Important guidelines and safety precaution for battery management in UPS and other applications

V. Chinnappan
Indian Institute of Astrophysics
Bangaluru- 560034
Email: vchin@iiap.res.in

Introduction

Computers and communication equipments need uninterrupted quality power for proper functioning. Electrical power is the most essential item for Industries and Institutions. The electricity consumer never worries about the quality of the power supplied to him. The most obvious defects in mains supply are complete interruption, voltage dips or sags. Power defects during disk or DVD read and writes operations may destroy the medium. Sometimes the operating system may be corrupted. In a worst case scenario, a hardware failure may occur in the mother board or the input / output interface cards. Computations which take days and months may be interrupted in the middle and it has to be run again wasting precious time.

In order to provide uninterrupted, quality power to computers and communication equipments, normally uninterruptible power supply (UPS) is used. The energy stored in the batteries is used when interruption comes. If high quality power is required, then the power is always taken from the batteries by converting the DC supply to AC supply by means of inverters and the batteries are always charged by rectifiers. This scheme has a well defined voltage magnitude, fixed frequency and good sinusoidal waveforms assuring quality power. As the sensitive equipments are powered by UPS and UPS always takes energy from the batteries, one has to have a good knowledge of handling batteries and its maintenance. This technical note summarizes some of the important technical aspects in operating maintaining battery system.

Batteries are the most unreliable component in the emergency power systems. As batteries have explosion risks, uses corrosive acids for operations, the guidelines provided by Institution of Electrical and Electronics Engineers (IEEE) and the safety and environmental regulations setup by government bodies shall be strictly adhered to.

Battery technology

Battery is a complex electro-chemical device. In a battery, two dissimilar metal electrodes are kept in an electrolyte. In a lead acid battery, Lead oxide and lead are the electrodes (positive and negative plates) and 1/3 sulphuric acid with 2/3 water is the electrolyte. The chemical equation is as shown below:

At +ve plate: $H_2O = 2H + ½ O_2$

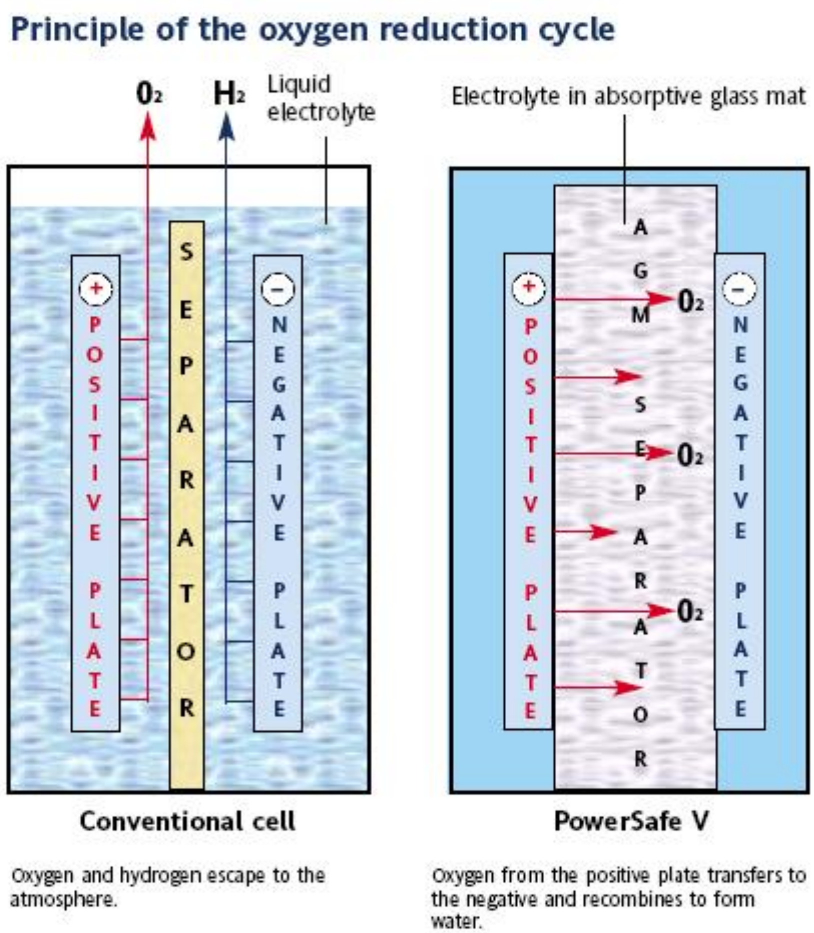
At -ve plate:

$$Pb_{o2} + Pb + 2 H_2S_{04} = 2 Pb S_{04} + 2 H_2 + ½ O_2$$

$$½ O_2 + Pb = PbO$$

$$PbSO_4 + 2 H = Pb + H_2S_{04}$$

Acid is depleted upon discharge and regenerated upon recharge. Hydrogen and Oxygen form during discharge and float charging. The gases escape through vents provided in the battery. This reduces the water level and periodic addition Of water is required.



(Source: Catalyst white paper)

Fig 1. Left : Wet cell (VLA) configuration Right: VRLA cell configuration

The other widely used battery is Nickel-Cadmium battery.

The chemical equation is as shown below:

$$2\ NiOOH + Cd + 2\ H_2O \leftarrow\text{---}\rightarrow Ni\ (OH)_2 + Cd\ (OH)_2 \qquad (2)$$

The ¼ potassium hydroxide (KOH) electrolyte does not enter the reaction like sulphuric acid. Ni-Cd batteries are more robust than lead acid batteries and costs more than the lead acid batteries. Lead-Acid batteries are commonly used for UPS applications.

Types of Lead-Acid Batteries and their application

Storage batteries are used in automotive industry like cars, buses and all other type of vehicle for push button starting application. A similar application is the starting of diesel generator sets. In this application, the energy taken form the battery is of short duration, typically in seconds. The voltage from the battery is fed to a D.C. motor which turns the flywheel of diesel engines and starts the engine. After this the power to the motor is cut off. The battery charger will recharge the battery and once it is charged, it will be in the trickle charge mode to take care of the self discharge of the battery.

The other important application of the batteries is in the Uninterruptible power supply (UPS). There are three types of batteries used in UPS systems.

1. Flooded or Vented Lear acid (VLA) battery. The schematic of VLA cell is shown in fig.1 (Left). Here the Electrolyte H_2S_{04} is in liquid form. During charging time, battery emits H_2 and O_2 gases which escape into atmosphere. Hence the electrolyte loses water and the acid concentration increases. Distilled water is added at regular intervals to keep the concentration of one –third acid and two thirds water. The specific gravity can be checked with hydrometer. These batteries are also called wet cell batteries. Unlike the batteries used for starting of IC engines, these batteries work for long hours when there is a power failure. Normally Tubular type plates are used. Some batteries need addition of water only twice in a year, hence they are called low maintenance batteries.
2. The second type is Valve Regulated Lead Acid (VRLA) batteries. The schematic of a cell is shown in fig.1 (Right). They are also called Sealed Maintenance Free (SMF) barriers, as there is no need to add water. The electrolyte is in the form of gel and filled the cavity of the plates. As any other type battery, they emit H_2 and O_2 gases. As the batteries are sealed H_2 and O_2 gases recombine to form water inside the battery. If due to any reason, the pressure build up inside the battery is more, it has s safety vent valve which opens and releases the gases. High capacity UPS need large number of batteries. A typical 60 KVA UPS needs 32 numbers of 12 Volt (V), 150 Ampere Hour (AH) batteries for about half an hour back-up. All 32 batteries are connected in series, giving a D.C. bus voltage of 408 Volts. In a standby use, one battery voltage may vary from 13.5 to 13.8

volts. On cyclic use, voltage may vary from 14.4 15.0 V. The battery cut off voltage is 12.5 V. The back-up time of UPS can be increased by adding one more bank of 32 batteries of same AH.

3. The third type is Modular Battery Cartridge (MBC). The batteries are SMF type as in Sl. No. 2; the batteries are mounted in a cat ride, which can be mounted inside a rack. Each cartridge may have a power rating of 10 KVA and if one needs 50 KVA, 5 modules can be inserted into the rack. In an N+1 redundant configuration, 6 modules can be installed. Adding or removing modules can be done with power on (Hot swap); hence maintenance can be carried out without shutdown of UPS.

Installation and handling of batteries.

Batteries should be installed in a cool, dust free environment. As it involves specialized knowledge, expert advice may be sought for designing battery rooms. For the wet cell rooms, the minimum air exchange per hour should be computed and exhaust fans of adequate capacity should be installed. VLRA and MBC systems also need the air exchange rates. Sometimes MBC systems are installed along with other server racks and under this condition the amount of air exchange under factory rules shall be adhered to. Factory rules specify six air exchanges per hour in the working rooms.

One of a leading manufacturer of the batteries (1) has given the following warning while handling the batteries:

Batteries produce explosive gases. Keep sparks, flames and cigarettes away from batteries at all times. Protect your eyes at all times. Never lean over battery when jump starting or performing other maintenance.

The author is a witness to one such accident. As the 200 KVA diesel generator set was not starting, maintenance personnel were checking the battery voltage, connection to the starter motor etc. The starting motor winding had a short circuit, which was found out later on, this has allowed high current to flow through the battery, resulting in the heating of the battery. The pressure inside the battery has increased to high levels and the acid was splashed out through vent plugs. Luckily, all persons were standing away from the battery and no one was injured. All this happened in a few seconds duration. The above incident shows the dangers associated in handling the batteries.
Flooded lead acid batteries with large AH weigh considerably and precaution is required while lifting or shifting them. When batteries kept on metal racks, the floor loading has to be checked before placing the batteries. The metal racks need to be earthed. Dry charged batteries are shipped fully charged, without any electrolyte added to them. Electrolyte is added at the site and the specific gravity is measured on each cell. VRLA batteries are delivered with 80 to 90 % charge.
Batteries have low impedance. The internal resistance is only a few milliohms. A 6V / 100 AH battery with thin plates typically have around 1.2 milliohms. Low AH

batteries like 2V / 2AH may have resistance around 80 milliohms. The battery or its connection can explode or molten metal can splatter from battery and wiring if a short circuit occurs. The tools used for tightening should be insulated so that it does not accidentally short the battery terminals. String of batteries in the DC bus has dangerous voltages and hence all the precaution in handling high voltage should be taken. The insulation resistance should be high, any leakage current may create Battery room should have restricted access to prevent unauthorized entrance. Only properly trained and experienced technicians only should handle the batteries. The terminals of the battery have to be tightened to the required level, over tightening may spoil the terminal post. Under torquing can lead to increased contact resistance, hence heating. Periodic checking of the terminal connection and re-torquing is required. There should be a minimum of 1000 mm space in-front of the rack and about 230 mm above the rack. Distance to the wall should be greater than 100 mm. The room temperature where batteries are installed should be maintained between 22 to 27° C especially for VRLA batteries. There is a 5 % reduction in life for 1° above this range. A 10° rise in temperature shortens the life by 50 %. There should be sufficient air flow around each battery.

Failure mode of the batteries

Battery is the most unreliable component in UPS system. Some times batteries fail within a few weeks of commissioning, some give longer life. The behavior of lead-acid batteries is extremely nonlinear and depends on many factors, including the temperature, rate of charge or discharge, and the state of charge. Far from being a simple constant voltage source, a battery's voltage will change under varying operating conditions. The expected life of a wet cell battery is 15 to 20 years. For VRLA batteries, it is 3 to 7 years. MBC also uses VRLA batteries and the life of MBC is also 3 to 7 years.

Flooded cell systems experience corrosion on the positive grid, losses mechanical strength and eventually lead to loss of contact with the grid. Internal resistance increases and capacity decreases. Shorted cell creates short between plates. This failure mode reduces the capacity of the cell but the battery string can still work, providing energy to UPS. Wicking of electrolyte at the terminal posts typically leads to corrosion of connections and other parts.

The main failure mode of VRLA and MBC system are cell dry out and negative strap corrosion. In these batteries, the electrolyte is in the form of gel and over time, the gel loses water and dry out. And 82 to 85 % of failure is due to cell dry out. In higher temperature and high voltage charging, dry out is accelerated. The cell opens; hence power to the UPS is cut off. To increase the reliability of the UPS, another string of batteries is connected in parallel to the first string, so that even if one string opens, the other will be in the circuit. Even if one cell in the series string has much lower capacity than the other cells, the remaining good cells drive the lower capacity cell to reverse polarity condition.

Explosion and fire risk in the battery rooms

a) Wet cell batteries

Flooded or vented lead acid (VLA) batteries emit hydrogen and oxygen as shown in equation (1). The gases escape through the vents provided in the battery. Hydrogen being lighter rises to the top most points like ceiling and other enclosed space. If the battery room did not have good ventilation, then the hydrogen concentration in the room will increase. A 4% hydrogen concentration in the air forms an explosive mixture. If any spark is created in the room, then the mixture explodes. Sparks can be created by the operation of circuit breakers and contactors installed in the room. Spark generating parts must have a distance to cell / block opening of at least 0.5 meter. Batteries should not be covered with polythene sheets; pulling the polythene sheet can create sparks. Insulation resistance should be higher than 1 mega-ohm. Leakage current could cause sparks, explosion and fire. Heaters with naked flame, glowing parts are forbidden in the battery room. The Institution of Electrical and Electronic Engineers (IEEE) have given guidelines (1) for the hydrogen concentration in the battery room. A maximum of 2% needs urgent attention and a 1% concentration is the maximum that can be allowed. Hence, it becomes mandatory to install exhaust fans in the battery rooms and the working of the exhaust fans should be monitored closely triggering alarms if the fans fail. Hydrogen gas monitor should be installed above the batteries and it should trigger alarm if the concentration exceeds 1%. There should be periodic exchange of air in the room; Exide battery manufacturers have given a guideline (2) for hourly air exchange volume as follows:

$$Q = 0.05 \times n \times I \ (m^3 / h) \quad (3)$$

Q is the air volume
N is the number of cells
I is the value of current

For a 220 V DC bus, with 400 Ah, vented battery in float service, float current is 1 A / 100 Ah and the number of cells for 220 V is 110. Hourly air exchange Q is 11 m^3 / h. Wet cell or Vented Lead Acid (VLA) batteries should be installed in a separate building for safety purposes.

b) Valve Regulated Lead Acid (VRLA) batteries

VRLA batteries are sealed batteries without the need to add distilled water. But they emit Hydrogen and Oxygen and they recombine inside the battery to form water. But if the production rate of gases are higher than the recombination rate, then there will a pressure build-up inside the battery. Safety valve opens up releasing the gases. Normally the gas release is 60 times lower than the VLA batteries. Normally UPS is also installed in the same room.

Thermal runaway problems in VRLA batteries

Even though VRLA batteries emit fewer gases, they have a failure mode called thermal runaway which are rarely experienced by flooded or VLA batteries. Higher charge current generates more oxygen at +ve and hydrogen at the -ve plates and leading to dry out of the electrolyte. This increases the internal resistance of the cell, decreases the capacity and in extreme cases, can lead to thermal runaway condition. In VRLA battery and MBC (MBC is a series parallel combination of VRLA batteries), thermal run away occurs when battery's internal components melt-down in a self sustaining reaction emitting hydrogen and hydrogen sulphide gases. Heat is generated faster than it is dissipated. Increasing battery temperature results in more current being drawn from the charger, which increases the battery temperature increasing the current further till the battery fail. The hydrogen concentration can increase to dangerous levels. In thermal runaway conditions the temperature reaches to 160 to 190 $^{\circ}$C. If the hydrogen gas within the battery ignites, there may be enough force to rupture the plastic case, creating plastic 'sharpnel' near battery. Flooded (wet) cell batteries have a longer service life and have fever failure modes than VRLA batteries. To avoid thermal runaway problems temperature compensated chargers can be used which reduces the charge current as the temperature rises.

In both flooded and VRLA batteries, interconnections of the cells operate at high currents during discharge and a high resistance interconnection can result in serious overheating and fire.

In case of fire, first switch of the mains supply and C_{O2} and chemical powder based fire extinguisher can be used to control the fire.

Preventive maintenance

Flooded cell batteries need periodic maintenance. The low maintenance tubular batteries need distilled water to be added to the electrolyte once in six months and the electrolyte level should be 12 mm more than the electrode top. Full charge for the battery is 12.6 V and the specific gravity of 1.26 for the electrolyte. If the open circuit voltage of the battery is less than 12.4 or the specific gravity less than 1.225, add water. Add water when it is charging and gassing will come if too much water is added. To remove corrosion or dirt from the terminal posts, use corrosion removing spray or use alkaline solution such as baking soda in the proportion of ½ Kg : 4 liters of water. Apply a light coat of NO-OX-ID grease on the terminal posts. Apply a light coat of heated NO-OX-ID grease to the contact surface of inter cell connection. Over charging is evident by excessive water consumption and / or spewing or bubbles of electrodes out of the vents. Corrosion is neutralized when the solutions stop bubbling. Apply sodium bi carbonate solution 0.5 Kg / 5 liters of water on clothing if acid is splashed on them. Apply the solution until bubbling stops, then rinse with clean water. Disconnect the ground cable first to avoid any dangerous sparks. Any battery that clearly has leaks in sealed areas like terminal posts should be scrapped. If the open circuit voltage is 8 to 10 V even after charging should be scrapped. Dead, low voltage, (less than 2 V per cell) or reverse polarity are all to be rejected. In VRLA batteries, float current is an indicator of battery problems like thermal runaway. When battery is fully charged, the only current flowing in the battery is float current which counteracts the self discharge of the battery (< 1% per week). Voltage decline of 10% quickly over a short period of time shows electric short between plates. It needs to be replaced immediately. Terminal voltage measurements may be within limits. VRLS batteries may have acceptable open circuit voltage values but unacceptable high impedance values. Measure of the AC impedance may be a valuable tool. AC impedance test is a no load test, so it does not give the capacity of the battery to hold charge or internal battery connection.

Infrared thermography is an excellent tool to determine where the weak connection that may be present.

The storage capacity of the battery can only be measured by load cycle testing. The batteries are discharged at a constant current or power to a specific terminal voltage. Load tests can be carried out only once or twice a year.

A 20% reduction in storage capacity puts a battery at great risk of failure if asked to perform. According to IEEE standards, it should be replaced immediately.

VRLA batteries offer a complex management issue; their life time is usually shorter than predicted life time. The 150 AH, 2 battery banks of 32 batteries (12 V) installed at Indian Institute of Astrophysics for the 60 KVA UPS system lasted nearly three and half years.

Battery monitoring

Load discharge tests are not predictive techniques. The health of the batteries can be monitored by periodic measurement of individual battery cell voltage, Impedance, temperature current and voltage during discharge by placing sensing wiring harness. One example of the battery monitoring system is the one manufactured by BTECH Company, USA (4). All the parameters of the battery are measured on line and any abnormal increase of battery impedance can be due to the detoriation of the battery.

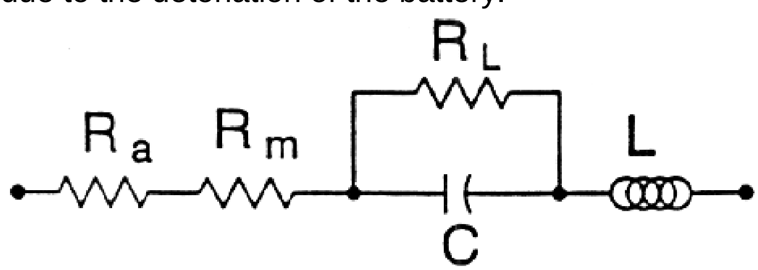


Fig 2 Electrical equivalent circuit of a battery

Ra - Resistance of electrolyte
Rm - Resistance of metal plates
C - Capacitance of the battery
L - Inductance

The impedance measurements predict the life of the battery so that catastrophic failures can be avoided. Impedance is the total resistance offered by the system to AC supply. Simpler battery testing systems from Megger (5) and other companies are also available. An electrical equivalent circuit of the battery is shown in fig. 2.:

Cell inductance ranges from 0.05 to 0.15 micro henries and capacitance from 1.3 to 2.0 Farads. Different companies are using different AC frequency for testing. If the impedance changes by 300 % or more during short time, the battery may fail soon. Hence impedance monitoring has become a valuable tool to predict the failure of the batteries before hand.

Disclaimer

The author disclaims liability for any personal injury, property or other damages of any nature whatsoever directly or indirectly resulting from use of this document. Anyone using this document should rely on his or her own independent judgment in determining the exercise of reasonable care in any given circumstances.

References:

1. Technical bulletin. Lion batteries Ltd

2. Battery impedance testing: A Practical technique for battery conditions assessment and capacity monitoring
   Trevor Lord
   AVO New Zealand

3. Battery Rooms Exide technologies

4. Explosion risks in battery rooms
   www.cholarisk.com

5. BTECH The complete guide to Battery monitoring
   http://www.btechinc.com

6. Electrical Tester
   Megger, January 2010, p 6

7. Catalyst Vent White Paper
   Issued 7/12/2005