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An Overview of Battery Guiding Principles and Selection

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Abstract

Batteries are typically the last resort or line of defense against total shutdown during power outages. Experience shows that failures in storage batteries can cause more down time and service calls on emergency system than other equipment's in the system. The aim of this paper is to present the principles of batteries operation, selection and maintenance for good performance and longevity. In this paper, principles guiding battery usage and as well as the maintenance are highlighted. Load test was carried out on 12v VRLA battery to test the performance and the reliability of the storage battery for efficient back-up supplies. It was found out that discharging the battery beyond the manufacturer voltage specification causes the battery voltage to decline rapidly. Hence, the end – users should adhere to the information provided for proper batteries selection and also, adhering to manufacturer's specification for maximizing the batteries efficiency and longevity.

1.0 Introduction

In electricity, a battery is a device consisting of one or more electrochemical cells that convert chemical energy into electrical energy. Battery can also be defined as a device that produces and store electrical energy from chemical reaction. The type of electric current produced in batteries is the direct current (DC) [1].

Battery has different meaning in various language register. For instance; in Law: Battery means the unlawful and unwanted touching or striking of one person by another with the intention of bringing about a harmful or offensive contact. In Music: Battery means the persecution section of an orchestra. In Military: Battery means fortified emplacement for heavy guns [2].

The basic parts of a battery are; the electrolyte (Semi-fluid that produces the change), the casing to hold the semi-fluid and the electrodes (positive and negative electrode). Battery electrolyte may be aqueous (composed of water) or non aqueous (not composed of water), in liquid paste or solid form. In a discharging battery or galvanic cell, the Anode is the negative (-Ve) terminal, because it is where current flow into the device, i.e. the battery cell, while the cathode is the positive (+Ve) terminal [1].

Consequently, in a recharging battery or electrolytic cell, the Anode is the positive (+Ve) terminal which receives current from an external generator. The current through a recharging battery is opposite to the direction of current during discharge. In other words, the electrode which was the cathode during battery discharge becomes the anode while the battery is recharging [3].

Today batteries are all around us, in several styles. They power our Wrist watches for months at a time. Batteries are used everywhere; in Automobiles, Security System, Medical systems, Power chairs, Scooters and computer backup supplies. They are used as a common power source for many household and industrial applications. Batteries have also become an essential power source for emergencies, especially in times of power outage. There are both tools and appliance that require power through batteries only and those equipped with both power cords for direct plugging into electrical outlets and the option to use batteries. Many innovative kitchen tools like can openers, pepper mills, camping fryers and kettles are battery powered. Home appliances like lamps, irons and air pumps also have battery powered choices [4].

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Batteries may lose its ability to accept, hold and deliver a charge due to sulfation (development of Sulphur on the electrodes). Sulfation drains a battery and causes early failures [1]. Batteries contains some harmful substances or chemicals such as acids, lead, cadmium, gel etc and hence used or damaged batteries need to be properly disposed and recycled. Recycling is a means of reducing waste, stop harmful chemicals from contaminating our soil, water and preserve our environment by decreasing the need for raw materials from the earth [5].

2.0 Types of Batteries

There are different types of batteries, but the basic concept by which they function remains the same. Two basic types are primary batteries and secondary batteries. Primary batteries are the disposable ones designed for one-time-use, while secondary batteries are the rechargeable ones, designed to be used multiple times. Secondary batteries are sub divided into shallow cycle (starting) and Deep cycle (Motive) type batteries.

The starting (cranking) or shallow cycle type is designed to deliver large bursts of power for a short time as is needed by an engine. Once the engine is started, the battery is recharged by the engine driving charging system. Starting batteries are intended to have a low depth of discharge on each use. They are constructed with many thick plates with thin separators between the plates and may have a higher specific gravity electrolyte to reduce internal resistance [6].

The deep cycle type is designed to continuously provide power for long period of time. They have thicker plates and are intended to have a greater depth of discharge on each cycle, but will not provide a high current on heavy loads. The thicker plates survive a higher number of charge or discharge cycles. The specific energy is in the range of 30 – 40 watt-hours per kilogram. It has a slower rate of discharge. Deep cycle batteries are used in a trolling motor for a small boat, auxiliary power for a recreational vehicle, traction power for golf cart. They can also be used to store energy from photovoltaic array or a small wind turbine [7].

In terms of application, batteries are categorizes as follows:

i. Lead-acid batteries; used in automobiles (cars, Trucks) and Emergency Lighting.

ii. Nicked Metal hydride (NiMH) batteries; used in Laptop computers and Cell phones.
iii. Lithium- ion (Li-ion) and Lithium Polymer (LiPoly) batteries: used in laptop computers, cell phones.
iv. Nicked – Cadmium battery; used in space craft, Tools, and two way Radios (Radio that uses AC outlets and battery powered options)

2.1 Lead-acid batteries: These are known as starting, lighting, ignition (SLI) batteries, used to power the starter motor, the lights and the ignition system of a vehicle engine. Lead-acid batteries are made up of six galvanic cells in series to provide a 12 volt system. Each cell provides 2.1 Volts for a total of 12.6 volt at full charge. Heavy Vehicles such as highway trucks or tractors often equipped with diesel engines may have two batteries in series for a 24 volt system or may have parallel strings of batteries [2]. The three common types of primary batteries are: Zinc-carbon, Alkaline and Lithium based batteries.

3.0 Battery Sizes and Codes

Batteries come in variety of sizes and it is important to choose the right size. The wrong size might not fit securely or provide sufficient power [8].

Primary batteries are made in a range of tiny button cells used for electric watches to those used for signal circuits or other small appliances that require a small current for a long duration. The long history of primary batteries means that many different manufacturer – specific and national standards were used to designate sizes, long before international standards were used to designate sizes, long before international standards were reached. Technical standard organizations such as International Electrotechnical Commission (TEC) and American National Standard Institute (ANSI). Popular sizes are still referred to by old standard or manufacturer designations, and some non-systematic designation have been included in current International standard due to wide use. The complete nomenclature of the battery will fully specify the size, Chemistry, terminal arrangements and special characteristics of a battery. The same Physical Interchangeability is not the sole factor in substitution of batteries [9].

The naming or coding of primary batteries is done with letters and numbers to denote battery characteristics. Lead-acid batteries are made with slightly different construction techniques, depending on the application of the battery. The “flooded cell” type (commonly called wet cell) indicating liquid electrolyte is typically inexpensive and long-lasting, but requires more maintenance and can spill or leak. Some flooded batteries have removable caps that allow for the electrolyte to be tested and maintained [9].

Most costly alternatives to the flooded batteries are the "sealed" batteries (commonly called dry cell batteries) also known as "valve regulated lead-acid" (VRLA) batteries. VRLA batteries are further classified as; Absorbed Glass Mat (AGM) battery and Gel Battery ("Gel cell").

An absorbed glass mat battery has the electrolyte absorbed in a fiber-glass mat separator. A gel Cell has the electrolyte mixed with Silica dust to form an immobilized gel. These batteries always include a safety pressure relief valve as opposed to vented (also called flooded) batteries. A VRLA battery cannot spill its electrolyte if inverted. The sealed batteries are not serviceable; the cells are sealed, so the degree of charge cannot be measured by hydrometer and the electrolyte cannot be replenished. They are typically termed "maintained – free" by proponents or "unable to be maintained" by skeptics [4].

The letter SR denotes silver oxide chemistry, LR and AG denote alkaline chemistry, CR denotes manganese dioxide lithium chemistry, and BR denotes Poly-Carbon monoflororide Lithium Chemistry. Examples are coded; CR 2032, SR 516, and LR 1154 where the letters and number in the code indicate the battery's characteristics. The number in the code correlate with the cell dimension, being the diameter in millimeter (except for the extra half millimeter in some cases), followed by the height in tenths of a millimeter [10].

Secondary batteries are made in large sizes. Below are some sizes of automobile batteries;

i. Size 65 (top terminal): Fits large cars, trucks and sport- utility vehicles from Ford or Mercury
ii. Size 24/24F (top terminal): Fits many Acura, Honda, Infiniti, Lexus, Nissan and Toyota Vehicles.
iii. Size 35 (top terminal): Fits most Japanese name plates, including many recent Hondas, most Nissan and Toyota Vehicles.
iv. Size 75 (Side terminal): Fits some general motors' midsized and compact cars.
v. Size 34/78 (dual terminal): Fits many large Chrysler Vehicles, many 1996-2000 general motors' Pickups, midsize and large Sedans.

Because of "sulfation" lead-acid batteries stored with electrolyte slowly deteriorate, hence they are date coded to ensure installation within one year of manufacture. In the United States, the manufacturing date is printed on a sticker. The date can be in plain text or using an alphanumeric code. The month is indicated by letters such as A, B, C, etc, which is normally the first letter, while the second character is a single digit that indicates the year of manufacture. For instance, C4 would tell us that the battery was manufactured in March 2004. A2 indicates that the battery was manufactured in January 2002.

In Nigeria today, only the major batteries dealers know the manufacturing dates of most batteries as they are removed before the batteries gets to the consumers or users. Identification of battery date of manufacture then depends solely on the dealer's information and the genuity of these information lies on the reliability of the dealer.

4.0 Capacity of Batteries

Battery capacity is rated in terms of amp-hour. The ampere-hour (Ah) is a way of describing a battery's capacity i.e. how long it will run before draining. Battery's capacity is the amount of electric charge it can store. The more electrolyte and electrode material in a cell, the greater the capacity of the cell [11]. One amp is a flow rate of one coulomb of electron per second, and there are 3600 seconds in an hour, we can state a direct proportion between coulomb and amp-hour; 1amp-hour = 3600 coulombs.

Amp-hour rating = continuous current *x* charge or discharge time [5]. In an ideal battery, this relationship between continuous current and charge or discharge time is stable and absolutes but real batteries do not behave exactly as this simple linear formula would indicate. Therefore, when amp-hour capacity is given for a battery, it is specified at either a given current, given time or assumed to be rated for a time period if no limiting factor is given. For example, an average automobile battery might have a capacity of about 70 amp-hour, specified at a current of 3.5 amps. This means that the amount of time that battery could continuously supply a current of 3.5 amps to a load would be 20 hours (70 amp-hour/3.5 amps). But let's suppose that a lower resistance load were connected to that battery, draining 70 amps continuously, our amp-hour equation tells us that the battery should hold out for exactly one hour (70 amp-hour/70 amps), but this might not be true in real life. With higher currents, the battery will dissipate more heat across its internal resistance, which has the effect of altering the chemical reactions taking place within. Chances are that the battery would fully discharge sometime before the calculated time of one hour under this greater load. Conversely, if a very light load (1 mA) were to be connected to the battery, our equation would tell us that the battery should provide power for 70,000 hours or about 8 years (70 amp-hour/1 milliamp) but the odds are that so much of the chemical energy in a real battery would have been drained due to other factors (evaporation of electrolyte, deterioration of electrodes, leakage current within battery) long before 8 years had elapsed. Therefore we must take the amp-hour relationship as being an ideal approximation of battery life, the amp-hour rating trusted only near the specified current or time span given by the manufacture. Some manufacturer will provide amp-hour derating factors specifying reductions in total capacity at different levels of current and/or temperature [7]. The capacity of the battery can be calculated using equation1;

$$Q_p = I^k t \quad (1)$$

Where; Q_p is the capacity of the battery
K is the peukert number for the battery
I is the load current
t is the time the battery discharge

For a charging battery, the amp-hour can be a rule for necessary charging time at any given level of charge current. For example, the 70 amp-hour automotive battery in the previous example should take 10 hours to charge from a fully-discharged state at a constant charging current of 7 amps (70 amp-hour/7 amps) [5].

As a battery discharges, not only does it diminish its internal store of energy but its internal resistance also increase (as the electrolyte become less and less conductive) and its open circuit cell voltage decreases (as the chemical become more and more dilute). The most deceptive change that a discharging battery exhibits is increased resistance. The best check for a battery's condition is a voltage measurement under load, while the battery is supplying a substantial current through a circuit. Otherwise, a simple voltmeter check across the terminals may falsely indicate a healthy battery (adequate voltage) even though the internal resistance has increased considerably. What constitutes a "substantial current" is determined by the battery's design parameter. It is worthy to note that installing batteries with different Amp-hour ratings will not affect the operation of a device, and except for the time it will work for [5].

5.0 Life Span

The lifespan of batteries varies considerably, depending on the usage, temperature or weather condition, how it is maintained and charged, how frequent one drives short distances, how often you keep your gadgets / electronics plugged in when a car is not running and other factors[12]. Two phrases, we hear most often are "Battery won't take a charge, and my battery won't hold a charge". Battery usage mark is between 6 months to 48 months, yet only thirty percent (30%) of batteries sold today reach the 48-month mark. Infact eighty percent (80%) of all battery failure is related to sulfation build up [13]. Some of the causes of sulfation are as follows:

i. Batteries sit too long between charges. As little as 24 hours in hot weather and several days in cooler weather.
ii. Battery is stored without some type of energy input.
iii. Excessive heat. As temperature increases so does internal discharge. A new fully charged battery left sitting 24hours a day at 110^0 F for 30 days would most likely not start an engine.
iv. Low electrolyte level; battery plates exposed to air will immediately sulfate.
v. Incorrect charging levels and settings: Most cheap battery chargers can do more harm than good.
vi. Cold weather is also hard to battery. The Chemistry does not make the same amount of energy as a warm battery. A deeply discharged battery can freeze solid in absolute zero weather.
vii. Parasitic drain: This is a load put on a battery with the key off. Most vehicles have clocks, engine management computers, alarm system, etc. In the case of a boat, you may have an automatic bilge pump, radio, etc. These devices may all be operating without the engine running. You may have parasitic load caused by a short circuit in the electrical system. If you are always having dead battery problems, most likely the parasitic drain is excessive [14].

5.1 Temperature Effects

Chemical reactions internal to the battery are driven either by voltage or temperature. The hotter the battery, the faster chemical reactions will occur. High temperatures can thus provide increased performance, but at the same time the rate of the unwanted chemical reactions will increase resulting in a corresponding loss of battery life. The shelf life and charge retention depend on the self-discharge rate and self-discharge is the result of an unwanted chemical reaction in the cell. Similarly adverse chemical reactions such as passivation of the electrodes, corrosion and gassing are common causes of reduced cycle life. Temperature therefore affects both the shelf life and the cycle life as well as charge retention since they are all due to chemical reactions. Even batteries which are specifically designed around high temperature chemical reactions, (such as Zebra batteries) are not immune to heat induced failures which are the result of parasitic reactions within the cells. The Arrhenius equation defines the relationship between temperature and the rate at which a chemical action proceeds. It shows that the rate increases exponentially as temperature rises. As a rule of thumb, for every 10 °C increase in temperature the reaction rate doubles. Thus, an hour at 35 °C is equivalent in battery life to two hours at 25 °C. Heat is the enemy of the battery and as Arrhenius shows, even small increases in temperature will have a major influence on battery performance affecting both the desired and undesired chemical reactions. The graph below shows how the life of high capacity tubular

Ironclad Lead Acid batteries used in standby applications over many years varies with the operating temperature. Note that running at 35 °C, the batteries will deliver more than their rated capacity but their life is relatively short, whereas an extended life is possible if the batteries are maintained at 15 °C [15].

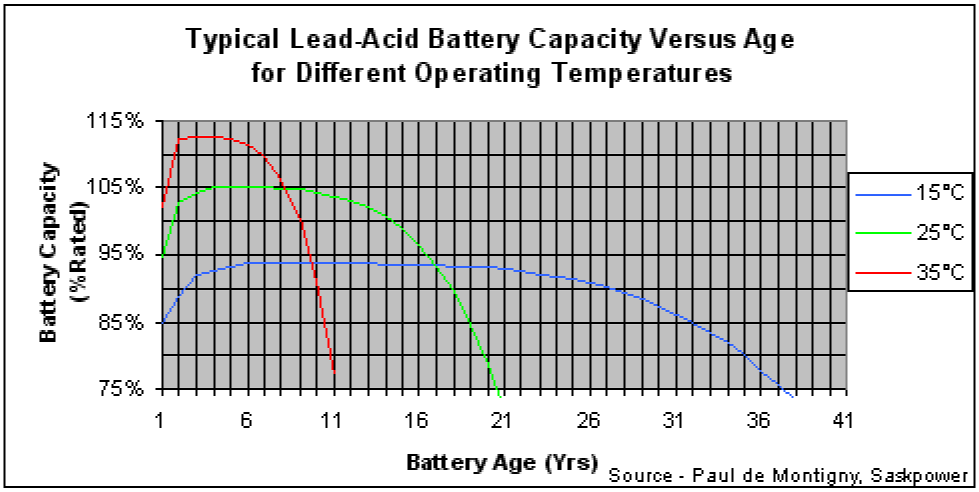

Fig.1: Capacity vs Operating Temperature [15].

As an example of the importance of storage temperature conditions - Nickel-metal hydride (NiMH) chemistry in particular is very sensitive to high temperatures. Testing has shown that continuous exposure to 45°C will reduce the cycle life of a I-MH battery by 60 percent and as with all batteries, the self-discharge rate doubles with each 10°C increase in temperature [15].

5.2 Depth of Discharge

The relation between the cycle life and the depth of discharge (DOD) is also logarithmic as shown in the graph below. In other words, the number of cycles yielded by a battery goes up exponentially the lower the DOD. This holds for most cell chemistries. There are important lessons here both for designers and users. By restricting the possible DOD in the application, the designer can dramatically improve the cycle life of the product. Similarly the user can get a much longer life out of the battery by using cells with a capacity slightly more than required or by topping the battery up before it becomes completely discharged. For cells used for "microcycle" applications (small current discharge and charging pulses) a cycle life of 300,000 to 500,000 cycles is common Mobile phone users typically recharge their batteries when the DOD is only about 25 to 30 percent. At this low DOD a lithium-ion battery can be expected to achieve between 5 and 6 times the specified cycle life of the battery which assumes complete discharge every cycle. Thus the cycle life improves dramatically if the DOD is reduced. Nickel Cadmium batteries are somewhat of an exception to this. Subjecting the battery to only partial discharges gives rise to the so called memory effect which can only be reversed by deep discharging. Some applications such as electric vehicles or marine use may require the maximum capacity to be extracted from the battery which means discharging the battery to a very high DOD. Special "deep cycle battery" constructions must be used for such applications since deep discharging may damage general purpose batteries. In particular, typical automotive SLI batteries are only designed to work down to 50% DOD, whereas traction batteries may work down to 80% to 100% DOD [15].

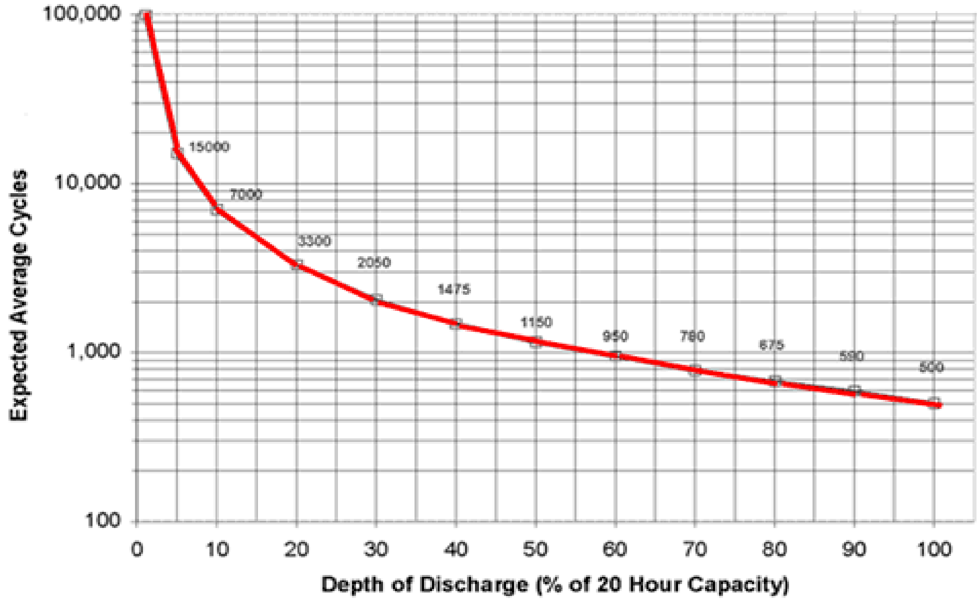

Fig.2: Depth of Discharge vs Cycle Life [15]

5.3 The Life Expectant of Batteries (Lifetime):

Batteries don't last forever but their lifetime is measured in cycles they performed or how many times they can be discharged and recharge before they will no longer take a full charge. The depth of discharge (DOD) has a major effect on the lifetime or life expectancy of a battery. Discharging a battery only 20% may make it last essentially for long time but discharging the battery about 80% of the total capacity of the battery will typically get you 25% more cycles of that full discharges, and discharging it up to 95% may kill or make the battery not retain charges or take full charge. Hence, discharging batteries above 80% of the total capacity may not be economical for the battery. However, car batteries have to be treated differently, they are not designed to discharge even 50%, and it will be damaged if they are deeply discharged. A ''deep cycle'' batteries, on the other hand, can typically survive full discharge since they are design for high discharge system. Batteries life expectancy or run time is given as:

$$Time\ Run = \frac{Q_p}{I_L + (I_c + t_A)xDOD} \tag{2}$$

Where: I_L is the load current
I_c is the circuit current
t_A is the average load operation time
DOD is the depth of discharge of battery

5.4 Load Test of a 12volts VRLA Battery Unit:

Load test was carried out on 12v VRLA battery unit. The load was connected to the battery and the battery discharging between 8-9 hours, this battery was already floating within the voltage specification from the manufacturer. The Figure 3 shows the loss of voltage for each cell in the battery unit when loaded. The loss of voltage contributed by one cell is about one quarter of the way through the discharge. The other cells continued to deliver normally until they had supplied about 50Ah. After that, the battery cells voltages continue to decrease rapidly as seen in the graph below. It was shown that when the battery is connected to a high voltage battery those drained cells became energy sink instead of energy contributors.

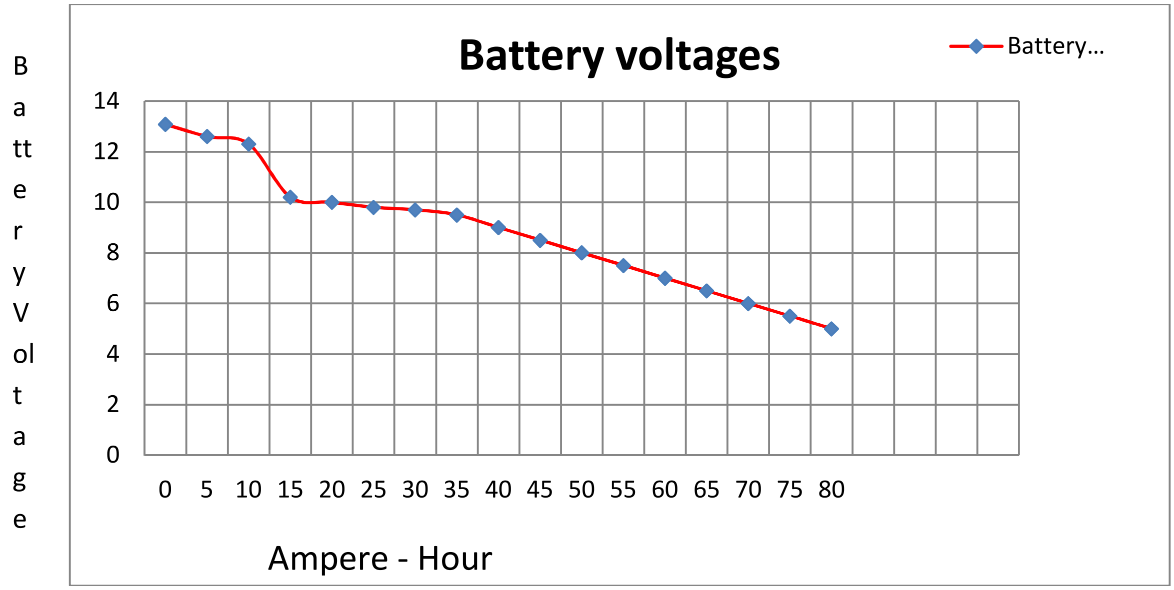

Fig. 3: Load Test on 12v VRLA Battery

6.0 Selection of Batteries

Selection of batteries is standout choices with high stores. Customers reports (CR) best buys offers exceptional value and resource in selecting a battery. When narrowing your choices, weigh features, price and attributes that matters to you. The time to consider purchasing a new battery is not when it leaves you stranded on a cold, dark and stormy night. In the case of car battery, you might not know it is on its last legs until it is too late, because modern ignition and fuel systems can start a car with a minimum of cranking (starting) [11]. Some analysts believe that a battery's service life is very important for optimum performance and longevity. Regular testing and inspection will help to maximize battery life. Below are some care and maintenance guide.

1. Ensure the battery top is clean, dry and free from dirt and grime.
2. Inspect the terminals, screws, clamps, and cables for breaking, damage or loose connection. These should be clean, tight and free of corrosion.
3. Don't disconnect, battery cables while the engine is running (i.e. don't put off a recharging battery).
4. Don't discharge a battery any deeper than you possibly have to; For instance, the alternator tends to over charge batteries that are very low, and overcharge can damage batteries.
5. When not in use, batteries should be stored in a cool place. The extreme allowable temperature is -40^{0}C to 50^{0}C (-40^{0}C to `122^0) for most batteries chemistry.
6. Lead acid batteries must always be kept at full charge during storage, while Nickel and Lithium – based batteries should be stored at around forty percent (40%) state-of-charge (SOC).
7. When changing a battery, the Negative connection should be disconnected first to prevent accidental short-Circuits between the battery terminal and the vehicle or engine frame. Conversely, the positive cable should be connected first.
8. Don't use unregulated high output battery chargers to charge batteries.
9. Don't let a battery gets hot to the touch and boil violently when charging.
10. Check electrolyte levels to ensure that fluid levels are over the top of battery plates. If necessary top up using distilled or demineralised water. Never top up fluid level with acid
11. Always check battery specific gravity and voltage with hydrometer, voltmeter, or battery tester if necessary.
12. Buy the highest reserve capacity or amp-hour battery that will fit your configuration.

7.0 Conclusion

Area where the frequency of power outages is of increasing order, the need for a reliable backup batteries system cannot be over emphasize, be an alternative mean of power supply. The load test can become a veritable tool to check the battery cell health periodically. Just imagine a world where everything that uses electricity had to be plugged into electrical outlets, flash lights (torch), hearing aids, cell phones and other portable devices would be awkward and cumbersome to handle.

Vehicles couldn't be started with the simple turn of a key; a strenuous cranking (Starting) would be required to get the pistons moving, wires would be strung everywhere, creating a safety hazard and an unsightly mess. But batteries provide us with a mobile power source and making lives convenient. It is the belief of this paper that strict adherence to the information and recommendations would guide towards making an informed decision when faced with the choice of batteries to meet needs and it will enable proper use of batteries for good performance, reliability and longevity.

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