A New Method for Maintaining the Charge of VRLA Batteries in Standby Power Systems

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Abstract

The conventional method for maintaining standby VRLA batteries in a fully charged condition is by float charging. This is an effective method for charge maintenance and is used throughout the telecommunications, data centers and many other industries. However float charging has a number of damaging consequences. The battery temperature is increased as a result of oxygen recombination with consequent increases in the rate of failure mechanisms such as grid corrosion, dry-out and electrode degradation resulting in premature battery failure. In this paper we present a new concept for charge maintenance which involves removing the batteries from continuous overcharging and replacing this with a periodic charge which charges the batteries only when necessary and for only as long as needed to maintain them at full charge. The benefits of this protocol are that the heat generating processes are largely eliminated with a consequent reduction in battery temperature. This significantly reduces the rates of grid corrosion, dry-out and plate degradation resulting in longer life. It also reduces the need for cooling and saves energy. A way that this system can be implemented in a practical battery management system is described and life test and other data are presented.

Introduction

Because of their critical applications standby batteries must always be maintained at full charge. The universally accepted way of doing this is by constantly charging them, a process known as float charging. This is done by attaching the batteries to a constant voltage rectifier which is set at a voltage high enough so that sufficient current is flowing through the batteries to overcome parasitic self-discharge arising from the inherent thermodynamic instability of lead-acid batteries, the effects of impurities that enhance gassing and cell-to-cell chemical or manufacturing variations.

Base transceiver stations (BTS), or cell towers, are almost universally equipped with VRLA batteries which do not allow water addition. There has been a tremendous increase over the last ten years of batteries deployed in uncontrolled outdoor installations and a high percentage of these are in tropical areas where high ambient temperatures are the norm. Although VRLA batteries have been very successful in reducing maintenance costs they have shorter life than the flooded type. They incorporate an exothermic oxygen recombination mechanism which generates heat inside them. Since there is minimal venting of gas this heat is trapped inside and can only be removed by inefficient transmission through the container walls. If they are closely packed in an installation very little heat can be removed. Therefore they operate at a higher temperature than flooded batteries which accelerates failure. In this paper we will discuss the mechanisms by which VRLA batteries fail and how these can be significantly reduced by a unique new maintenance system involving periodic charging instead of continuous float.

Float charging

A major characteristic of VRLA batteries while being float charged is their increased temperature primarily as a result of oxygen recombination. Additionally, VRLA batteries are floated at higher voltages and currents than flooded batteries so that the electrode potential of the positive plates is maintained in the region where grid corrosion is accelerated. The combined effects of high electrode potentials and high temperatures significantly increase the rate of grid corrosion and water loss resulting in short battery life. Continuous overcharging also causes active material degradation resulting from the long-term effects of oxygen and hydrogen evolution at the plate surfaces.

Berndt[1] has shown that the amount of heat released in a valve regulated cell amounts to approximately nine times the heat released in a vented cell under similar conditions.

In flooded cells:	Energy input = 31.5mW/100Ah Removed with gas = 20.7mW/100Ah Remaining heat = 10.8mW/100Ah.
In VRLA cells:	Energy input = 101.3mW/100Ah Removed with gas = 5.9mW/100Ah Remaining heat = 95.4mW/100Ah.

This is primarily due to the heat produced by oxygen recombination and elimination of heat removal by vented gas as would be the case in flooded cells.

Positive Grid Corrosion

Positive grid corrosion, which has been widely studied[8-32], takes place because lead in the grid reacts with water to form lead dioxide and hydrogen ions. The hydrogen ions are reduced to hydrogen gas at the negative.

$$Pb + 2H_2O \rightarrow PbO_2 + 4H^+ + 4e$$
$$4H^+ + 2SO4^{2-} \rightarrow 2H_2SO_4$$

Willihnganz[2] showed that in flooded batteries a linear relationship exists between the logarithm of life and the reciprocal of the temperature as a consequence of positive grid corrosion. This allowed calculation of the expected life at any operating temperature. The relationship follows the Arrhenius law and shows that life of flooded batteries is halved for every 10ºC increase. This has been verified by practical testing[3]. The same relationship holds reasonably well for VRLA batteries.

As shown in Figure 1, corrosion is also strongly affected by the polarization applied to the battery plates[4]. In continuous float charging, the applied voltage is distributed between the negative and positive plates. A characteristic of VRLA batteries is that when oxygen evolved from the positive plates is recombined at the negative plates the negative plate polarization is lowered. In order to maintain sufficient negative electrode polarization to assure charging the float voltage must be increased resulting higher currents. This increases the positive electrode potential leading to increased corrosion.

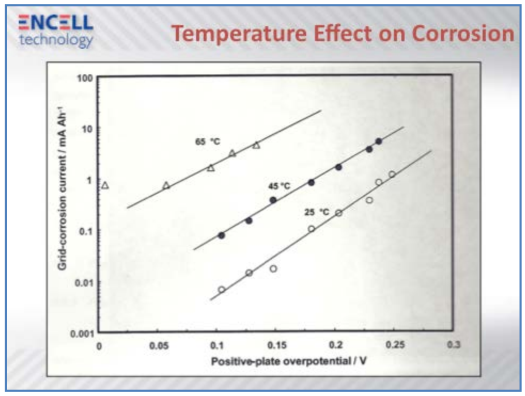

Figure 1. Corrosion of lead-calcium-tin positive grid alloy as a function of polarization and temperature.

This chart shows that the corrosion rate increases logarithmically as the positive plate overpotential and the temperature are increased. At a polarization of 0.100v the corrosion current increases from 0.006mA per ampere hour of battery capacity at 25°C to 1.5mA/Ah at 65°C. This example clearly shows that the rate of grid corrosion is significantly increased at high positive electrode potentials and high temperatures.

Gas Evolution and dry-out

Since floated batteries are continually on charge, gas is constantly evolved. In VRLA batteries most of the oxygen is recombined internally on the surface of the negative plates, but in some circumstances it can be released through the valve leading to dehydration and premature failure. The gas evolution is a complex function of the electrochemical reactions that take place when the battery is charged[5]. During charging the current is composed of the reactions taking place at the positive and negative plates and the current flowing through the positive and negative plates must be the same. At the positive: conversion of lead sulfate to lead dioxide, oxygen evolution and grid corrosion. At the negative: conversion of lead sulfate to lead, oxygen recombination and hydrogen evolution.

$$i_{PbSO4/PbO2} + i_{Oe} + i_{gc} = i_{PbSO4/Pb} + i_{He} + i_{Or}$$

Where:

$i_{PbSO4/PbO2}$ is the current from converting lead sulfate to lead dioxide

i_{Oe} is the current from oxygen evolution

i_{gc} is the current from positive grid corrosion

$i_{PbSO4/Pb}$ is the current from converting lead sulfate to lead

i_{He} is the current from hydrogen evolution

i_{Or} is the current from oxygen reduction

When the battery is fully charged no further formation of PbO_2 and Pb takes place therefore $i_{PbSO4/PbO2}$ and $i_{PbSO4/Pb}$ are zero and only oxygen evolution and positive grid corrosion takes place at the positive plates, and hydrogen evolution and oxygen recombination at the negative plates.

$$i_{Oe} + i_{gc} = i_{He} + i_{Or}$$

If all of the oxygen is recombined at the negative electrodes $i_{Oe} = i_{Or}$ and the rate of hydrogen evolution is equal to the grid corrosion current. However, for a number of reasons oxygen recombination is not always 100% efficient. For example the battery may be overfilled with electrolyte which will impede the flow of oxygen from the positive plate to the negative plate. The pressure release valve may be set at a low pressure allowing gases to vent and a degraded valve may allow air ingress. When the oxygen reduction current ($i_{Or)}$ is lower than the oxygen evolution current ($i_{Oe)}$ the hydrogen evolution current must increase to balance the equation and hydrogen production increases. Hydrogen and uncombined oxygen must be vented from the batteries resulting in dry-out, a common cause of VRLA battery failure.

A new concept – periodic charge

Float charging, as we have seen, contributes to short battery life primarily as a result of grid corrosion, dry-out and lack of equalization, all of which are inevitable consequences of continuous overcharging at constant voltage. The damaging consequences of overcharging have, in fact, been known for many years and it is normal practice in automotive and traction applications to charge batteries only when necessary and then only for as long as necessary. Why, then, are standby batteries still subjected to continuous overcharge? There is certainly a compelling reason to replace floating and eliminate its life limiting consequences. Encell Technology, Inc.[7] has developed an innovative periodic charging solution named the Sentinel. This is a solution that actively manages and monitors battery strings to achieve the longest possible life. It replaces continuous float with periodic charging, determines battery state-of-health, identifies failing or failed batteries and removes strings with defective batteries from charging to prevent them from shortening the life of other strings.

The operating principles are as follows:

(a) The batteries are taken off float which is replaced by a daily maintenance charge for only the time required to restore the batteries to full charge.

(b) The batteries are maintained in a standby (off charge) mode by isolating them from the rectifier bus. The benefit of this is that life is significantly increased by reducing temperature (no oxygen recombination) and thereby reducing grid corrosion and dehydration. Since there is no charge-related temperature increase thermal runaway is virtually eliminated and cooling costs are reduced. In this standby mode the batteries are still available for instantaneous discharge in case of a power outage. In the standby mode the batteries remain connected to the bus by a switching system involving diodes and MOSFETS that allow instantaneous connection when required. This is shown in Figure 3.

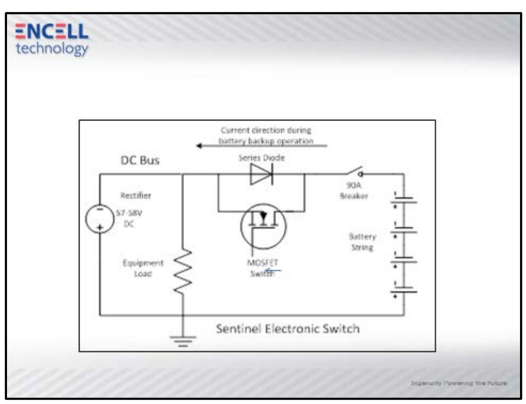

Figure 3. Circuit diagram showing the current path from the batteries through the diode to the DC bus.

The solution utilizes one-way electronic switching. This removes all of the EMI and equipment-damaging voltage spikes caused by electro-mechanical contactors and relays. The electronic switch MOSFET is controlled by the software, only for charging the batteries.

When the bus voltage begins to drop, from a resulting AC mains failure, the bus voltage will become lower than the battery string voltage. When this happens the diode one-way switch will start to forward-bias and conduct. This happens at the same rate that the bus voltage is dropping, so there are no voltages dips or spikes. Also important, is that there are no control functions required to make this happen. The actual circuit has several diodes in parallel and each diode is capable of handling 200% of the breaker current. The total diode current handling capability is over 900A. When the system detects that the batteries are supplying power to the bus, the MOSFET switch is enabled. The MOSFET switch is important, because it eliminates the voltage drop across the diodes, reducing power dissipation. At 90A, a diode with a typical 1V drop, will dissipate 90 watts of power as heat. The MOSFET switch resistance is less than 500 micro-ohms and dissipates about 4 watts of power at 90A of battery string current saving 86 watts of power to powering the bus. The MOSFET switch reduces the voltage drop across the diode, to about 0.05 volt and has the same current-handling capabilities as the diodes.

(c) Every day the batteries are given a maintenance charge by placing them on the rectifier bus until they are fully charged. As soon as the full charge criteria are satisfied the batteries are again isolated from charging. If the batteries have been discharged for more than a cumulative 5 minutes during the day they are immediately connected to the rectifier for charging to eliminate any possibility that they could stand in a partial discharged condition. A dv/dt charge control is used which involves pulse charging the batteries for 5 minutes followed by an off-charge period of five minutes. The voltage of every battery is recorded at the end of the off-charge period. This is repeated until the change in off-charge voltage is ≤0.020 volts at which time the charge is terminated. An example of this is shown in Figure 4.

This algorithm requires less daily energy because it is terminated as soon as the batteries are charged. Our measurements show that it reduces energy consumption of a 12v, 145Ah VRLA battery at a float voltage of 13.5V by 86%.

(d) In a multistring application, the strings are charged sequentially to assure string-to-string equalization. Each string is brought to full charge independent of the other strings in the system. This significantly reduces the inter-string variation that can occur when parallel strings are charged together.

(e) Once all the battery strings are charged they are given a state-of-health test. In this test a DC pulse discharge is applied to each individual battery for ten seconds. The voltage transient is recorded and used to calculate the internal resistance using the time of rest technique.

(f) Following the discharge test the batteries are again placed in the standby mode for 24 hours.

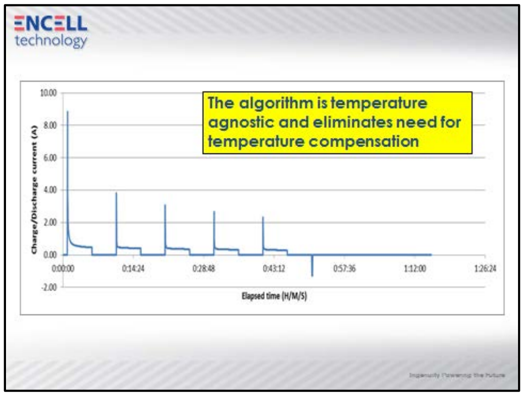

Figure 4. Example of the charge algorithm.

Life testing

The above sequence of tests is designed to assure that the batteries receive the minimum amount of charge consistent with returning them to a full state of charge at the end of each day. This eliminates the battery-destroying mechanisms that cause premature failure when continuously overcharged. It reduces their temperature since heat-generating processes are no longer occurring and eliminates plate polarization. Consequently, grid corrosion, gassing and plate degradation are significantly reduced resulting in much longer battery life.

VRLA batteries controlled by the battery management system are being tested in the field and laboratory to verify the life extension benefits of replacing continuous float charging with periodic charging. An independent test laboratory is being used to compare the capacities of VRLA batteries over time when they are on continuous float and when managed by the system. The tests are being carried out at 40°C (104°F) to simulate hot weather operating conditions. Five strings of batteries are being tested in each case. The battery capacities are measured at approximately three month intervals and are then averaged and charted as shown in Figure 5.

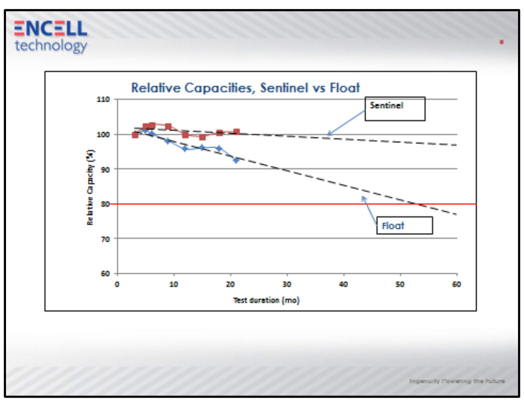

Figure 5. Capacities of batteries on continuous float and operated by the management system. Test temperature = 40°C.

The batteries are still under test and none have failed at this point. However a very clear trend has developed showing that the batteries under periodic charge management are showing much better capacity retention than those on continuous float.

Conclusions

Continuous overcharging as a method of maintaining standby batteries at 100% state of charge has been in use for many years but has serious negative consequences. It accelerates battery failure due to increased temperature, grid corrosion, plate degradation and dry-out. This results in high battery replacement costs. Battery life can be increased by removing these harmful failure mechanisms and by charging only when necessary and only for as long as necessary (the universal practice in most non-standby applications). The periodic charge solution is a new concept in battery management and monitoring, removes standby batteries from continuous charging while still allowing them to be available for discharge when needed.

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