Stationary Batteries and Battery Management

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Power distribution system protections, computers and communication equipment demand clean uninterrupted power for reliable functioning. Uninterrupted power is provided by batteries and if high quality power is the need then UPS supplying clean power with input from batteries. However it is a fallacy that batteries are the most unreliable component in the emergency power systems. As batteries have explosion risk, uses corrosive acids for operation and have limited life span than other associated electrical equipment, hence it needs to be carefully selected and closely monitored for reliable functioning.

Lead acid Battery

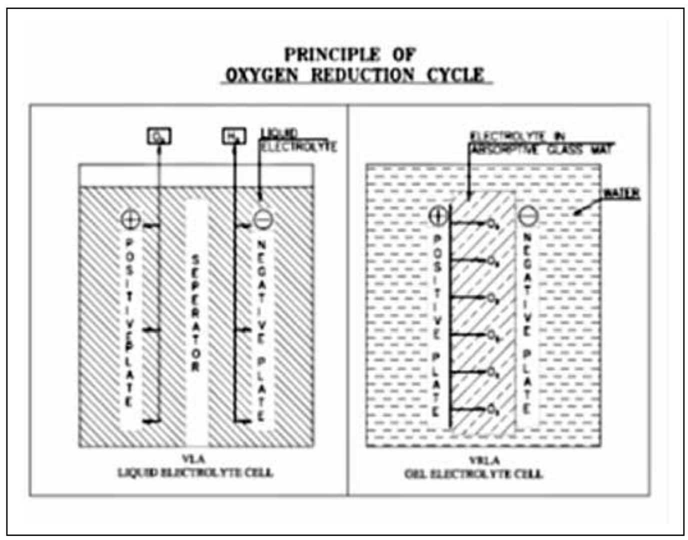
Lead acid batteries are most widely used method of energy reserve. Battery is a complex electro-chemical device .Two dissimilar metal electrodes, Lead oxide and Lead (Positive and negative plates) are in 1/3 sulphuric Acid +2/3 water electrolyte. Simplified equation for charging and discharging can be written as under-

Discharge cycle

$$Pb+2H_2SO_4+PbO_2 \rightarrow Pbso_4+2H_2O+PbSO_4$$

Charge Cycle

$$Pbso_4+2H_2O+PbSO_4 \rightarrow Pb+2H_2SO_4+PbO_2$$

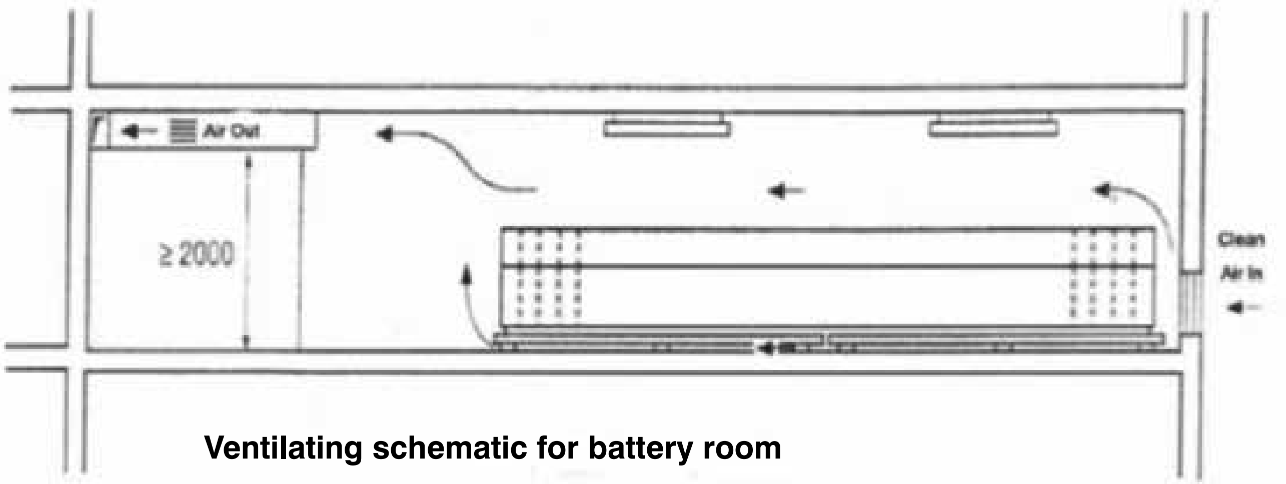


Lead electrode supply Positive ions and Lead dioxide Electrode supply Electrons while discharging and process is reversed when external current is injected. Acid is depleted during discharge and regenerated during charging. Hydrogen and oxygen form during charging and float charging. The gases escape through vents provided in battery. This reduces water level and periodic addition of water is required.

Lead acid Battery Types.

There are three types of batteries used for applications under discussion-

1. VLA (Vented Lead Acid) or Flooded battery shown in schematic on Left above. Here the Electrolyte



Ventilating schematic for battery room

H_2SO_4 is in liquid form, gases H_2 and O_2 escape to atmosphere. Hence electrolyte loses water and concentration increases. Water is added at regular intervals to maintain the dilution level.

2. VRLA (Valve Regulated Lead Acid) battery, also called SMF (Sealed Maintenance Free Battery) as water is regenerated in the battery and need of adding water is not there as indicated on right in schematic. Electrolyte between plates is either absorbed in glass mat or gelled. Safety vent valves are provided to release any over pressure built inside the battery.
3. MBC (Modular Battery Cartridge) They are basically assembly of SMF batteries, in series -parallel combinations, which can be mounted in a rack. Each cartridge is for a power rating of say 5 or 10 KVA and multiple of them can be mounted to meet the requirements.

Handling and installation of batteries.

Fully charged dry batteries may be better alternative for installation of heavy large batteries.. Electrolyte of correct concentration can be added after putting the dry batteries at site. Free space above batteries of 2 m and between stacks of 250 mm should be kept. Metallic stands should be treated and painted to avoid corrosion from acids and effectively earthed. The room should be with acid proof flooring or with pan below battery stand .

A factor often overlooked that optimum operating temperature for operation of batteries is 25°C and rise of 10°C above that reduces life to half. A dust free well ventilated room for housing batteries is a must. Hydrogen vented during charging and float charging being lighter gas accumulates at top. It forms an explosive mixture at 4% concentration with Air hence it is absolutely necessary that roofs of a battery rooms are without any pockets to not allow any accumulation of Hydrogen. Critical installations are provided with Hydrogen monitoring devices to keep the level less than 2% as specified by IEEE standard.

The quantum of fresh air to be circulated can be calculated from as per EN 50272-2 standard using following formula-

$$Q = 0.05 \times n \times I \quad m^3/\text{Hour}$$

Where-

n = number of cells.

I = Value of current as defined in the standard depending on battery duty and type.

Natural ventilation is adequate in case batteries are housed in a room where free air circulation is possible, inlet and outlet openings should be dimensioned as greater than 28 x Q cm ^{2}. In case of forced ventilation is necessary system should be charged with quantum of air as calculated above, care is to be taken that inlet is fresh outside clean air.

It is advisable that expertise of battery manufacturer is taken regarding large installations specially where flooded cells are being used which generate Hydrogen ,almost continuously, during charging .However as specified in IS 12332 for industrial environment of 12 air changes /hour and ensuring fresh air inlet at bottom with circulation above the batteries and exhaust at top is normally adequate.

VRLA & MBC are vulnerable to overheating if voltage and/or ambient temperature exceed recommended levels. They can be housed in the same room where other electronic equipment are there but they should not be inside a cabinet and air circulation on top of battery is ensured. The environmental conditions ensured for Electronic equipment is adequate for batteries of VRLA or MBC type.

Failure Modes

Behaviour and life of batteries is extremely non linear which depends on many factors viz. temperature, rate of charge & discharge and state of charge. Batteries do not remain as source of constant voltage and vary a lot due to different operating conditions. Broadly stated, expected life, under optimum conditions, of wet cell batteries are 10-15 years while VRLA &MBC batteries may work for 3-7 years.

Flooded cell systems experience corrosion on positive grid, looses mechanical strength and eventually lead to loss of contact with the grid. This increases Internal resistance and capacity gets reduced. Dust particles and water soluble salts accumulate on equipment surface and increase corrosion level and cause surface tracking, wicking of electrolyte at terminal post also is a contributing factor. A dust free battery room maintained at a 22-28° C can increase battery life.

VRLA & MBC batteries main failure mode, about 80-85%, is drying out of electrolyte due to high charging currents.

Thermal runaway (Failure Mode)

A problem with VRLA &MBC batteries and rarely with Flooded batteries may occur due to generation of more Oxygen on +ive plate and Hydrogen -ive plate at higher Charging Currents. High charging currents cause drying out of Electrolyte which in turn increases internal resistance. Increase in resistance heats up the cells further and may cause failure of cell/s which further increasing the currents, The reaction becomes self sustaining and temperatures can rise to a dangerous level .Extreme situation may arise when Hydrogen ignites inside the battery and battery case burst causing damages and injury. This failure mode is avoidable by introducing a temperature Compensation circuitry in Chargers which reduces currents on temperature rise. Manufacturers recommend this compensation factor in terms of voltage adjustment per degree of temperature; typical example is 0.94 mV per ºC. This means that the charger should be programmed to adjust its voltage output up or down by this amount based upon the reading of a temperature probe placed on a battery. This is important in order to prevent overcharging or undercharging, in case of low temperatures.

Charging of batteries

All too often, stationary batteries are not correctly or adequately charged. This leads to a shortened battery life and may also cause a premature and sometimes catastrophic battery failure. Battery charging is a complex process. Consideration has to be given to several fixed and varying parameters such as battery type and chemistry, battery application, and the environment in which the battery is being used. In many cases batteries are installed and put into service connected to chargers that have been factory preset and not readjusted to suit the particular batteries that they are charging.

A panel of experts when asked what they considered were the three most important things to monitor on a battery, the unanimously agreed on two, which were battery temperature and current.

The VLA cell is somewhat more forgiving to overcharging than the VRLA cell due to their inherent design of ventilation of gases and cooling due to convection in liquid electrolyte. However, the higher charge current caused by the higher charge voltage will accelerate the positive plate corrosion and shorten the life of the cell. VRLA cells' are not designed for replenishment of water and over charging may cause pressure relief valves to open and cause dry out condition a irreversible loss of capacity. The heat dissipation is also impaired due to semisolid mass of absorbed or gelled electrolyte.

Undercharging when occurs over a period of time or the cell is left discharged or not fully charged, it causes "plate Sulfation" and results in the reduction of cell capacity which is irreversible and the cell will fail. Even before Sulfation occurs, undercharging will mean that the cell is never at full capacity.

Charging Voltage

The SG of the electrolyte determines the open circuit voltage (OCV) of a battery cell. If a constant of 0.845 is added to the SG that will determine the OCV. To maintain a charge on the cell, the charging voltage must be slightly higher than the OCV in order to overcome the inherent losses within the battery caused by chemical reaction and resistance. For a lead-acid battery the value above the OCV is approximately 0.12 volts. This "adder" voltage will vary very slightly (+/- 0.02V) for different plate additives and construction but it is a very good rule of thumb. Although the following shows some example calculations, the manufacturer's recommended float voltage should be used at all times.

For a typical VLA battery with a SG of 1.215 the OCV would be: 1.215 + 0.845 = 2.060V. The correct charging voltage would therefore be approximately 2.060V + 0.12V = 2.18V

For a typical VRLA battery with a SG of 1.300 the OCV would be: 1.300 + 0.845 = 2.145V The correct charging voltage would therefore be approximately 2.145V + 0.12V = 2.265V

The above examples are for a single battery cell. To determine the float voltage for a 6 cell (12V) battery unit the cell charge voltage would be multiplies by 6. For a complete battery string, the cell voltage would be multiplied by the number of cells in the battery.

Note. With VLA cells, the distribution of charge voltage between the positive and negative plates sometimes leads to a higher recommended float voltage.

Freshening Charging

Lead-acid batteries will self discharge until they are put into service. As this often is a period of several months but should never exceed 6 months, it is important that they be given a "freshening" charge before they are placed on float charge. This freshening charge is manufacturer defined but is normally about 100 mV per-cell above the recommended float voltage for a period of about 24 to 72 hours. If batteries that have been in storage do not receive a freshening charge and they are placed on float charge immediately after installation and are used in standby service where they are not regularly cycled, they may never reach full charge.

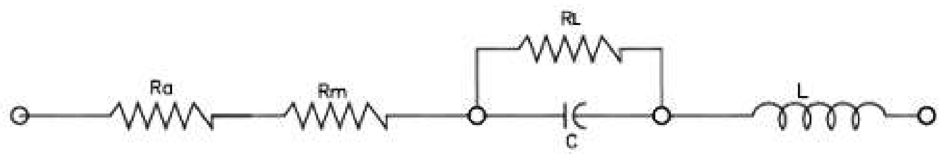
If batteries are stored for more than six months or for a shorter period at a temperature above 77ºF (25ºC) they should routinely be placed on float charge.

Equalize Charging

An equalize charge is essentially a boost charge for an extended period at an elevated level above the normal float voltage of the entire battery string and is normally manufacturer specified. It is so called because it is used primarily to "equalize" the voltage and SG inequalities between individual cells. It is also used to try to remove Sulfation from the plates, and with VLA cells to prevent electrolyte stratification causing capacity loss. It can also be used to recharge the battery more rapidly after a discharge although this should be avoided with VRLA cells unless recommended by the manufacturer.

There is a "caution" when applying an equalize charge. As with float charging, the level is largely determined by the SG and plate chemistry. Because of the elevated charging current, all cells in the battery are basically overcharged, and this should only be allowed for a short period of time which shouldn't exceed about 72 hours. As equalize charging increases the rate of gassing, with VLA batteries it is important that the electrolyte level is correct before applying an equalize charge. For VRLA batteries, it is important not to exceed the gassing rate of the cells which can be as low as 2.4 volts-per-cell. Typically, manufacturers of VRLA cells do not recommend the use of periodic equalize charging except for cycling service applications.

BATTERY EQUIVALENT CIRCUIT



Ra – Resistance of Electrolyte; Rm – Resistance of metal plates;

RL – Leakage resistance; C- Capacitance; L- Inductance.

When equalize charging is used, always follow the manufacturer's instructions with respect to voltage levels and time, Also always check the upper voltage tolerance of the load as the higher voltage being applied to the DC bus may not be acceptable to the load.

Charge Current Control

Most manufacturers recommend a maximum recharge current that can be applied to their VRLA product. This is usually indicated on the data sheet in terms of battery cell capacity at a given discharge time divided by a constant. For example, C/5 amps at the 8 hour rate. What this simply means is that, for example, a cell rated at 100 ampere hours (Ah) at the 8 hour rate, the recharge current should not exceed 100/5 or 20 amps. Some UPS manufacturers of repute have patented combination of constant voltage and current charging for floating the batteries for standby duty ,which increases the life of batteries.

The Charger

It is important that the battery charger is suitable for charging the battery to which it is connected. Just as all batteries are not alike, all chargers are not the same. In order to adequately charge a battery without damaging the battery, a charger must have tight voltage regulation, low ripple voltage and low EMI and RFI noise characteristics.

Output voltage should be regulated over the full range of the charger output and typically this should be +/- 0.5%. In other words the voltage output should be stable irrespective on the load that is being placed on it. Output ripple for communication application typically required to be less than 30 mV rms for avoiding noise in communication network also charger output having high ripple contents affect battery life.

Monitoring the batteries

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 sensors and harnesses. All parameters of the battery are measured on line and abnormal increase of Impedance of the battery due to the deterioration of battery.

Impedance measurement predicts the life of the battery to avoid catastrophic failure. Total Impedance is measured by A C supply. Simpler battery testing systems are marketed by Meggar and some other makers. An equivalent Circuit of battery is as shown above showing inductance and capacitance in circuit which asks for AC measurements. Researchers are further evaluating about reliability of AC impedance method and recommending DC resistance measurement. However AC methods are still prevalent and fairly reliable. Cell Inductance ranges from 0.05 to 0.15 μ Henries and Capacitance 1.3 to 2.0 Farads. Different companies use different frequency. If impedance changes by 300% or more in short time, the battery may fail soon.

Battery Capacity, battery energy

Battery capacity shows how long the battery after full charge can feed the load connected to the battery. Usually the unit of battery capacity is ampere-hours (Ah) or mill ampere -hours (mAh) for small batteries. It is the product of constant current flowing through load and discharge time.

C(Ah) = I (A) X T (h)

Battery Energy is the total energy stored inside the battery which is different from capacity as it depends on voltage which can be expressed as.

E(Wh) =C(Ah) x U_{nom}(V)

If several batteries of the same capacity are connected in series the capacity of this large battery is the same as the capacity of single battery. The energy of the large battery is the product of energy of a single battery and number of batteries connected in series.

$$V = \sum_i^n V_i, C = C_i, E = E_i \times n$$

If several batteries of the same voltage are connected in parallel the capacity of this large battery is the sum of the capacity of all batteries. The energy of the large battery is the product of energy of a single battery and number of batteries connected in parallel.

$$V = V_i, C = \sum_i^n C_i, E = E_i \times n$$

So called "energy capacity" is the constant power with which the battery can discharge during some short period - usually 15 minutes (not 10 minutes as some manufacturers state). Energy capacity is measured in watts per cell or (sometimes) in watts per battery.

Usually a manufacturer of lead-acid battery assigns as nominal capacity the capacity during prolonged (10, 20 or 100 hours) discharges. This capacity is denoted by C_{10}, C_{20} or C_{100}, respectively. The current that flows through the load during 20-hour discharge is denoted by I_{20}. If we know the battery capacity we can calculate this current:

Final Discharge Voltage

Battery voltage decreases while battery discharges. Battery discharge should be stopped when battery voltage falls below some pre-designated voltage - so called final discharge voltage (or cut off voltage). The less is the final discharge voltage the more is battery capacity. Battery manufacturer assigns the absolute minimum final discharge voltage (dependant on discharge current). If battery is discharged below this point the battery can be damaged due to over discharge.

Temperature& Battery capacity

Nominal battery capacity is usually rated at some standard temperature (most often 20°C (68°F) to 25°C (77°F). If battery temperature rises from 20°C to 40°C (104°F), lead-acid battery capacity increases by about 5%. With temperature decreasing from 20°C to 0°C (32°F), lead-acid battery capacity is reduced by about 15%. As the temperature decreases by 20°C (68°F), the lead-acid battery capacity falls by another 25%.

Battery depreciation (aging)

When lead-acid battery is delivered it's capacity may be slightly more or slightly less than the rated (nominal) capacity. After several cycles of discharge-charge or a few weeks at a "floating" charge the battery capacity increases. With further use or storage battery capacity falls - the battery wears out, gets older and eventually needs to be replaced with a new battery. To replace the battery in time one needs to watch battery capacity degradation with the help of modern battery tester. Battery life depends on design for a type of duty and depth of discharge a shallow discharge battery can last more than 1000cycle at depth of discharge (DOD) of about 30% capacity while similar life can be predicted for deep discharge battery at 50% DOD. Hence selection of batteries for duty cycle is needed for having good per formance.

Tubular and Flat Plate Lead Acid Battery

Tubular batteries were developed in pursuit of improving storage capacity of energy .Lead -Acid battery Positive plates are essentially consisting of Lead Dioxide (PbO_2) and negative Plate is of sponge lead. In both tubular and Flat plate cells negative plates are similar in construction and function. Tubular Batteries the positive plates are formed with Lead -Antimony alloy the tubes are filled with active material. Performance of tubular Batteries are different and suits the applications where battery is required to brought to full capacity after a deep discharge quickly but normally these batteries shed capacity faster and also corrosion of grids and active material are faster. They reach to end voltage faster. While Plate electrodes are suited for applications where deep discharge is not there as a regular duty and longer cycle life is required such as UPS and Switch gear application.

Battery Sizing for switchgears and other stationary application

Certain Basic principles /steps are stated these are based on IEEE485-1997 and Exide Handbook for GEL VRLA Part 2 referring to them is recommended for sizing the batteries. Also most of the soft-wares are based on referred IEEE standard.

Loads are classified Continuous, Non continuous (for > 1min) and momentary (< 1min). A duty cycle is plotted to see the loads in Amp. (or power)against time.

Battery size is calculated as under:

$$\text{Number of Cells} = \frac{\textit{Maximum Voltage}}{\textit{Float charge Voltage}}$$

$$\text{Minimum Cell voltage} = \frac{\textit{Min. Battery Voltage}}{\textit{Number of cells}}, \ \textit{V/Cell}$$

However correction factors are to be applied for arriving at recommended Batteries-

1. Temperature Correction- As capacities of Battery vary as per ambient temperatures appropriate factors are to be applied as per data of manufacturer.
2. Aging Factor- Standard cites that 125% of designed capacities are should be used for stable performance during entire life of batteries.
3. Design Margin- To safeguard against increased loads, poor maintenance, sudden discharge etc. 10-15% extra capacity is built.

Lead Acid batteries remain the main work-horse for reliable energy reserve for critical applications. Though there are rapid developments in the field with other type of electrolytes and electrodes, they are for specialised application or not economically viable yet. Nevertheless as in many other fields, much work is being done to improve performance, serviceability and sustainability of Lead Acid batteries and it is worthwhile to keep track of the same.

References-

1. EN 50272-2: Safety requirements for Secondary Battery and Battery installations
2. IEEE Std 485-1997: Recommended Practice for Sizing Lead Acid Batteries for stationary application.
3. Hand books and guidelines by Exide Technologies.