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Methods of optimal charging of lead-acid battery for improving its performance and life span

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Battery is an electrochemical energy storage device that converts chemical energy into electricity, by use of a galvanic cell. The paper presents operation of lead acid battery, its chemical reactions and the charging methods to improve its performance and life span. The constant current charging mode results in overcharging of the battery as it is being pushed at full current. The constant voltage charging mode takes more time to charge the battery fully due to float charge, but the battery will not overcharge improving the life span. If the lead acid battery is undergoing deep discharge repeatedly then the life span of the battery will be less than its rated value. The operating temperature also has bearing on the life span. The paper is also presents the introduction to battery management system (BMS,) which is the heart of the battery system. The BMS involves a sophisticated supervisory control and data acquisition system (SCADA) with data management, control, protection and prediction.

Keywords: *Valve regulated Lead Acid (VRLA), Ampere hour (Ah), constant current charging, constant voltage charging*

1.0 INTRODUCTION

Battery is an electrochemical energy storage device that converts chemical energy into electricity, by use of a galvanic cell. Batteries do not generate electricity, they store it. Due to chemical reactions, the electrical energy will be stored or released. The characteristics of energy storage devices are energy density and discharge time. The energy density is the amount of energy that can be supplied from a storage source per unit weight. The discharge time is the period over which an energy storage device or source releases the stored energy. In rechargeable batteries this process can be repeated several times. Batteries are not 100% efficient but some energy is lost as heat due to chemical reactions during charging and discharging. Alkaline Batteries, with alkaline electrolytes have been developed during late 19th century. Most of these batteries use nickel oxide as positive plate material, with negative plates based on cadmium, iron, zinc, or hydrogen (the latter in the form of metal hydrides). Nickel-iron batteries were popular in the early 20th century, due to their higher specific energy and longer cycle life compared to lead-acid batteries. They received a renewed interest during the 1980s, but currently completely abandoned due to their poor low temperature performance and energy efficiency resulting in unacceptably high water consumption. The nickel-cadmium battery has positive electrode made from nickel oxide while the negative electrode is of metallic cadmium. The electrolyte consists of a solution of potassium hydroxide with lithium hydroxide, the latter having a stabilizing effect during cycling. The nominal cell voltage is 1.2 Volt. The nickel-zinc battery uses the same type of positive electrode

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as the nickel-iron and nickel cadmium, but with a metallic zinc negative plate. One of its advantages is the higher cell voltage (1.6 V) compared to other alkaline battery types. The use of hydrogen as negative active material gives a good energy to weight ratio. Storing and maintaining hydrogen gas can be quite cumbersome. Hydrogen is stored in metal alloys, in case of nickel-metal-hydride battery. Lithium-ion batteries operate based on the migration of lithium ions between a carbon anode and a lithium metal oxide alloy cathode. The electrolyte is an organic solution without any metallic lithium.

2.0 LEAD-ACID BATTERIES

The lead-acid battery was developed by Gaston Planté in 1859, but first demonstrated at French Academy of Sciences. In its basic form, the lead-acid battery consists of a negative plate of metallic lead and a positive plate made from brown lead dioxide, submerged in an electrolyte consisting of diluted sulphuric acid [1]. Lead-Acid batteries store energy by the reversible chemical reaction as shown below:

$$PbO_2 + Pb + 2H_2SO_4 \rightleftharpoons 2PbSO_4 + 2H_2O \quad ....(1)$$

At the negative terminal the charge and discharge reactions are:

$$Pb + SO_4^{2-} \rightleftharpoons PbSO_4 + 2e^- \quad ....(2)$$

At the positive terminal the charge and discharge reactions are:

$$PbO_2 + SO_4^{2-} + 4H^+ + 2e^- \rightleftharpoons PbSO_4 + 2H_2O \quad ....(3)$$

2.1 Classification Of Lead-Acid Batteries

Different types of lead-acid batteries are manufactured in various sizes depending on their construction and application.

2.1.1 Classification based on application

Automotive batteries: Theses batteries are commonly used to start and run engines. Engine starters need a large starting current for a very short duration of time. Starting batteries have a large number of thin plates to maximize the surface area. The plates are composed of a lead "sponge", similar in appearance to a very fine foam sponge. This gives a large surface area, but if deep cycled, the sponge gets consumed quickly and gets accumulated at the bottom.

Automotive batteries will generally fail after 30-150 deep cycles, while they may last for thousands of cycles under normal condition.

Deep cycle batteries: These batteries are designed for repetitive discharge to 80%. True deep cycle batteries have solid thick lead plates.

2.1.2 Classification based on construction

Flooded lead-acid Batteries: Flooded cells are those where the electrodes/plates are immersed in the electrolyte. Since gases produced during charging are vented to the atmosphere, distilled water must be added occasionally to bring the electrolyte back to its required level and concentration [2-3].

Gelled lead-acid Batteries: Gelled batteries contain acid that has been immobilized by the addition of silica gel. The advantage of these batteries is that there is no acid spill on breakage and need not be kept upright all the time as required in the case of the flooded batteries.

Absorbed Glass Mat (AGM) batteries: This type of sealed battery uses Absorbed Glass Mats a very fine fiber, boron-silicate glass mat between the plates as separator. These types of batteries have all the advantages of gelled cells and are more rigid. They are also called starved electrolyte, as the mat is about 95% saturated rather than fully soaked. They do not leak acid when broken. Nearly all AGM batteries are recombinant type wherein the oxygen and hydrogen produced during charging recombine to form water. The gelled and AGM batteries are also known as Valve Regulated Lead Acid (VRLA) batteries [4].

3.0 CHARGING METHODS OF LEAD-ACID BATTERIES

When the battery is being discharged, the lead (Pb) on the negative plate and the lead oxide (PbO_2) on the positive plate are converted to lead sulphate ($PbSO_4$). At the same time the sulphuric acid (H_2SO_4) is converted to water (H_2O). During normal charging process, the chemical reaction is reversed. The lead sulphate and water are electro-chemically converted to lead, lead dioxide and sulphuric acid. During a full charge cycle any gas produced need to be re-combined in a so called 'oxygen cycle'. Oxygen is generated at the positive plates during the latter stages of the charge cycle, reacting with sponge lead (negative plate) and gets partially discharged. As charging continues, the oxygen produced also re-combines with the hydrogen being produced on the negative plate forming water. With accurate voltage control of the cell, the gas produced gets re-combined completely into the negative plates and returned to the electrolyte.

If the battery is over charged, the excess cell voltage will result in the conversion of the electrolyte into large amounts of hydrogen and oxygen which cannot be recombined by normal process. Later the excess gas gets evaporated or vented, resulting in the loss of electrolyte leading to loss of capacity. If the battery is undercharged; the low cell voltage will cause the charge current to diminish to zero well before full capacity is achieved. This will allow some of the lead sulphate produced during discharge to crystallize on the plates, causing permanent loss of capacity [1].

There are different methods of charging lead-acid batteries. The popular two methods are constant current charging and constant voltage charging based on the type [5-8].

3.1 Constant current charging

Constant current charging is another simple but effective method of charging lead acid batteries. A current source drives a uniform current through the battery in a direction opposite that of discharge. As the battery is always being pushed at a constant rate, when it is close to being fully charged, the charger would force extra current into the battery, causing overcharge which is a major drawback.

Usually the constant current charging mode is used for charging the vented, flooded or tubular type lead acid batteries as the positive electrode grid will be in the form of tubes and these will be thicker in size. Due to its thickness a constant continuous current can be withstood by these batteries but overcharging will still reduce the life span due to repeated overcharging. The Figure 1 shows the practical charging and discharging characteristics of a 12V tubular lead acid battery at constant current. Negative cycle indicates that the battery is discharging.

It is tested as per the Indian standard IS: 13369. So as per the standard during the discharge cycle, when voltage reaches 10.8V the discharge ceases. It is seen that with the same amount of charging, the battery gives less discharge compared to the first discharge. The Figure 2 shows the charging characteristics of tubular lead acid battery.

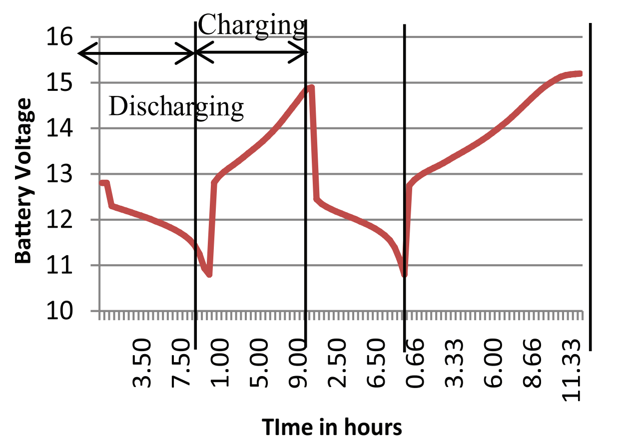

FIG. 1 CHARGE AND DISCHARGE CHARACTERISTICS OF A TUBULAR LEAD ACID BAATTERY AT CONSTANT CURRENT MODE

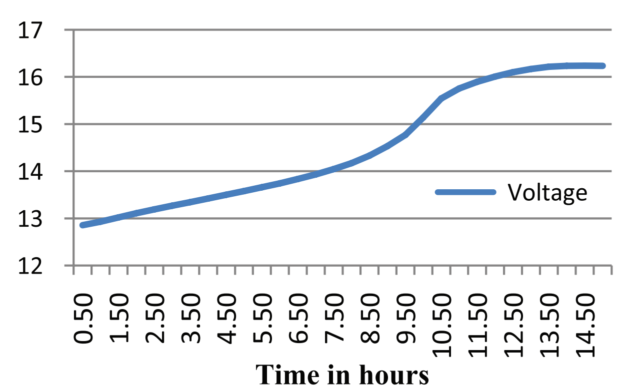

FIG. 2 CHARGE CHARACTERISTICS OF A TUBULAR LEAD ACID BAATTERY AT CONSTANT CURRENT MODE

3.2 Constant voltage charging

Constant voltage charging is commonly used for change of lead acid batteries. A constant voltage is maintained across the terminals of the battery at all times. Initially, a large current will be drawn from the voltage source, but as the battery charges with increase in internal voltage, the current will slowly fold and decays exponentially. The draw-back, of course, is that it takes a longer time to get fully charged as the current exponentially de-creases during the charging cycle.

Usually the constant voltage charging mode is used for charging the Valve Regulated Lead Acid (VRLA) battery. In these batteries the electrode plates will be thinner in size compared to the tubular lead acid batteries. When the current is decaying there will not be much stress on the plates and life can be improved but the charging time will be longer. The Figure 3 shows the charging characteristics of valve regulated lead acid battery in constant voltage mode while Figure 4 shows the charge and discharge characteristics of valve regulated lead acid battery at constant voltage mode.

The 12 V VRLA battery is tested as per the Japanese industrial standard to check its performance. The totally dead battery i.e. fully discharged battery is charged at 14.1V in constant voltage mode. Figure 4 shows after being fully charged, it discharges up to 10.5V as per the standard. Negative current shows that it is discharging. The Figure 5 shows the constant current mode charging of a VRLA battery.

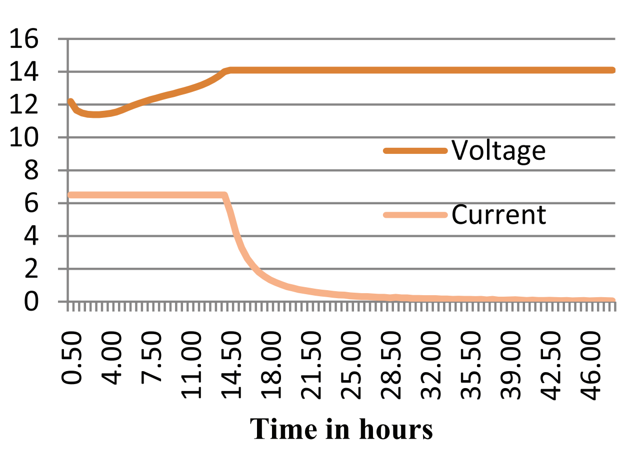

FIG. 3 CHARGE CHARACTERISTICS OF A VRLA BAATTERY AT CONSTANT VOLTAGE MODE

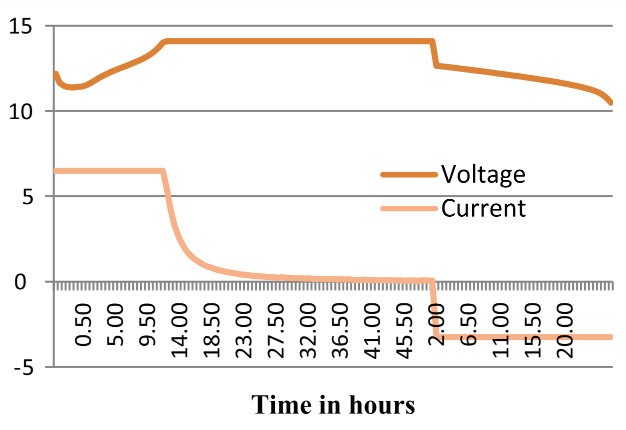

FIG. 4 CHARGE AND DISCHARGE CHARACTERISTICS OF A VRLA BAATTERY AT CONSTANT VOLTAGE MODE

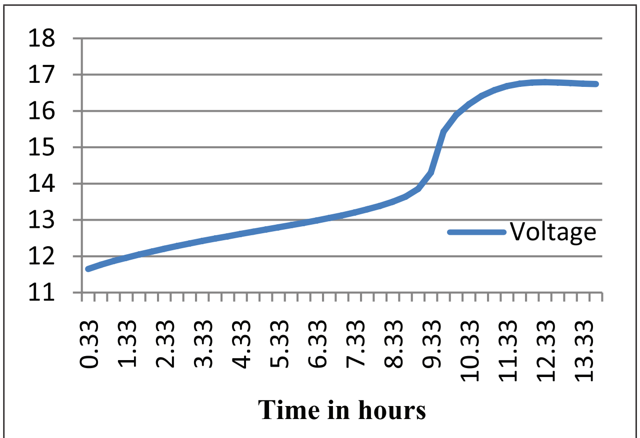

FIG. 5 CHARGE CHARACTERISTICS OF A VRLA BAATTERY AT CONSTANT CURRENT MODE

Figure 5 clearly indicates that the voltage has reached 16.795 V, charging the battery at higher voltage and higher constant current will reduce the life span of the battery.

4.0 PERFORMANCE AND LIFE SPAN OF LEAD-ACID BATTERIES

The lifespan of a battery will vary considerably with method of use, how it is maintained, method of charging, operating temperature, and other factors. The overcharging or undercharging will have adverse effects on its lifespan. In particular life span gets seriously shortened if used for a deep cycle application when not designed for. Often the expected life span of the battery is referred to in terms of "cycles". A battery cycle is one complete discharge and recharge cycle. The discharge state of a battery is often measured in term of Depth of Discharge (DOD). This refers to how far down the battery has been taken, for instance a battery that has 25% of its capacity remaining would be said to be at 75% DOD. The lifetime of a battery is directly related to the depth of the discharge that it regularly experiences. The Figure 6 shows the battery life in terms of number of cycles versus depth of discharge. Repeated deep discharge clearly indicates the decrease in the life span to less than half of its original value.

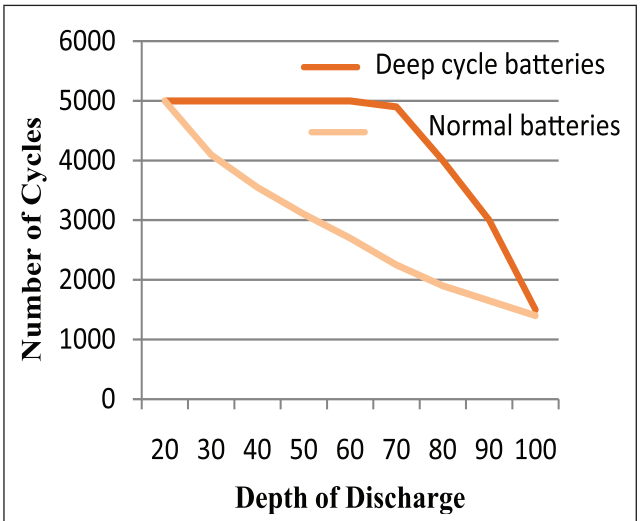

FIG. 6 GRAPH OF BATTERY LIFE IN TERMS OF DOD

Effect of temperature on storage capacity. The temperature of the storage area should be maintained to improve its performance and life span. As ambient temperature is proportional to the self-discharge of the battery necessitates the control of temperature when not in use.

The electrolyte temperature also affects its performance and life span. If the battery is operated above 25^{0}C the capacity improves at the cost of life span of the battery and vice versa. The Figure 7 shows the graph of capacity in percentage versus the temperature in ^{0}C. The Figure 8 shows the variation in electrolyte temperature during the charging and discharging the battery.

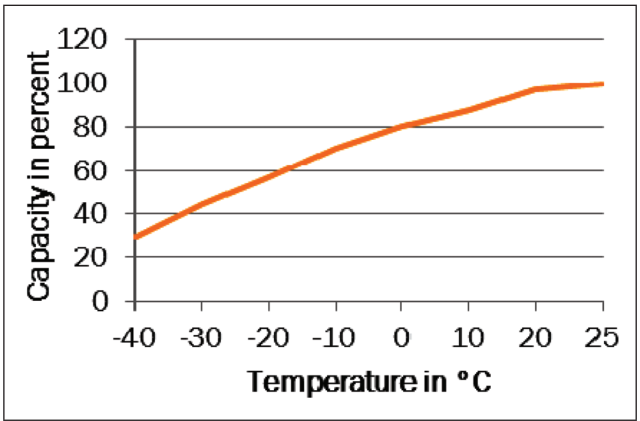

FIG. 7 GRAPH OF CAPACITY VERSUS TEMPERATURE

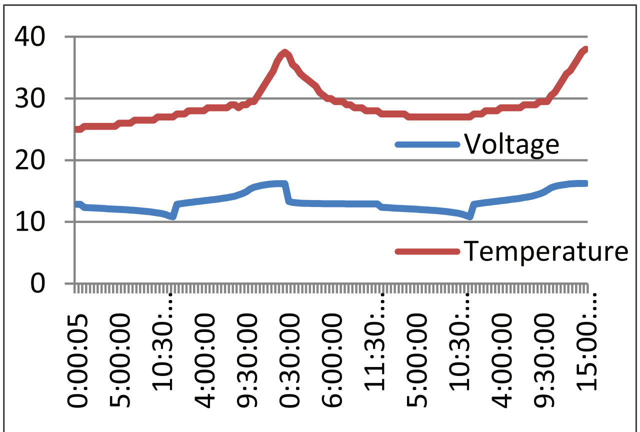

FIG. 8 GRAPH OF ELECTROLYTE TEMPERATURE VARIATION

It has been observed that there is an increase in temperature of the electrolyte during charging and it is found to increase rapidly when voltage gets stabilized at its peak value.

A lead-acid battery of ten hour rating (C10) 150Ah capacity will give increased back up at more than ten hour rating as load to the battery is reduced. When it is discharged at less than ten hour rating, load will be higher and back up decreases and life span of the battery reduces due to operating at high load. 30A is the cut off current as shown in the Figure 9. Operating the battery at more than

30A load will reduce the life span. It indicates that the battery is not suitable for operating at more than 30A.

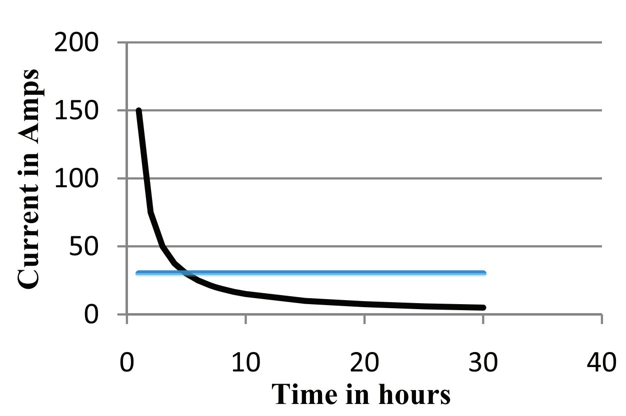

FIG. 9 GRAPH OF CURRENT VERSUS TIME

5.0 BATTERY MANAGEMENT SYSTEM

The manual operation and maintenance (O&M) processes are inadequate to ensure the high life and optimal operation of batteries. The deployment of BMS is essential for trouble free O&M of the battery systems.

Some of the basic objectives of BMS are asset management oriented- to maintain the state of health of the battery bank at high levels through:

- Instrumenting the various parameters, acquiring the same through a data acquisition system (DAS) and providing the feedback to the end user to predict the state of health of the battery.
- To effect control action based on the parameters measured.
- To provide protection to the bank against abnormal operating conditions, transients, unbalance.
- To optimize the performance and life of the battery bank.

Earlier concepts of battery management systems consisted on basic safety features and protections. Now many new features are introduced. The present day BMS is a SCADA (supervisory control and data acquisition system) which has the following features:

- Instrumentation
- Data acquisition
- Protection
- Supervisory control
- Prediction through Expert systems
- Operations
- Maintenance (routine and occasional)
- Performance and life optimization

6.0 CONCLUSIONS

Charging methods of lead acid battery are discussed. Based on the design of the battery and as per the test conducted the constant current charge mode can be used for charging the tubular, vented or flooded type lead acid batteries while constant voltage charge mode can be used for VRLA batteries.

The constant current charging mode causes the overcharging the battery when it is attaining the full charge as battery is being pushed at full current. The constant voltage charging mode will take more time to charge the battery fully as it is on float charge. The battery will not get overcharged and hence does not affect the life span.

As per the test conducted under constant voltage charging the time taken for full charge is more. A 12V 65Ah VRLA battery has taken 33 hours in constant voltage charging mode while it has taken 13 hours 30 minutes under constant current charging mode to attain full charge.

The constant current charging of VRLA battery causes the terminal voltage to reach 16.975V during the test; the life span reduces unless it is designed for the same.

If the battery is undergoing deep discharge repeatedly for which it is not designed for then the life span of the battery reduces to less than its rated value.

The operating temperature also affects the life span. It reduces with increase in temperature.

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