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Alternative Power Supply Systems' Efficiency: Battery Maintenance and Charging Techniques

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Abstract—Alternative or backup power supply systems are often necessary for homes, offices and industries in Nigeria and other developing countries due to irregular, erratic and unstable mains supply. In most alternative/backup power supply systems, the cost of the batteries exceeds the cost of other components in the system. A battery converts the chemical energy contained in its active materials directly into electric energy by means of an electrochemical oxidation-reduction (redox) reaction. Comprehensive understanding and regular care for the battery are vital for safe, smooth, economical and functional operation of alternative or backup power supply systems. A comprehensive review of Battery Chemistry, Capacity, Characteristics, Maintenance and Charging Techniques is presented. Due to constant power outages, batteries are left in discharged state most of the time, which causes loss of charge capacity and formation of sulfates. This reduces the efficiency of the battery which will affect the entire backup power supply system. Pulse charging technique has been found to decompose the formed sulfates in batteries. Introducing a smart charge controller that will apply constant voltage and pulse charging techniques to recharge the battery has been found to improve the service life of the battery.

Keywords—Battery Chemistry; Battery Characteristics; Battery Capacity; Battery Maintenance; Charging Techniques

I. INTRODUCTION

The mains supply in Nigeria and other developing countries is irregular, erratic and unstable. Citizens are faced with persistent power outage or low voltage or voltage fluctuations at homes, offices and industries [1,2,3,4,5]. Each company or each home needs to install alternative or backup power supply systems to augment the mains power supply. An example of such alternative or backup system is shown in Fig. 1 and is presented in [5].

In most alternative or backup power supply systems, the cost of the batteries exceeds the cost of other components in the system. Batteries are also very crucial in portable electronics [6]. Proper battery charging ensures the battery safety and increases the credibility and reliability of the system.

Therefore, a comprehensive review of Battery Chemistry, Capacity, Characteristics, Maintenance and Charging Techniques is discussed. Comprehensive understanding and

regular care for the battery are vital for safe, smooth, functional and efficient operation of alternative or backup power supply systems.

A battery converts the chemical energy contained in its active materials directly into electric energy by means of an electrochemical redox reaction [7,8,9,10]. Redox is a process in which one substance or molecule is reduced and another oxidized; oxidation and reduction are considered together as complimentary processes. In the case of a rechargeable system, the battery is recharged by a reversal of the process. This type of reaction involves the transfer of electrons from one material to another through an electric circuit. While the term “battery” is often used, the basic electrochemical unit being referred to is the “cell”. A battery consists of one or more of these cells, connected in series or parallel, or both, depending on the desired output voltage and capacity.

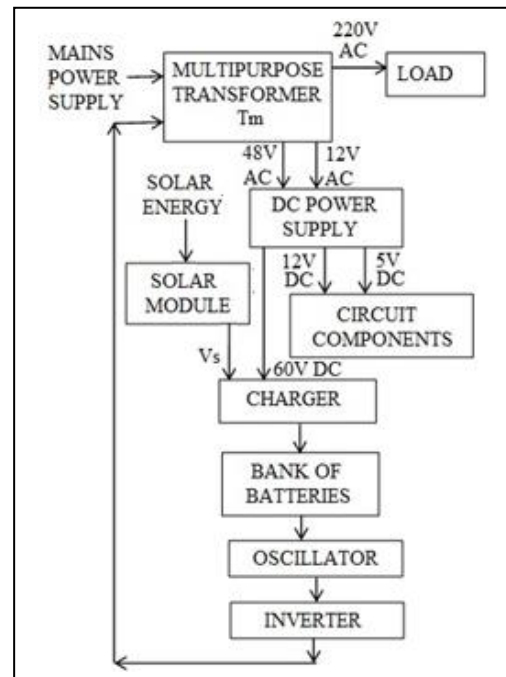


Fig. 1. Alternative or Backup Power Supply System [5].

The cell consists of three major components: the anode, the cathode and the electrolyte. The anode or negative electrode is the reducing or fuel electrode, which gives up electrons to the external circuit and is oxidized during the electrochemical reaction. The cathode or positive electrode is

the oxidizing electrode, which accepts electrons from the external circuit and is reduced during the electrochemical reaction. The electrolyte is the ionic conductor, which provides the medium for transfer of charge, as ions, inside the cell between the anode and cathode. The electrolyte is typically a liquid, such as water or other solvents, with dissolved salts, acids, or alkalis to impart ionic conductivity. Some batteries use solid electrolytes, which are ionic conductors at the operating temperature of the cell. The most advantageous combinations of anode and cathode materials are those that will be lightest and give a high cell voltage and capacity [7].

The cell itself can be built in many shapes and configurations: cylindrical, button, flat, and prismatic, and the cell components are designed to accommodate the particular cell shape. The cells are sealed in a variety of ways to prevent leakage and dry-out. Some cells are provided with venting devices or other means to allow accumulated gases to escape. Suitable cases or containers, means for terminal connection and labeling are added to complete the fabrication of the cell and battery.

Electrochemical cells and batteries are identified as primary (non-rechargeable) or secondary (rechargeable), depending on their capability of being electrically recharged [7,8,11]. Primary cells or batteries are not capable of being easily or effectively recharged electrically and, hence, are discharged once and discarded. Secondary or rechargeable cells or batteries are batteries that can be recharged electrically, after discharge, to their original condition by passing current through them in the opposite direction to that of the discharge current. They are storage devices for electric energy and are also known as “storage batteries” or “accumulators.”

There are commercial smart chargers which are designed to recharge Lead-acid batteries appropriately but Lead-acid batteries used in inverters in developing countries still do not live their entire life span in good charge capacity due to improper recharging as a result of utility supply outages. The batteries are left in discharged state most of the time, which causes loss of charge capacity and formation of sulfates. There is need to compensate for the formed sulfates, because its negligence will lead to the reduction in the efficiency of the battery which will affect the entire power supply backup system. The cost implication of the system cannot be compared to the loss of battery as a result of formation of sulfates, since the battery constitutes the major cost of alternative/backup power supply systems.

II. BATTERY CHEMISTRY

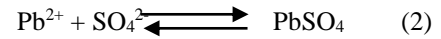
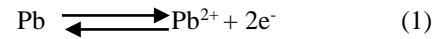
Four major types of commercial rechargeable batteries are considered in this study [7,8,9,10].

A. Lead Acid (LA)

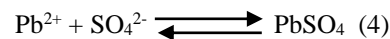
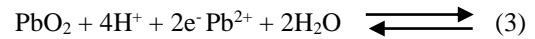
The chemical process of a lead acid battery consists of two electrodes: metallic lead (Pb) as negative electrode (anode), and lead dioxide (PbO₂) as positive electrode (cathode), immersed in a sulfuric acid solution (H₂SO₄). On discharge,

both the electrodes build up lead sulfate PbSO₄ and the electrolyte is converted to H₂O while the opposite occurs during charging. The processes at both electrodes are described by the chemical Eqns. (1) to (5). Arrow towards the right indicates discharge reaction while arrow towards the left indicates charge reaction.

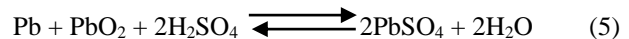
Negative electrode



Positive electrode



Overall reaction

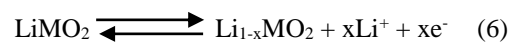


As the cell approaches full charge and the majority of the PbSO₄ has been converted to Pb and PbO₂, the charging cell voltage becomes greater than some critical point called the ‘gassing voltage’. At this point the overcharge reaction begins in addition to the normal charge reactions, resulting in the production of hydrogen and oxygen gas. Excessive production of battery gasses is undesirable as it results in wasted energy and a substantial increase in charging time. If the gas is not properly vented, it will collect and has explosive potential, particularly in environments where electrical sparks are possible.

B. Lithium-Ion (Li-Ion)

In this battery, carbon material is used in the anodes and a metal oxide material containing lithium is used in the cathodes; lithium ions migrate between the two electrodes via an organic electrolyte. By designing these batteries in accordance with the reversible capacity of the carbon material, lithium does not exist in the metallic state during either the charging or discharging processes. As a battery is cycled, lithium ions (Li⁺) exchange between the positive and negative electrodes. They are also referred to as rocking chair batteries as the lithium ions “rock” back and forth between the positive and negative electrodes as the cell is charged and discharged. The charge and discharge reactions are as follows:

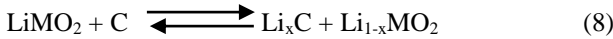
Positive electrode:



Negative electrode:

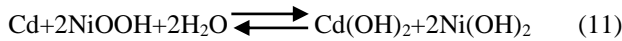
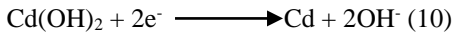
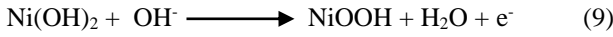


Overall reaction:



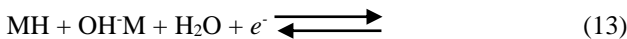
C. Nickel-Cadmium (Ni-Cd)

In the charged state, cadmium is the negative electrode, nickel oxy-hydroxide is the positive, and a solution of potassium hydroxide is the electrolyte. In the discharged state, nickel hydroxide is the active material of the positive electrode, and cadmium hydroxide is the material of the negative electrode. During charge, nickel hydroxide, Ni(OH)_2 , is converted to a higher-valence oxide as given by Eqn. (9). At the negative electrode, cadmium hydroxide, Cd(OH)_2 , is reduced to cadmium as given by Eqn. (10). Eqn. (11) gives the overall discharge/charge reaction.

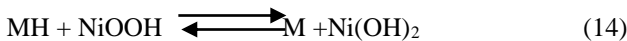


D. Nickel-Metal Hydride (Ni-MH)

Ni-MH characteristics are similar to those of the nickel-cadmium battery. The principal difference is that the nickel-metal hydride battery uses hydrogen, absorbed in a metal alloy, for the active negative material in place of the cadmium used in the nickel-cadmium battery. The metal hydride electrode has a higher energy density than the cadmium electrode. Therefore the amount of the negative electrode used in the nickel-metal hydride cell can be less than that used in the nickel-cadmium cell. This allows for a larger volume for the positive electrode, which results in a higher capacity or longer service life for the metal hydride battery. Furthermore, as the nickel-metal hydride battery is free of cadmium, it is considered more environmentally friendly than the nickel-cadmium battery and may reduce the problems associated with the disposal of rechargeable nickel batteries. During discharge, the nickel oxy-hydroxide is reduced to nickel hydroxide as in Eqn. (12) and the metal hydride MH is oxidized to the metal alloy M as in Eqn. (13).



The overall reaction is



III. THEORETICAL CELL ENERGY, VOLTAGE, AND CAPACITY

A. Free Energy

Whenever a reaction occurs, there is a decrease in the free energy of the system, which is expressed as

$$\Delta G^0 = -nFE^0 \quad (15)$$

where F is a constant known as Faraday constant ($F = 96,500\text{C}$ or 26.8 Ah); n is the number of electrons involved in the stoichiometric reaction and E^0 is the standard potential in Volt.

B. Theoretical Voltage

The standard potential of the cell is determined by the type of active materials contained in the cell. It can be calculated from free-energy data or obtained experimentally. A listing of electrode potentials (reduction potentials) under standard conditions is also available [7]. The standard potential of a cell can be calculated from the standard electrode potentials as in Eqn. (16). The oxidation potential is the negative value of the reduction potential.

$$E_{\text{cell}}^0 = E_{\text{oxidation}}^0 + E_{\text{reduction}}^0 \quad (16)$$

C. Theoretical Capacity (Coulombic)

The theoretical capacity of a cell is determined by the amount of active materials in the cell. It is expressed as the total quantity of electricity involved in the electrochemical reaction and is defined in terms of coulombs or ampere-hours. The ‘‘ampere-hour capacity’’ of a battery is directly associated with the quantity of electricity obtained from the active materials. Theoretically, 1 gram-equivalent weight of material will deliver $96,487\text{ C}$ or 26.8 Ah .

A gram-equivalent weight is the atomic or molecular weight of the active material in grams divided by the number of electrons involved in the reaction. A listing of the electrochemical equivalence of typical materials is also available [7]. The theoretical capacity of an electrochemical cell, based only on the active materials participating in the electrochemical reaction, is calculated from the equivalent weight of the reactants.

IV. BATTERY CHARACTERISTICS

A. Charge Characteristics

During the recharge of a rechargeable or storage cell, the current flow is reversed and oxidation takes place at the positive electrode and reduction at the negative electrode, as shown in Fig. 2(a) [10,12,13]. The capacity of a cell can also be considered on an energy (watt-hour) basis by measuring both the voltage and the quantity of electricity into consideration as in Eqn. 17. This theoretical energy value is the maximum value that can be delivered by a specific electrochemical system. Battery capacity, C, is expressed in Amp-hours and is a figure of merit of battery life between charges. Battery current is described in units of charge rate (C-Rate).

$$\text{Watt-hour (WH)} = \text{voltage (V)} \times \text{ampere-hour (AH)} \quad (17)$$

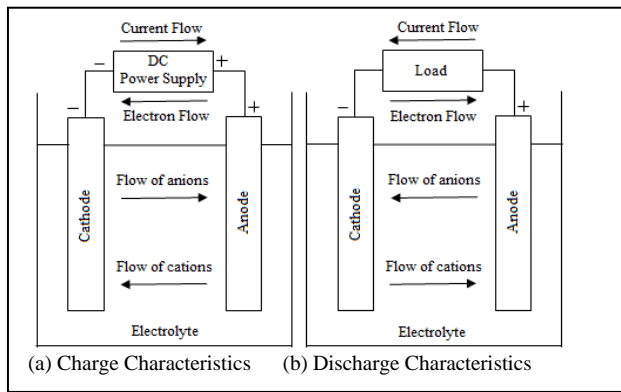


Fig. 2. Charge and Discharge Characteristics of a cell.

For instance, a 1000mA-h battery has a C-Rate of 1000mA. The current corresponding to 1C and 0.1 C are 1000mA and 100mA respectively. At nC, a battery charges and discharges at a current which is n times it's marked AH rating and will be fully charged or fully discharged in 1/n hour.

In the realm of battery charging, charging methods are usually separated into two general categories: fast and slow charging. Fast charging is typically a system that can recharge a battery in about one or two hours while slow charging usually refers to an overnight recharge (or longer). Time required to completely recharge a battery depends on factors such as depth of discharge of the battery, charge rate and ambient temperature. The time required to recharge a battery is a major concern to the battery system user.

B. Discharge Characteristics

The operation of a cell during discharge is shown schematically in Fig. 2(b). When the cell is connected to an external load, current flows from the anode through the external load to the cathode. The electric circuit is completed in the electrolyte by the flow of anions (negative ions) and cations (positive ions) to the anode and cathode respectively. The number of charge and discharge cycles is the average number of times a battery can be discharged and then recharged and is a measure of the battery's service life. The discharge profiles of the four popular types of battery using 0.2C are shown in Fig. 3.

C. Battery Storage

Self-discharge is the rate at which a battery discharges with no load. This is the major factor to be considered if a battery is to be stored. The rate of self-discharge is a function of storage temperature and battery chemistry.

D. Battery Disposal

Mass-production and mass-consumption of battery and battery supported systems have progressed in recent years. This has spurred a sharp increase in hazardous substances that have adverse effects on the environment and people, and have consequently degraded the environment. One of these hazardous substances is lead. Lead diffuses into the environment via illegal dumping of batteries. If the lead from these batteries infiltrates the human body, the lead

concentration in the blood rises, possibly resulting in neurological disorders including loss of perception and behavioral problems. In children, it can stunt growth, cause brain damage and mental retardation.

Land disposal of batteries is prohibited in most countries and it is recommended to recycle. The most significant parts of the battery in this respect are the cell stacks, electrodes and electrolyte. The battery stacks are nearly all plastic and can be recycled by conventional processes and new processes that are being developed by the plastic industry. The electrolyte is not consumed in the battery. It will be removed and reused in other batteries. Environmental concerns exist regarding the proper disposal of lead-acid and Ni-Cd batteries because of hazardous metal content. Ni-MH and Li-Ion batteries do not contain significant amounts of pollutant, but nevertheless, some caution should be used in their disposal.

V. CHARGING TECHNIQUES

Charging techniques are the methods of putting energy into a discharged battery. Charging techniques are dependent on battery chemistry, application, and environment where the battery is to be used. The applications are roughly classified into main power and stand-by/back-up power applications. Accurate control of battery voltage and current is the key to proper charging, irrespective of cell chemistry [15,16,17,18,19,20,21,22,23,24,25]. Basically, there are four major types of charging techniques; namely: Constant voltage technique, Constant current technique, Constant current/constant voltage technique and Pulse technique.

A. Constant Voltage Technique

Constant-voltage (often called constant-potential) is to maintain a specific voltage input to the battery throughout the charging process, regardless of the battery's state of charge. Constant-voltage technique provides a high initial current to the battery because of the greater potential difference between the battery and charger. A constant voltage technique sources current into the battery in an attempt to force the battery voltage up to a preset value (usually referred to as the set-point voltage or set voltage).

A constant-voltage technique may return as much as 70% of the previous discharge in the first 30 minutes. As the battery charges its voltage increases quickly as illustrated in Fig. 4. This reduces the potential that has been driving the current, with a corresponding rapid decrease in charge current. As a result, even though the battery reaches partial charge quickly, obtaining a full charge requires prolonged charging. Thus, constant-voltage technique is often found in applications that normally allow extended charging periods to attain full charge.

Constant-voltage technique should not be used where there is frequent cycling of the battery. Repeated discharges without returning the cell to its full charge will eventually decrease the battery capacity and may damage individual cells. If the appropriate constant voltage is applied to a fully discharged battery, charging is commenced at the battery's amp-hour rating (1 C), and then depreciates as the battery absorbs energy.

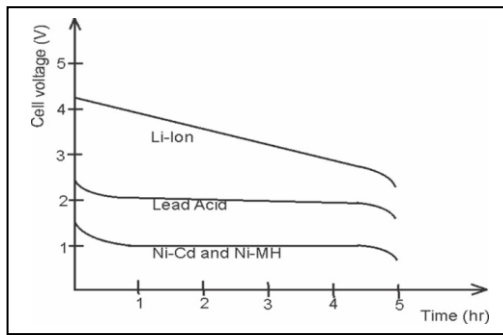


Fig. 3. Battery discharge profiles at 0.2 C-rate [13].

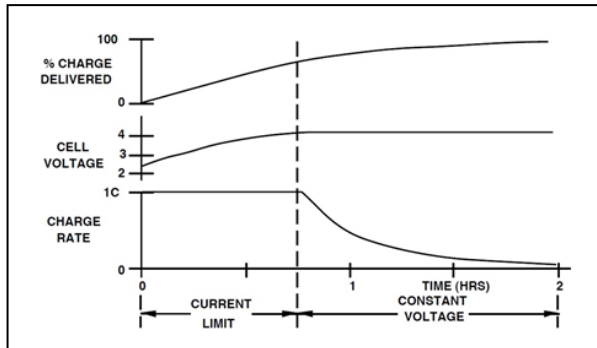


Fig. 4. Constant Voltage Technique Characteristics [14].

The constant voltage is the recommended battery's charge cut-off voltage. The charge and discharge cut-off voltages of the four commercial battery chemistries are shown in Table 1. The accuracy on the cut-off voltage is critical as the safety of the battery is dependent on it. This type of technique takes about three (3) to six (6) hours to recharge an empty battery.

TABLE I. RECOMMENDED CHARGE AND DISCHARGE CUT-OFF VOLTAGES OF CELLS.

Battery Chemistry	Nominal Cell Voltage (V)	Charge Cut-Off Voltage (V)	Moderate Discharge Cut-Off Voltage (V)
Lead Acid (LA)	2.00	2.40	1.75
Lithium-Ion (Li-Ion)	3.60/3.70	4.20	2.50
Nickel Cadmium (Ni-Cd)	1.20	1.50	1.00
Nickel Metal Hydride (Ni-MH)	1.20	1.50	1.00

B. Constant Current Technique

In this technique, the charging voltage is varied to maintain a constant current flow to the battery as long as the battery's cut-off charge voltage is not exceeded. This technique maintains a specific charge rate throughout the charge process. The charge process is terminated once the condition for end of charge is detected. Fastest charging process can be achieved with this technique but the state of the battery such as temperature and voltage must be continuously monitored and the charge process adjusted or terminated depending on the battery status. Fig. 5 shows the Constant Current Technique Characteristics.

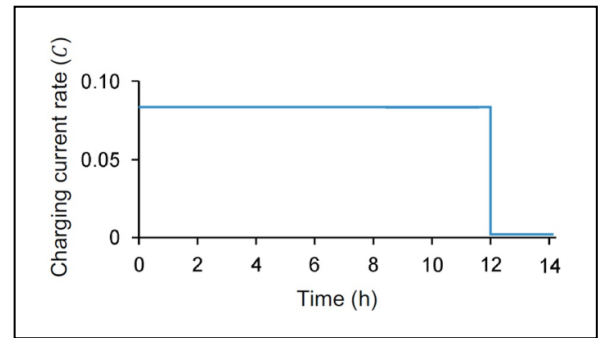


Fig. 5. Constant Current Technique Characteristics [27].

C. Constant Current/Constant Voltage Technique

This technique is the combination of constant current and constant voltage techniques. Battery charging starts with a constant current until a certain voltage is reached (usually slightly below cut-off charge voltage of the battery). Battery charging continues with a constant voltage equal to cut-off charge voltage until the conditions for end of charge is detected. This is a two-step charging technique where the first part of the charge cycle can be referred to as bulk charge phase and the second part of the charge cycle can be referred to as equalizing phase. The Constant Current/Constant Voltage Technique characteristics is shown in Fig. 6.

D. Pulse Technique

Pulse technique feeds the charge current to the battery in pulses. The charging rate (based on the average current) can be precisely controlled by varying the amplitude, width, and frequency of the pulses. During the charging process, short rest periods between pulses allows the chemical reactions in the battery to stabilize by equalizing the reaction throughout the bulk of the electrode before recommencing the charge. This enables the chemical reaction to keep pace with the rate of inputting the electrical energy. This can also reduce unwanted chemical reactions at the electrode such as gas formation, crystal growth, and formation of sulfates. If required, it is also possible to sample the open circuit voltage of the battery during the rest period.

In pulse charging system, the charging frequency affects the battery charging performance. The hydrogen and oxygen gas development in a battery is not immediate but has a time constant relating to the state of charge of the battery. Therefore if an applied current pulse is short enough, most of the current will be consumed by the charge reaction rather than producing hydrogen gas. This is the principle of pulse charging - applying relatively large currents into a battery at periodic intervals with a defined pulse width to reduce or avoid gassing and thus increase charge acceptance and efficiency. An additional advantage is that this principle can even be applied to almost fully charged batteries and has the ability to recover the capacity of exhausted or cycled cells [20,26]. Typical pulse technique characteristics is shown in Fig. 7.

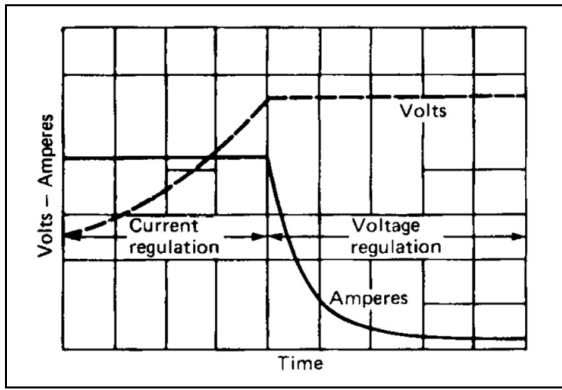


Fig. 6. Constant Current/Constant voltage Technique Characteristics [7].

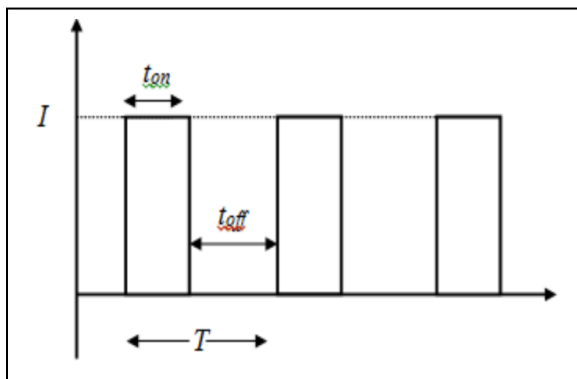


Fig. 7. Pulse Technique characteristics [20].

Pulse technique can be combined with the other techniques to achieve the desired charging effect such as pulsed constant voltage technique; pulsed constant current technique and pulsed constant current/constant voltage technique.

VI. RECHARGE AND MAINTENANCE OF LEAD ACID BATTERY

Lead Acid battery is the battery of choice in deep cycle system due to its cost effectiveness and energy capacity, but the discouraging factor is that the service life is not always as expected. This is due to the environment where the systems are being used.

In advanced countries where power supply is stable, any desired technique can be used to recharge the battery and still get the best performance, as the battery is never left in the discharged state most of the time.

In developing countries where power supply is seriously fluctuating, the batteries are hardly well charged and are in the discharged state most of the time. This encourages the formation of sulfates on the electrodes and when this is not cared for, it eventually reduces the efficiency of the battery.

A lead-acid battery manufacturer often recommends a charging process normally referred to as dual-level charging. A dual level battery charger has three states: a high-current bulk charge state, an equalize charge state, and a float charge state. The recommended charging graph for lead acid is shown in Fig. 8.

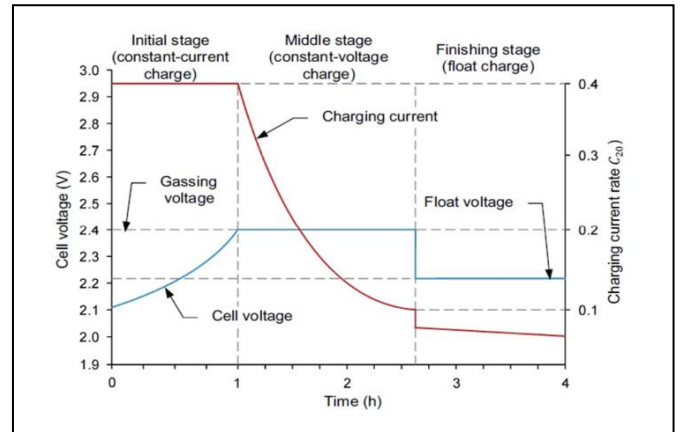


Fig. 8. Recommended Lead Acid Charge profile [27].

A. Battery Chargers

The performance and service life of a rechargeable battery is to a large extent governed by the quality of the charger. Undercharged batteries have reduced capacity, while overcharging can damage the battery, cause catastrophic gassing of the electrolyte, and even explode the battery. All presently available commercial battery chargers are made for a specific battery chemistry and size. In terms of the battery voltage and capacity, chargers are classified into simple and smart chargers.

B. Simple Charger

A simple charger works by supplying a constant DC or pulsed DC power to a battery being charged. The simple charger does not alter its output based on time or the charge on the battery. This simplicity means that a simple charger is inexpensive, but there is a tradeoff in quality. Typically, a simple charger takes longer to charge a battery to prevent severe over-charging. A battery being charged by a simple charger for too long will be weakened or destroyed due to over-charging. Simple AC-powered battery chargers have much higher ripple current and ripple voltage than other kinds of DC-powered battery chargers. When the ripple current is within the battery-manufacturer-recommended level, the ripple voltage will also be well within the recommended level.

A low cost charger may consist solely of a transformer and full-bridge rectifier. Usually such a circuit has no output filter so that during float charge operation the 50Hz AC ripple can produce micro-cycling of the battery consisting of small charge/discharge cycles which are increasingly detrimental over time. In more advanced low-cost models, an output voltage regulator with adjustable current limit is added. However, if the limit set by the operator is too high, this may be detrimental to the battery as little or no battery monitoring is undertaken. Such chargers form the bulk of available chargers in the market.

C. Smart Charger

A smart charger is defined as a charger that can respond to the condition of a battery and modifies its charging actions

accordingly. Some smart chargers are designed to charge smart batteries and dumb batteries. A smart charger contains some sort of electronic device or chip that can communicate with a smart charger about battery characteristics and condition while a dumb battery does not contain any such circuitry. A smart battery generally requires a smart charger it can communicate with. The output current of a smart charger depends upon the battery's state.

A typical smart charger fast-charges a battery up to about 85% of its maximum capacity in less than an hour, then switches to trickle charging, which takes few hours to top off the battery to its full capacity. A smart charger may monitor the battery's voltage, temperature or time under charge to determine the optimum charge current and when to terminate charging.

D. Charge Termination Techniques

When the battery reaches full charge, the energy being supplied to the battery is no longer being consumed in the charge reaction, and must be dissipated as heat within the cell. This results in a very sharp increase in both cell temperature and internal pressure if high current charging is continued. The cell contains a pressure-activated vent which opens if the pressure gets too great, allowing the release of gas (this is detrimental to the cell, as the gas that is lost can never be replaced). In the case of Ni-Cd, the gas released is oxygen. For Ni-MH cells, the gas released will be hydrogen, which will burn violently if ignited. A severely overcharged cell can explode if the vent fails to open (due to deterioration with age or corrosion from chemical leakage).

It is necessary for the charger to detect when the battery has achieved a full state of charge and either stop charging or reduce the charging current. Because of the importance of proper charge termination, a primary and secondary method is generally used, depending on the battery type. The charge may be terminated based on monitoring battery voltage, voltage change vs. time, temperature change, temperature change vs. time, minimum current at full voltage, charge time, or various combinations of the above. Battery voltage and temperature are the most popular methods of terminating the charge of Ni-Cd and Ni-MH batteries. Fig. 9 and Fig. 10 show the cell voltage and temperature as a function of charge time for these two types of batteries (charging at the 1C-rate).

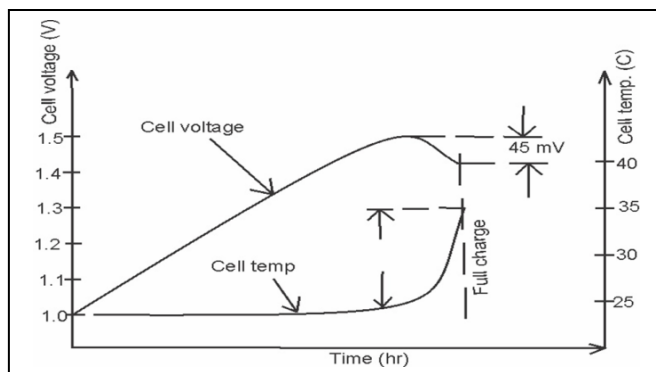


Fig. 9. Cell Voltage and Temperature Charge Characteristics of Ni-Cd [14].

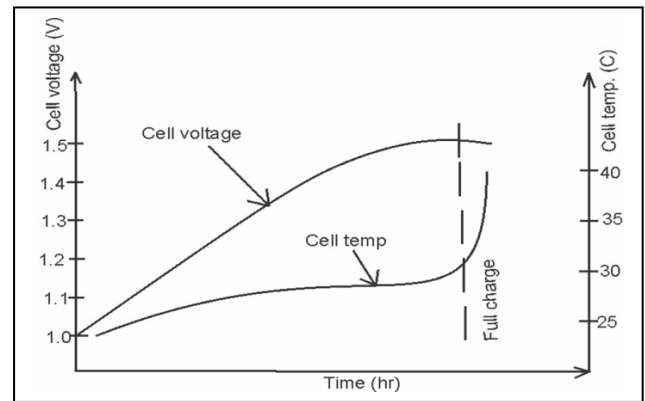


Fig. 10. Cell Voltage and Temperature Charge Characteristics of Ni-MH [14].

Note that Ni-Cd has a distinct peak in the cell voltage immediately preceding full charge. Because of the much less pronounced voltage peak in the Ni-MH characteristic, the change in temperature with respect to time (dT/dt) is most often used as a primary charge termination method. In addition to the primary termination, secondary terminations are used as backups for added protection. Where charge termination is not critical, a timer is sometimes used to end the charge if the battery draws minimum current at full charge voltage; such as in Lead Acid and Li-Ion batteries.

E. Battery Charging Termination Issues with System Load Applied Across Battery While Charging

Applying a system load across the battery while it's being charged may result in an altered voltage or current reading and thus an improper termination.

The typical problem with applying a system load to the output of a Li-ion battery charger, while charging the battery, is the loss of properly terminating the charge cycle. This often results in a maximum timeout fault condition which prohibits future charging without cycling the input power. Li-ion battery chargers designed solely for battery charging, make charging and termination decisions based on the current and voltage out of the charger.

The typical problem with applying a system load to the output of a nickel battery while it's being charged is often false termination of the charge cycle. Early termination results in a partially charged battery and reduced running time which can be a problem. Not detecting termination can lead to overstressing the battery and shortening its life of the battery.

VII. CHARGER

A. Charging Techniques Experiment

The charger controls the charging technique applied to a lead acid battery bank. It sends either a constant voltage or pulsed energy to the battery bank. The circuit diagram of the charger is shown in Fig. 11 [5,28,29,30]. In Fig. 11, the frequency of the oscillator is determined by the values of R92, R93, and C9 [14]. For a 50Hz oscillation, R92 and R93 are chosen to be 100K Ω each, and C9 is calculated as in Eqn. (18).

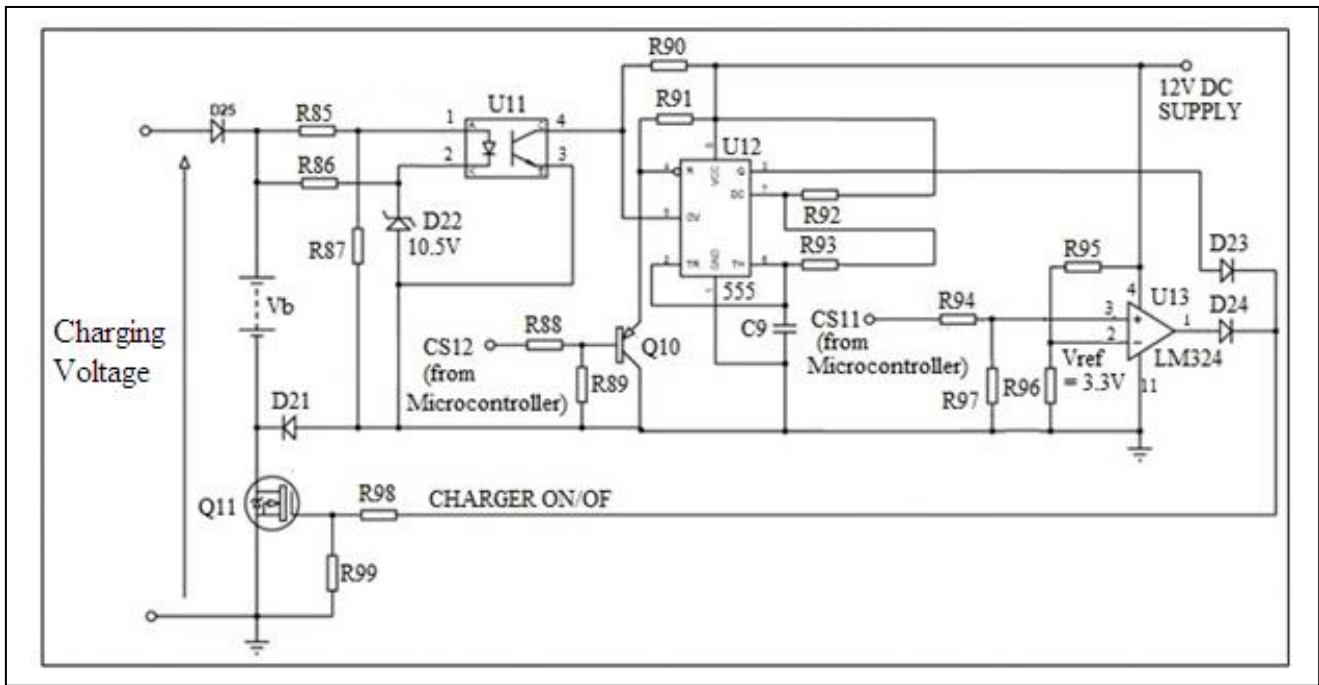


Fig. 11. Charger.

$$C9 = \frac{1.44}{(R92+R93)f} = \frac{1.44}{(100+200)50} = 0.096\mu F \quad (18)$$

R95 and R96 is a voltage divider network, R95 is chosen as $1K\Omega$, then R96 is calculated as 379Ω to set $V_{ref}=3.3V$. CS10 and CS11 are control signals from a microcontroller. If CS10 is 0V, U12 is shutdown, otherwise operational while if CS11 is +5V, U13 produces +5V output, otherwise the output is 0V. U11 adjusts the control voltage of U12 thereby adjusting the amplitude of the pulse width to ensure that the charge voltage across the battery does not exceed the float charge voltage of 55V (48V battery system) during pulse charging.

The charge controller is designed to recharge a battery with two charging techniques. In the first stage of the charging, the charge controller will apply a constant charging voltage of about 55V to charge the battery and monitor the voltage across the battery to ensure that it does not exceed the desired value. In the second stage, it will apply a pulse charging technique to the battery and will also ensure that its float voltage is maintained.

In order to determine the performance of the charger, the charge profile was obtained from three different charging voltage levels; the first is below the gassing voltage of the battery (55V), the second is at the battery gassing voltage (60V), and the third is above the gassing voltage (68V). These constant voltage levels were applied to a discharged 48V/20AH battery and the voltage across and the current through the battery were measured and recorded every 5 minutes for 180 minutes (3 hours).

B. Charging Techniques Experimental Results

It was observed that when a discharged battery was connected to the charge controller, it applied a constant voltage to the battery and the battery initial charge current started at about one-fourth of the battery ampere hour rating. It stayed at the initial charge current for some time before it started decreasing as the battery voltage rose. When the battery voltage got to the full charge voltage, the system detected it and put the charge controller to pulse technique mode. The charge controller stayed on this mode for the rest of the charging period.

The charge profiles obtained for the three different charging voltage levels are presented in Fig. 12. For charging voltage of 55V which is less than the gassing voltage, only constant voltage charging technique was applied. With charging voltage of 60V and 68V, constant voltage charging technique was applied up till battery voltage rose to 58V when the constant voltage technique was replaced with pulse charging technique. The higher the charging voltage level, the higher the starting current and the shorter the time taken for battery voltage to rise to float voltage level.

VIII. CONCLUSION

Battery Chemistry, Capacity, Characteristics, Maintenance and Charging Techniques have been reviewed. Introducing a smart charge controller that will apply constant voltage and pulse charging techniques to recharge the battery has been found to improve the service life of the battery. Pulse charging technique has been employed to decompose the formed sulfates in batteries. Adequate care of battery bank improves the efficiency of alternative/backup power supply systems.

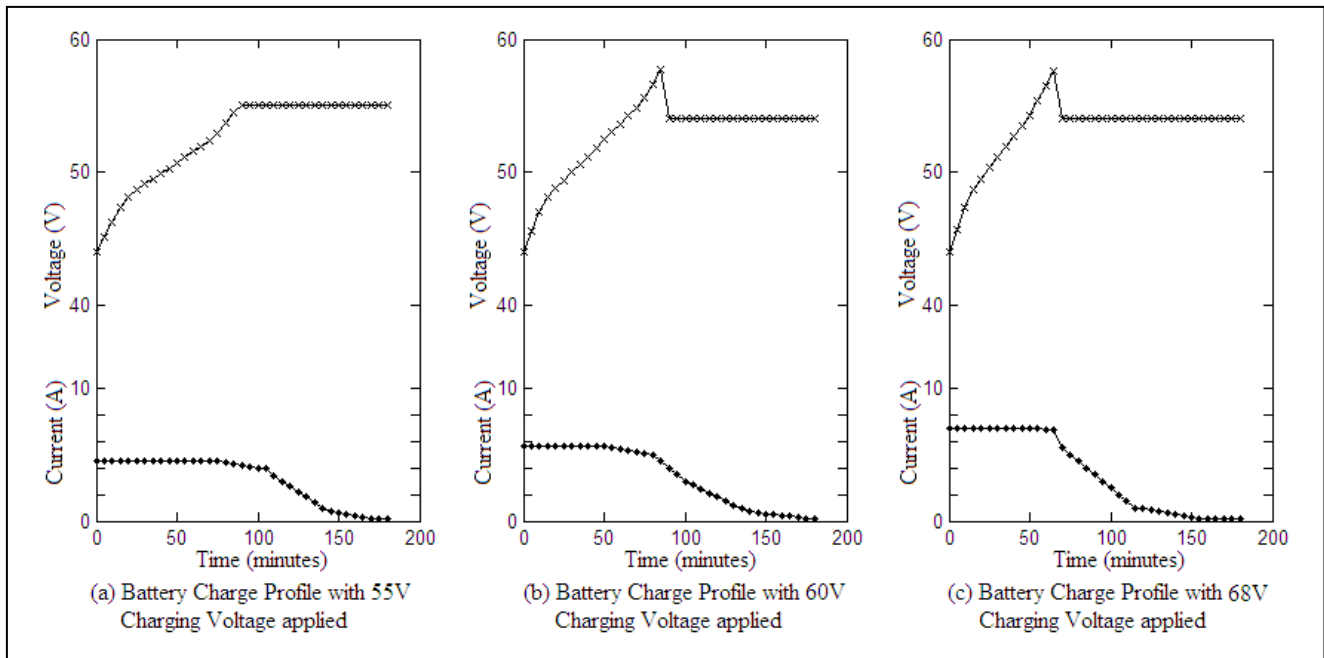


Fig. 12. Charge Profiles for three different charging voltage levels (55V, 60V and 68V).

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