INTERMITTENT VRLA CHARGING: A MOSTLY BAD HISTORY, BUT IS THERE A BETTER WAY?

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Abstract

Intermittent charging of VRLAs has been around for a long time, and sometimes there is no choice (the application can only charge intermittently: think for example, of vehicle engine-starting VRLAs, and standalone photovoltaic applications). Intermittent charging by choice has also been tried many times as a potential way to lengthen battery life. In most cases, this has failed miserably in its goal. This paper will examine the theory behind why intermittent charging should work in lengthening life if done properly, as well as show examples of how it has been done improperly, and why it didn't work.

Understanding Corrosion, Gassing, and Sulfation

The key to properly designing an intermittent charging scheme that lengthens VRLA battery life, as opposed to shortening it or having little to no effect on life[1], is to properly understand what happens in a traditional VRLA battery when it is overcharged and undercharged. As can be seen[2] in Figure 1, when overcharged, the positive electrode is corroded and the VRLA slowly but surely outgasses and dries out[3], eventually resulting in failure. In a traditional VRLA, undercharging causes sulfation of the positive and negative electrodes. If the sulfate crystals that are formed in the negative do not exist for long in a traditional lead-acid battery before an overvoltage (proper charge) is applied, it is referred to as "soft" sulfation, and most of those crystals can be converted back to lead and sulfuric acid. However, if a traditional lead-acid battery remains in an undercharge state for long, the crystals on the negative plates turn to "hard" sulfation, which might or might not be able to be removed by a relatively high overcharge. And even if they are removable by that "higher" overcharge, that overcharge will result in positive plate corrosion and excessive gassing, which leads eventually to dryout in a VRLA and failure. Prolonged undercharging results in permanent hard sulfation (unrecoverable) on the positive electrode.[4]

The question then becomes, why not charge the lead-acid cells at exactly the critical minimum float voltage[5] shown in Figure 1, which would result in the lowest rates of sulfation, positive plate growth, and gassing? The reason is that except for a battery composed of only a single individual 2 V cell of 2 internal plates (a single positive and negative), this is impossible. To increase the voltage (to reduce conductor sizes, and thus cost), battery cells are put in series-connected strings. Despite the best efforts at quality control and factory formation charge voltage matching, no two lead-acid plate pairs or cells come off the line exactly equal. Thus when these inherently unequal individual cells and plate pairs are placed in a series-connected cell or string, and where by Kirchoff's laws the current is equal throughout the string, the cells and plate pairs will be at slightly unequal float voltages. It is useless to try to make these individual cell float voltages all equal, since they are inherently unequal cells, and in truth, each plate pair is inherently unequal.

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[1] If intermittent charging is used in a non-cycling application, but doesn't lengthen life, the cost of such a system is wasted

[2] Figure 1 is derived from seminal papers by Lander; Willinghanz; and Brecht, et al

[3] The recombination efficiency of evolved H_2 and O_2 due to nearly unavoidable overcharge is typically no higher than 99%

[4] Some of the sulfation information is derived from an Isidor Buchmann tutorial

[5] Critical minimum cell voltage is the open circuit voltage of the cell plus approximately 50-75 mV of overall polarization to overcome the effects of "local action" (i.e., trying to keep the sulfuric acid from discharging the plates while on charge). The critical minimum of approximately 2.135 V/cell for a 1.215 s.g. VLA cell is found in IEEE1635/ASHRAE 21. It is the point where float current reaches 0 as voltage is decreased, and was derived from data in the Enersys PowerSafe/DataSafe Flooded Lead-Acid Batteries Owner's Manual. Local action is occurring at voltages below where float current has decreased to zero.

Because of this series string of inherently unequal cells and plate pairs, even if the float voltage were to be set at a voltage equal to the critical minimum float voltage per cell times the number of cells, some of the cells would end up on the corrosion/gassing part of the curve, and others would end up on the sulfation part of the curve. When they are in the sulfation part of the curve, they have less than their practical capacity due to the lower voltage (thus lower energy), and the positive plate growth due to sulfate crystals is increasing. So, due to the desire of users to achieve close to full capacity out of their batteries, almost all users (per manufacturer recommendation) float their batteries at a float voltage that is a few hundredths of a volt per cell (on average) higher than the critical minimum float voltage. This can be as much as 12 hundredths of a volt average in longer strings (higher voltage) vented cells, and as little as 3 hundredths of a volt in VRLA strings in order to avoid premature dryout. This slight average overcharge ensures that the standby battery will have as much capacity as it is capable of. However, it also means that vented lead-acid batteries will typically die of positive grid growth, and VRLA batteries will usually die first from dryout due to gassing, since water cannot normally be added back in, unlike a vented cell.

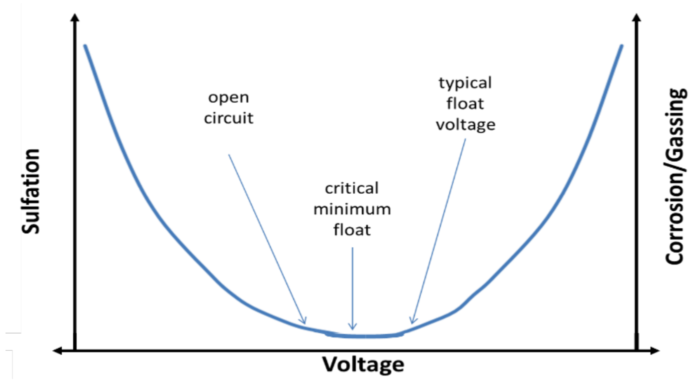

Figure 1. Lead-Acid Battery Corrosion/Sulfation "Well"

In an intermittent charging scheme, the float charge is removed for a period of time before charging is reapplied for a period. During the removal of charge from the battery (and while any loads connected in parallel are fed by the rectifier), the battery begins to self-discharge. It is generally accepted that for lead-acid batteries, the decay time from float voltage to open circuit is approximately 72 hours (see Figure 2)[6]. However, sulfation begins long before the cell reaches open circuit voltage under natural decay conditions (see Figure 3).

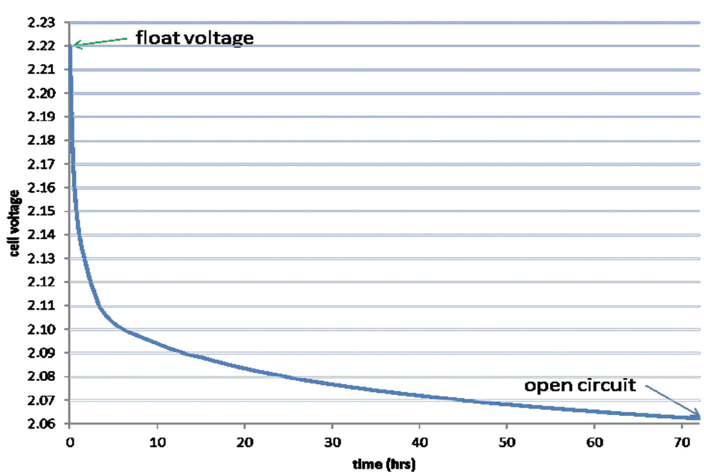

Figure 2. Natural Loadless Decay to Open Circuit Voltage of a Vented Lead-Calcium 1.215 s.g. Cell

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[6] Figures 2 and 3 were derived from Nuclear Logistics Inc. data observed in 1997.

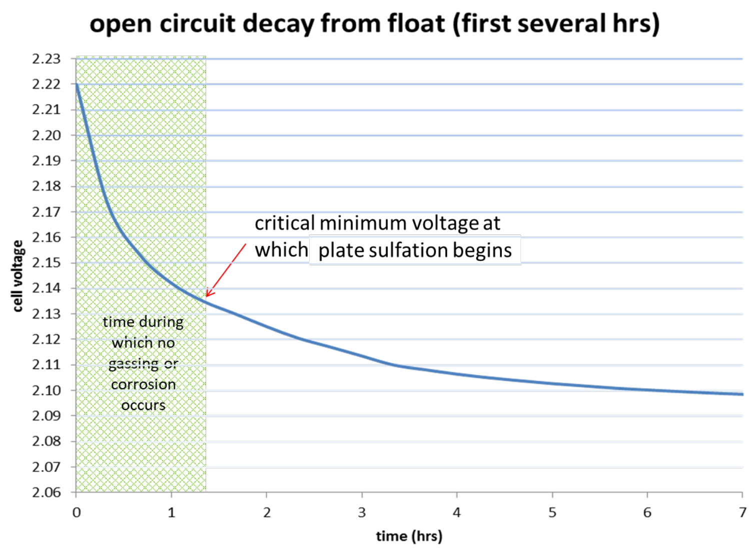

Figure 3. The First Several Hours of a The Decay Shown in Figure 2

Examples of Unavoidable Intermittent Charging

While intermittent charging of lead-acid batteries in stationary standby applications has gotten a bad rap (deservedly so due to some of the misapplications of it that will be highlighted later in this paper), there is nothing inherently wrong about intermittently charging a lead-acid battery. In fact, there are some applications where intermittent charging of lead-acid batteries is natural and unavoidable, such as a car (see Figure 4)[7], or a standalone solar photovoltaic system (see Figures 5 and 6)[8]. At least 3 manufacturers have developed intermittent chargers (as opposed to commonly found pulse-chargers) for stationary engine starting applications. These chargers somewhat mimic the natural overcharge and rest cycles of an automotive application. In the opinion of this author however, there would be no need to overcharge if the rest cycle time were minimized (see the last major section of this paper for more information on this idea).

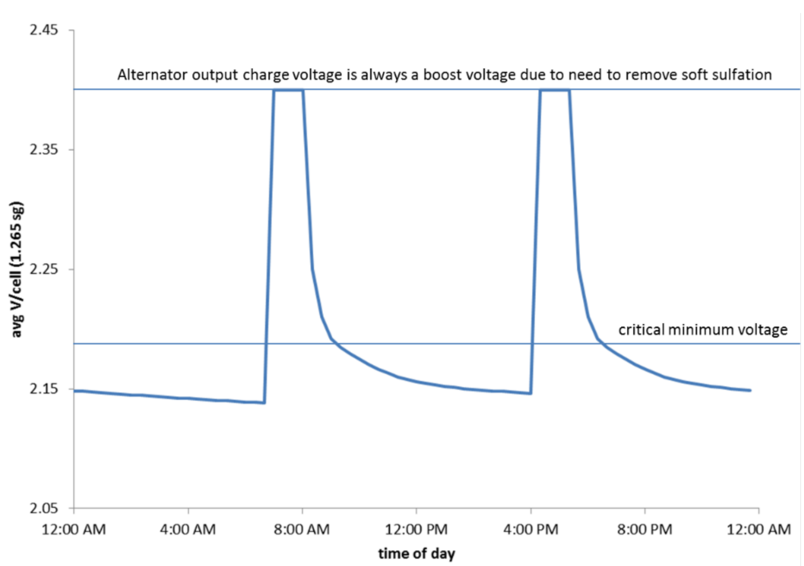

Figure 4. Typical Car Battery Daily Charge-Rest Cycle

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[7] The idea for figure 4 came from a 2017 Bill Kaewert Battcon paper
[8] Figures 5 and 6 were derived from papers published by T. Murphy of UCSD

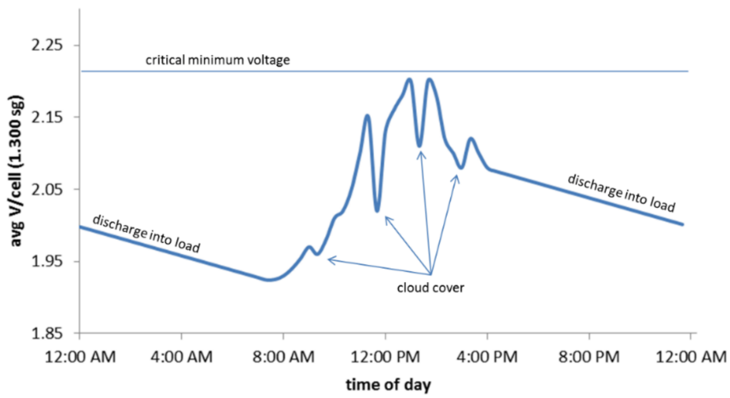

Figure 5. Typical Winter Standalone PV Daily Battery Cycle

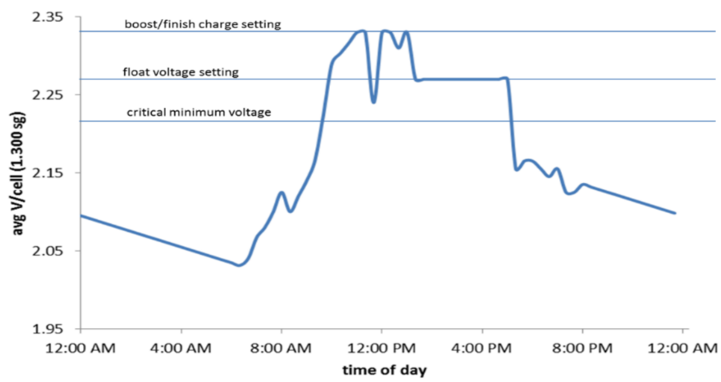

Figure 6. Typical Summer Standalone PV Daily Battery Cycle

Intermittent VRLA Charging by Choice – Failed Schemes

As mentioned in the previous section, there have been several misapplications of intermittent charging of VRLA batteries that have given intermittent charging a bad name among many in the stationary standby lead-acid battery industry. The first the author ran across was a scheme invented by power engineers at Northern Telecom (later Nortel) in the 1980s. It used (and still does because there are still thousands of these systems) two separate charging buses, one being a boost charge bus (above typical float voltage), and the other a rest charge bus whose setting is between open circuit and critical minimum voltage. The parallel strings (typically 6-8 of them) of relatively small VRLA batteries are rotated (usually 2 strings at a time) between the rest bus and the boost charge bus as shown in Figure 7.

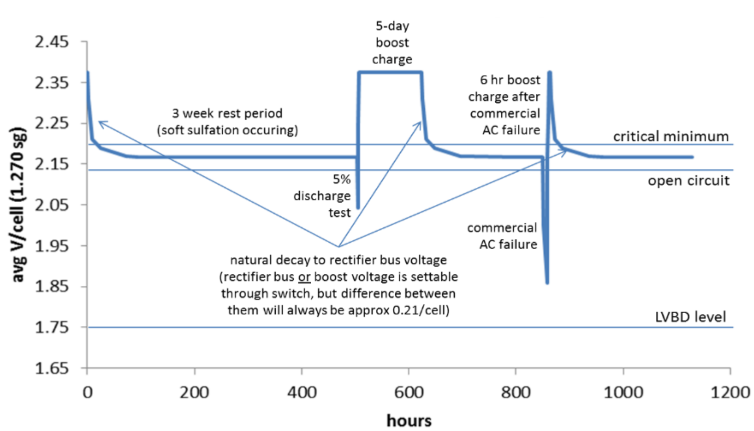

Figure 7. Old Nortel Remote Terminal (RT) Intermittent Charging Scheme

Experience has shown that this Nortel scheme neither lengthens nor reduces life, but simply costs extra money in the form of the DC-DC converter that produces the secondary bus voltage, as well as the relays that transfer the battery strings between the two buses. The problem with the scheme is that it leaves the batteries under the critical minimum voltage for too long (although the rest bus voltage and timeframe probably do not allow the sulfation to ever become "hard", especially because of the boost charge that will remove the majority of the sulfation). It also leaves the batteries in boost charge for too long, gassing them and drying them out. In sum, the resting probably lengthens battery life (especially when overcome by the boost charging); however, the overly long time on boost charge negates the advantages of the rest cycles, thus resulting in no relative net gain or loss in average battery life.

Another "infamous" intermittent charging scheme that still exists is the Advanced Battery Management System (ABM®) offered by one UPS manufacturer. This scheme is illustrated in Figure 8. This scheme, as originally designed, probably shortens battery life based on most user experience. Similar to the Nortel scheme, the rest period is too long (in this case, way too long, leading to not just "soft" sulfation, but some "hard" sulfation), and allows the voltage to fall way too low. In addition, the boost charge (though relatively short in duration) gasses the VRLA and corrodes the positive, and is probably not long enough to remove all the "hard" sulfation buildup from the excessive "rest" period. Finally, the excessive rest period, which may even include some very short outages without a battery recharge, causes problems for ohmic measurement accuracy (both permanent and portable instruments), since trending analysis of ohmic readings requires that they be taken with a battery at the same state-of-charge. In response to user complaints, the UPS manufacturer in question has allowed users to completely disable ABM®, or set the boost voltage to a lower level (typically float). The latter "fix" helps decrease the life loss a slight bit, but due to the "hard" sulfation buildup from the excessive rest periods, there is still significant premature capacity loss (PCL).

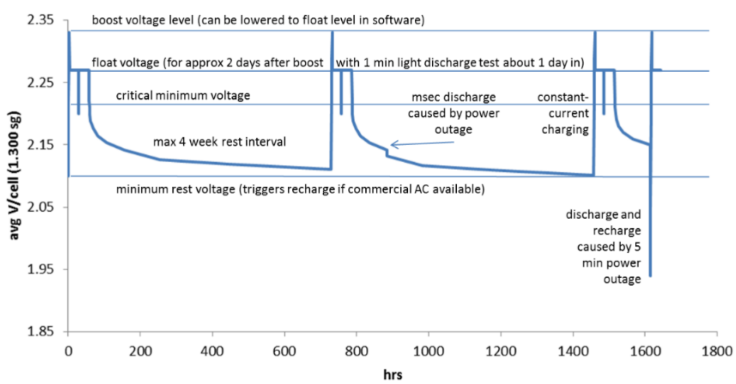

Figure 8. One UPS Vendor's ABM® (Advanced Battery Management) Charging Scheme

Some Lab and Field-Trial Work to Try to Improve Intermittent Charging

More than one battery vendor (who wished to remain nameless) shared non-published data with this author from lab and field trials conducted in the early part of this century. The intermittent charging schemes are presented in graphical form in Figures 9-11, and represent 1 day on float for every week of "rest", 1 day on float for every 3 days of rest, and a day on / day off float cycle, respectively. To the best of the author's memory, the preliminary data from 3-4 years of field testing at ambient temperature and in heat ovens from these two vendors seemed to indicate actual lifetime expectancy improvements of 10-30%, 30-40%, and 40-60%[9] for these 3 schema, respectively.

[9] These improvements were determined based on both nominal temperature and accelerated life temperature testing of aged batteries vs control batteries. A couple hundred batteries were used in these studies.

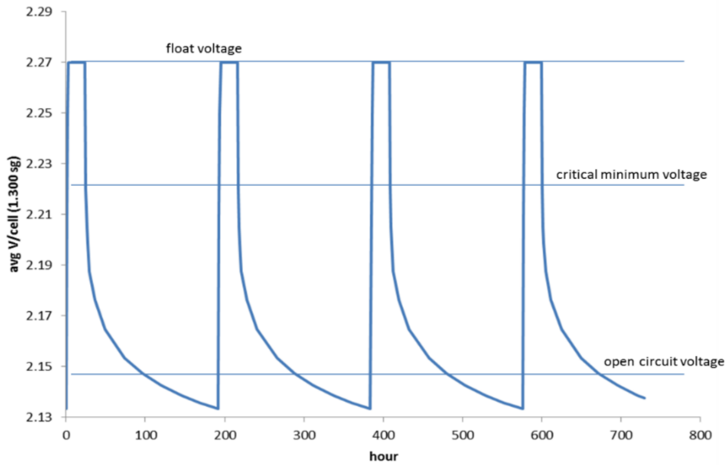

Figure 9. Intermittent Charging Scheme (1-Month of Charge-Rest Cycles) of Vendor #3, First Lab Trial

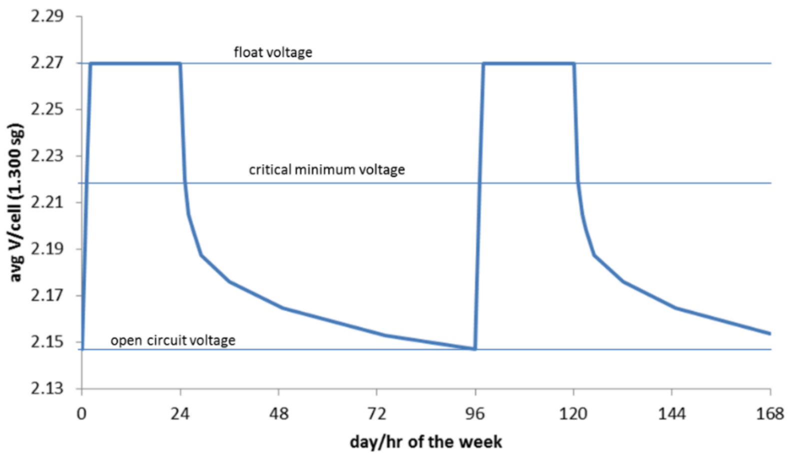

Figure 10. Intermittent Charging Scheme (a Week of Charge-Rest Cycles) of Vendor #3, Second Lab Trial

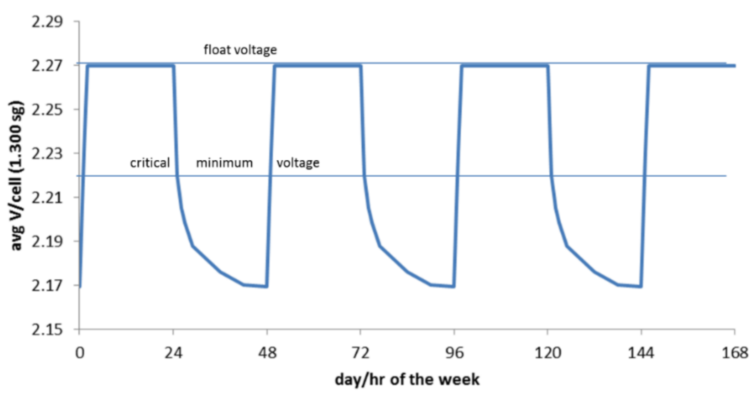

Figure 11. Intermittent Charging Scheme (1 Week of Charge-Rest Cycles) for Vendor #4 Field Trial

Is There a Better Way?

The results of the two battery vendors' lab and field trials (as well as the field experience with the Nortel and ABM® charging schemes) seem to indicate that it is probably best to not allow the voltage to decay into the region of sulfation for constant float applications[10]. The results of the Nortel and ABM® intermittent charging schemes (especially when the boost voltage is active in the original ABM algorithm) seem to suggest that boost charging of VRLA AGMs should be avoided. Even though boost-charging can overcome "soft" sulfation, it significantly speeds up positive plate corrosion (and gassing/dryout) in VRLA AGMs.

Another vendor has given two previous Battcon papers that show their results to date using a charging scheme that float charges on average about 15-20% of the time, and the rest of the time "rests" the battery, rarely letting the voltage fall below (or much below) the critical minimum. Based on the field and lab trial results of the vendor (under both standard temperature and accelerated life testing), and field trial experience with the system by the author, the author believes (without field trial data, but based on real data from similar schemes used previously, as well as the electrochemical principles covered in this paper) that the simple intermittent charging scheme shown in Figure 12 (and blown up in Figure 13) will lengthen VRLA AGM battery life by even more than the 60% that one battery vendor found as the high-water mark of their day-on / day-off intermittent charging scheme. Note that this scheme is not as complex as the scheme used by the vendor (which is proprietary, and covered under patents) mentioned at the beginning of this paragraph, but should produce similar results, if not quite as good; but is simpler to implement.

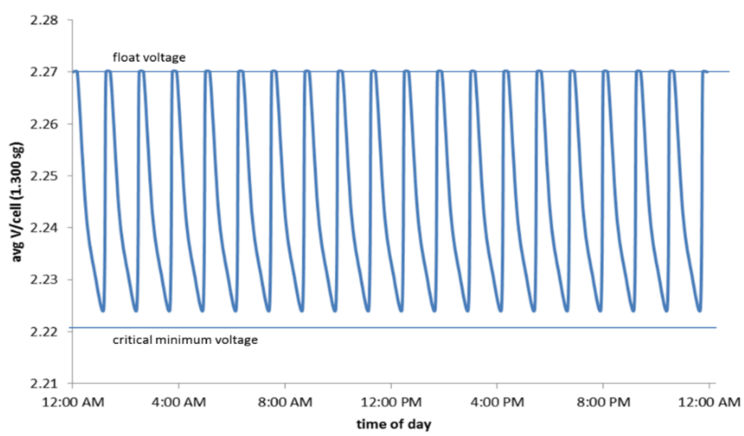

Figure 12. A Day of "Ideal"? Intermittent Charging

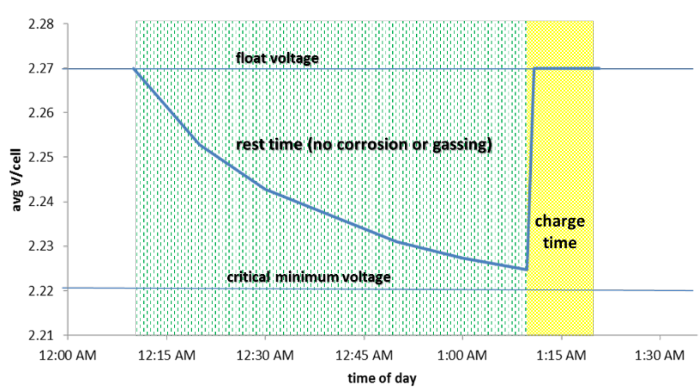

Figure 13. Single "Idealized"? Rest-Charge Cycle

[10] For VRLA cycling applications where the battery must operate portions of the time in the sulfation region, carbon additives have been shown to reduce the effects of sulfation.

Summary

While intermittent VRLA charging by choice has a mostly bad history, based on electrochemical principles and some lab and field trials, this author feels that there is a proper way to do it which will significantly lengthen VRLA (especially AGM) battery life.

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The contributions of Bill Cantor, Jim McDowall, and Mike Nispel in getting the electrochemistry right (along with the correct reference documents) are highly appreciated. Also appreciated in improving other parts of the paper, are the contributions of Eric Hedlund, Kurt Uhlir, Brian Zimmerman, and the aforementioned trio. The contributions of the author's colleague, Scott Miyoshi, in properly understanding the Nortel intermittent charging scheme are also acknowledged.

References

1. D. Berndt and U. Teutsch, "Float Charging of Valve-Regulated Lead-Acid Batteries: A Balancing Act Between Secondary Reactions," Journal of the Electrochemical Society, Vol. 143, No. 3, March 1996, pp. 790-798.
2. D. Boden, "A new method for maintaining the charge of VRLA batteries in standby power systems," Proceedings of Battcon 2014.
3. D. Boden, D. Carr, S. Mulawski, and A. Rawitz, "Adaptive charging: a further development of intermittent float for charge maintenance in VRLA batteries in telecommunications standby systems," Proceedings of Battcon 2016.
4. W.B. Brecht, D.O. Feder, J.M. McAndrews, and A.J. Williamson, "The Effect of Positive Plate Polarization on Grid Growth, Cell Performand and Life: 'Willinghanz Revisited – 20 Years Later'," Proceedings of Intelec 1988, paper 5-7.
5. I. Buchmann, Battery University (sponsored by Cadex) BU-804b, "Sulfation and how to prevent it," last updated September 22, 2016.
6. Eaton 00DATA1018811, "Powerware® series: ABM® technology," Revision A, September 2009.
7. Enersys US-FL-IOM-AA, "PowerSafe/DataSafe Safety, Storage, Installation, and Operations Manual for Flooded Lead-Acid Batteries C, D, E, F, and G," September 2016.
8. Enersys US-ODY-PC-AA, "Odyssey® Battery Portable Chargers," March 2016.
9. J. Frankhouser, J.Anderson, and E.Lehmann, "Advanced lead-carbon batteries in partial state-of-charge operation in stationary applications," Proceedings of Battcon 2017.
10. IEEE 1635 / ASHRAE 21, "Guide for the Ventilation and Thermal Management of Batteries for Stationary Applications", 2012.
11. W. Kaewert, "Intermittent charging increases flooded SLI battery life and cuts risk of catastrophic battery failure in emergency situations," Proceedings of Battcon 2017.
12. J.J. Lander, "Silver, Cobalt, and Positive-Grid Corrosion in the Lead-Acid Battery," Journal of the Electrochemical Society, 1958, pp. 288-292.
13. J. McDowall, "Avoiding the Pitfalls of VRLA Battery Charging", Proceedings of Battcon 1998.
14. X. Muneret, "Practical Influeence of Float and Charge Voltage Adjustment on the Service Life of AGM VRLA Batteries Depending on the Conditions of Use," Proceedings of Intelec 2004, paper 20-2.
15. T. Murphy, UCSD (University of California at San Diego), Do the Math, "Blow by blow PV system efficiency: a case study for storage," September 18, 2012.
16. T. Murphy, UCSD, Do the Math, "Death of a Battery", December 11, 2012.
17. T. M. Phuong Nguyen, G. Dillenseger, C. Glaize and J. Alzieu, "Traditional Float Charges: are they Suited to Stationary Antimony-free Lead Acid Batteries?" Trends in Telecommunications Technologies, Christos J Bouras (Ed.), 2010, ISBN: 978-953-307-072-8, InTech.
18. Nortel Std 297-8361-550, Section 04.01 of "OPM Maintenance Manual," September 2000.
19. E.D. Sexton, R.F. Nelson, and J.B. Olson, "Improved Charge Algorithms for Valve Regulated Lead Acid Batteries," Proceedings of the IEEE 15th Annual Battery Conference on Applications and Advances, January 2000, pp. 211-216.
20. F. Vacarro, R. Landwehrle, and G.Evans, "Accelerated life testing: Does it satisfy VRLA and designer needs," Proceedings of Battcon 2004.
21. E. Willinghanz, "Accelerated Testing of Stationary Batteries," Electrochemical Technology, Iss. 6, 1968, pp. 338-341.