactly in the same order of magnitude with both recharging modes (around 10 h). Only the last percent is longer to be reached in alternate mode (with MMM parameters).

3.3. Influence of the parameters of the alternate mode

In this section, the influence of the parameters of the alternate mode (see Section 2.3) is investigated. First, the time rate of the recharging process following a same discharge is measured with the different alternate conditions. The Table 2 brings together these results. The first line with MMM parameters corresponds to three different experiments, to allow estimation of the experimental reproducibility.

The only parameter that logically plays a role on the duration of the first constant current step (at a $C/10$ regime) is the maximum voltage. When the maximum voltage is high (+ value at 2.40 V) the constant current step allows to reach almost 95% of capacity in less than 6 h. On the opposite with a lower maximum voltage (− value at 2.28 V) the constant current step ends sooner and therefore leads to slightly less than 90% of capacity.

Afterwards during the second alternate period, the three parameters have an effect on the recharging rate. Until 98% of capacity, the maximum voltage value remains the most influencing parameter: the recharging rate is globally higher with a high maximum voltage value. However, a high minimum voltage value will also improve the recharging rate. The influence of the level of recharging current is not obvious (some coupled effects exist): a high current accelerates the recharging procedure when high maximum voltage is used and, on the opposite, reduces it when low maximum voltage is chosen.

An important conclusion is that in these studied conditions, the time required to reach 95% of maximum capacity is on the same order of magnitude (10 h) that with the usual floating mode. This result is illustrated in the Fig. 7, where the evolution of capacity with the time of recharge for the extreme cases (that is to say + + + and − − + conditions) is compared to the floating conditions.

In standby applications, the time required to recover the last 5% of capacity is not a critical property. The previous experiments allow the choice of alternate parameters that meet these requirements.

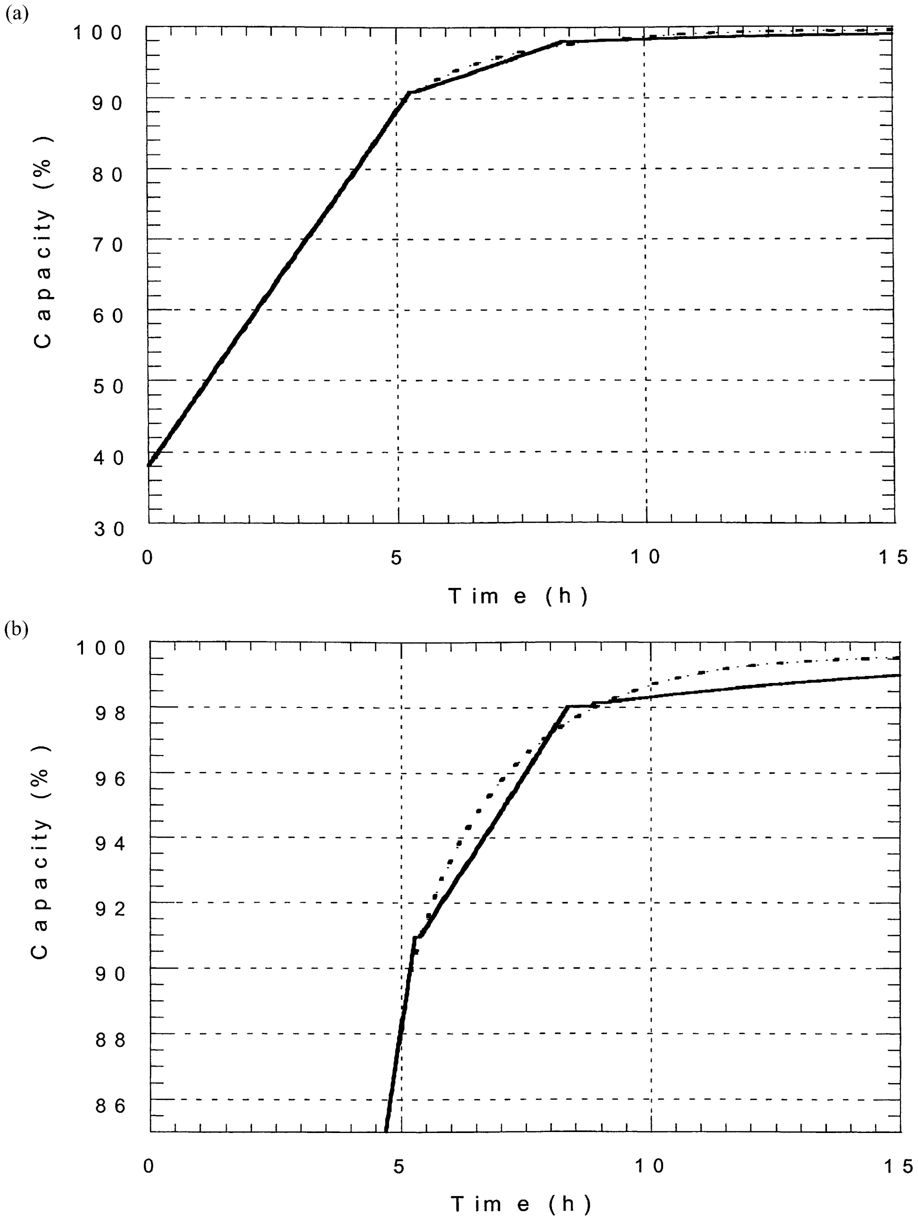

Fig. 6. Evolution of the percent of capacity with recharging time following a 3.8 Ah discharge. Continuous line corresponds to the response of the battery with an alternate mode and the dotted line corresponds to the floating mode. The (b) figure is a zoom of the (a) one.

The second type of results, which are important to study, are the average current obtained in stabilized conditions (that corresponds to maximum capacity, as shown for MMM parameters in previous experiment, Section 3.2). This value is actually connected with the amount of irreversible damages (like grid corrosion) in the battery, as shown by accelerated aging tests (see footnote 1).

The Table 3 brings together these results. The first line with MMM parameters corresponds to three different experiments, to allow estimation of the experimental reproducibility, which is not very good.

Due to the bad reproducibility, the following discussions have to be taken only as tendencies, that should be confirmed by other experiments. The most influential parameter is the value of the minimum voltage in the alternate mode. A low value of the minimum voltage (− value at 2.14 V) leads to a significant decrease of the average current in maximum capacity maintaining conditions. On the contrary, high value of the minimum voltage (+ value at 2.18 V) can lead to higher value of stabilized current than in floating conditions. The recharging current value does not seem to have a significant influence. But a high maximum voltage is favorable with a low minimum voltage and unfavorable in the other case.

Finally, if the time required to reach the fully maximum capacity is not the first criterion (for example, if the last 2%

Table 2
Temporal characteristics of the recharge procedure with different parameters in alternate mode

Recharging conditions (see Section 2)	Duration of the constant current step (at *C*/10 regime) (h)	Capacity achieved at the end of the constant current step (%)	Time required to reach 85% of maximum capacity (h)	Time required to reach 90% of maximum capacity (h)	Time required to reach 95% of maximum capacity (h)	Time required to reach 98% of maximum capacity (h)
MMM	5.3–5.8	91–96	4.6[a]	5.2[a]–5.3	6.5–7.3	8.0–10.5
− + −	5.6	94	4.6[a]	5.2[a]	7.9	10.1
− + +	5.6	94	4.6[a]	5.2[a]	7.0	8.0
− − −	5.0	87	4.6[a]	7.2	10.5	32.0
− − +	4.9	87	4.6[a]	6.1	10.9	70.0
+ + −	5.7	95	4.6[a]	5.2[a]	6.2	8.4
+ + +	5.6	94	4.6[a]	5.2[a]	6.0	7.0
+ − −	5.1	89	4.6[a]	6.0	9.4	12.5
+ − +	4.8	86	4.6[a]	6.1	8.2	17.3
Floating	4.9	87	4.6[a]	5.3	6.5	9.0

[a] Points out the values that correspond to the first recharging step at constant current.

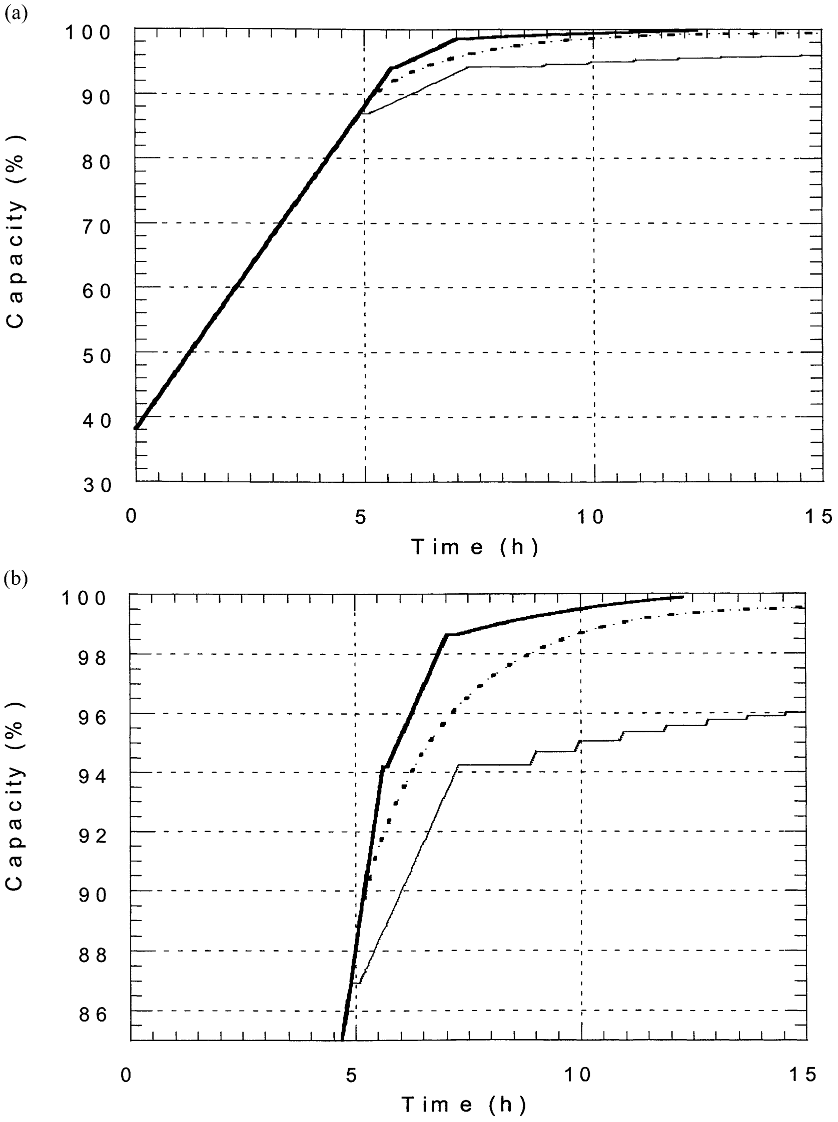

Fig. 7. Evolution of the percent of capacity with recharging time following a 3.8 Ah discharge. Continuous lines correspond to the responses of the battery with alternate modes (thick line for + + + parameters and thin line for − − + parameters) and the dotted line corresponds to the floating mode. The (b) figure is a zoom of the (a) one.

Table 3
Stabilized characteristics of the recharge procedure with different parameters in alternate and floating mode

Recharging conditions (see Section 2)	Stabilized average current (mA/Ah)	Time required to reach stabilized conditions after a discharge (h)
MMM	0.13–0.23	40–130
− + −	0.13	66
− + +	0.10	70
− − −	0.16	92
− − +	0.14	72
+ + −	0.30	15
+ + +	0.35	25
+ − −	0.21	27
+ − +	0.18	25
Floating	0.2–0.4	20–35

could be reached in a few days, which is generally the case), the best parameters in the explored domain are the − + + conditions, that is to say: minimum voltage at 2.14 V, maximum voltage at 2.40 V and recharging current at 33 mA/Ah.

4. Conclusions

We have reported here some experiments that allow quantitative conclusions about the use of alternate mode (alternation of constant current charge and open-circuit periods) instead of floating mode (constant voltage condition) in standby applications of VRLA batteries.

1. First of all, alternate mode with suitable parameters really allows the maintaining of the maximum capacity of the battery. Secondly, it lowers the average overcharge current in standby conditions. This result can be put together with previous results of improved service-life with alternate mode.
2. The efficiency of recharging procedures using alternate mode is also evaluated. The recharging rate is on the same order of magnitude than with usual floating mode up to 95% of maximum capacity. Only the last percents are longer to reach in alternate mode.
3. A discussion about the influence of the parameters in alternate mode is done. The maximum voltage plays a significant role on the recharging rate whereas the minimum voltage plays a more significant role on the level of stabilized average overcharge current.

Aging tests in order to confirm the best parameters would advantageously complete these results. It would also be interested to explore alternate responses with lower minimum voltage and higher maximum value, provided the achievable capacity level is kept in mind.

References

[1] D. Linden, Handbook of Batteries, 2nd Edition, Mac Graw Hill, 1995, pp. 25.1–25.39.

[2] F.A. Flemming, L. Gao, P.R. Shumard, R. Evans, R. Kurian, in: Proceedings of the INTELEC 1999, IEEE, 1999, 3 pp.

[3] D. Berndt, Maintenance-Free Batteries, 2nd Edition, Research Studies Press Ltd., Taunton, Somerset, UK, 1997, pp. 403–427.

[4] D. Berndt, U. Teutsch, J. Electrochem. Soc. 143 (1996) 790–798.

[5] L.T. Lam, H. Ozgun, O.V. Lim, J.A. Hamilton, L.H. Vu, D.G. Vella, D.A.J. Rand, J. Power Sources 53 (1995) 215–228.

[6] R.F. Nelson, E.D. Sexton, J.B. Olson, M. Keyser, A. Pesaran, J. Power Sources 88 (2000) 44–52.

[7] D.P. Reid, in: Proceedings of the INTELEC 1984, IEEE, 1984, pp. 67–71.

[8] R.F. Nelson, J. Power Sources 73 (1998) 104–109.

[9] W. Jones, D. Feder, in: Proceedings of the INTELEC 1996, IEEE, 1996, pp. 184–192.

[10] W. Jones, D. Feder, in: Proceedings of the INTELEC 1996, IEEE, 1996, pp. 358–366.