An Overview of Batteries for Photovoltaic (PV) Systems

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ABSTRACT
PV stand alone or hybrid power generation systems has to store the electrical energy in batteries during sunshine hours for providing continuous power to the load under varying environmental conditions. This article deals with the requirements, functions, types, aging factors and protection methods of battery. The PV system performance depends on the battery design and operating conditions and maintenance of the battery. This paper will help to have an idea about the selection of batteries, ratings and maintenance of batteries for PV applications.

Keywords
PV Systems, Batteries – types, Requirements, Ageing Factors, Regulators, Battery Protection

1. INTRODUCTION
Globally, there are isolated areas where access to an electricity grid is too expensive. Small and medium sized diesel generators were used to provide electrical energy to these isolated areas. Diesel generators have low initial cost but have high running and maintenance cost. The diesel generator pollutes the environment by producing 3kg of CO2 gas for every liter of diesel fuel [1]. To avoid environmental pollution, global warming and ozone layer damage renewable energy sources are the suitable alternatives. Among all renewable energy sources (such as wind, solar, geothermal etc) solar photovoltaic energy is mostly used because of its clean, pollution free and in- exhaustible nature.

The PV power generation may be standalone type as in figure 1 or hybrid type as in figure 2. In PV power generation system the generated power and load power requirement are not equal. Hence a necessity for a storage system arises to limit the effect of the variation of the solar power due to the variation in the environmental conditions such as intensity of solar radiation and temperature. If standalone type of PV power generation is used the battery backup capacity should be high to provide power without interruption during winter season also. The minimum size of the storage unit for the PV powered system is energy supply for one night. The maximum size depends on the days of autonomy required. [1]

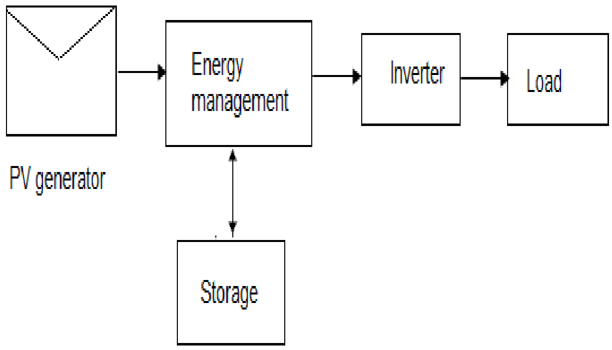

Fig 1. Standalone PV system with storage battery

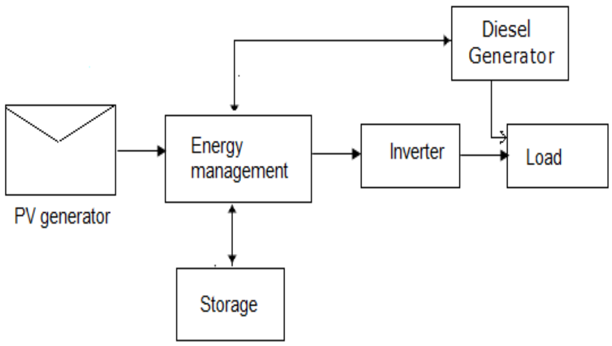

Fig 2. Standalone PV system with storage

2. PV STORAGE SYSTEM
Batteries of PV systems are subjected to frequent charging and discharging process. Lead acid battery with deep discharge is commonly used for PV applications. Gel type lead acid batteries are used for remote applications where maintenance free operation is required.

For portable applications Nickel-Cadmium or Ni-Metal hydride batteries are used. The life time of the batteries varies from 3 to 5 years. The life time depends on charging/discharging cycles, temperature and other parameters.

The batteries for PV applications are to be designed to meet the following characteristics: [1]

1. Low cost

2. High energy efficiency
3. Long life time
4. Low maintenance, robust construction
5. Good reliability and less self discharge
6. Wide operating temperature

2.1 Low Cost
The cost can be represented by the initial cost or annual cost. The initial costs are the cost fixed during planning phase to purchase the storage batteries. The maintenance and operation costs need not be included in the initial cost. But these costs must be included in the annual cost calculation. The battery lifetime strongly influence the cost of the system. If the lifetime of the battery is less than 3.5 years then battery is the highest cost incurring component in the system.

2.2 Efficiency
The battery units are not ideal. There may be energy losses during charging, discharging and self discharging during unused time also. The energy efficiency is calculated as the ratio of charged energy to the discharged energy.

Energy efficiency = charged energy (KW)/Discharged energy (KW).

The self discharge depends on internal leakage losses of the battery and external losses due to the energy consumption of electronic components. The self discharge of the battery increases with increase in temperature. To reduce self discharge batteries should be stored at lower temperature.

2.3 Maintenance
Low maintenance or maintenance free operation of battery is prepared for small systems at rural areas.

3. FUNCTIONS OF STORAGE BATTERY IN A PV SYSTEM [2]

3.1 Energy storage and autonomy
To store electrical energy produced by the PV array and to supply energy to electrical loads as and when needed (during night time and non sunshine days in winter).

3.2 Stabilization of voltage
To supply power to electrical loads at stable voltages by suppressing voltage fluctuations in PV systems and protecting loads from damage.

3.3 Surge supply current
To supply the high starting currents to electrical loads such as motor or other inductive loads. The performance of the PV system with battery storage depends on the battery design and operating parameters of the system. If the battery is not designed for the operating conditions of the PV system then it will fail to work prematurely.

4. OPERATING PRINCIPLE OF BATTERY
Battery is an electrochemical device that converts chemical energy into electrical energy and electrical energy to chemical energy by oxidation-reduction reactions as in figure 3. [1]

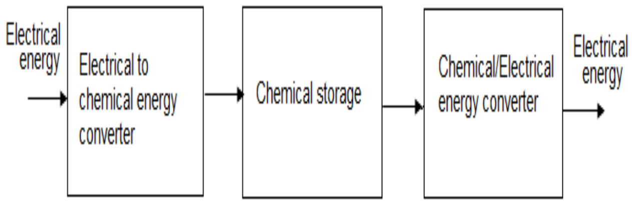

Fig 3. Principle of battery

5. BATTERY PARAMETERS

5.1 Battery capacity
The storage capacity of the battery is represented in Ampere hour or Ah. If V is the battery voltage then the energy storage capacity of the battery can be Ah x V = Watt-hour. Usually battery capacity will be specified for a given discharge/charge rating or C rating. The actual capacity depends on operating conditions such as load, temperature, etc.

5.2 Battery voltage
The terminal voltage during operating condition is known as nominal voltage or working voltage. This voltage will be specified by manufactures. It may be 3V, 6V, 12V, 24Vetc

5.3 Depth of discharge (DOD)
It gives a measure of energy withdrawn from a battery as a percentage of its full capacity. The state of charge of a battery is the difference between the full charge and the depth of discharge of the battery in percentage. If the DOD is 25% then the state of charge is (100 - 25) = 75%.

5.4 Battery life cycle
It is the number of complete charge – discharge cycles a battery can work before the nominal capacity decreases less than 80% of its rated initial capacity. After the specified life cycle, the battery will work with reduced capacity. It can be used but the capacity will be lower.

5.5 Discharge/charge rate or C – rate
C rating is the value obtained by giving the ratio of the capacity of the battery to the number of hours for full charge or discharge represented as C/X, where X is the time in hours for full charge or discharge. If X = 10 h then C-rating is C/10 or 0.1C.

The charge or discharge current for a C- rating can be calculated by dividing Ah capacity by the total hours of charge and discharge. For a 50Ah capacity battery if C rating is 0.1 C then the charge or discharge current will be 50/10 = 5A.

5.6 Self discharge
It is the electrical capacity lost when a battery is not being used due to internal electrochemical process with the battery. The self discharge increases with increase of temperature. The batteries can be stored at lower temperatures to reduce self discharge.

6. TYPES OF BATTERIES [1-4]

6.1 Lead acid batteries
Lead acid batteries are the common energy storage devices for PV systems. Lead acid batteries can be either 6V or 12V type in tough plastic container. The batteries can be flooded cell type or sealed/gel type.

6.1.1 Flooded cell type battery
This is the most commonly used type of battery for renewable energy systems today. Flat and Tubular plate type are the versions of flooded batteries. In flooded batteries the electrodes are completely submerged in the electrolyte. During charging of flooded batteries to full state of charge, hydrogen and oxygen gases produced from water by the chemical reaction at negative and positive plates passes out through vents of the battery. This necessitates the periodic water addition to the battery.

6.1.2 Sealed /Gel type battery
These batteries have immobilized form of electrolyte. The sealed maintenance free lead acid batteries are also called as valve regulated lead acid (VRLA) batteries or captive electrolyte lead acid batteries. The sealed batteries are of two types namely gelled electrolyte type and absorbed glass mat type.

Immobilized electrolyte batteries will have less electrolyte freeing problems compared to flooded electrolyte batteries. During charging process, hydrogen and oxygen gases are produced from water due to chemical reactions at the negative and positive plates. These gasses recombine to form water, thus the need for water additions is eliminated.

This type of lead acid batteries is suitable for PV applications because of the following reasons:

1. Easy transportation.
2. Suitable for remote applications because of less maintenance requirement.
3. No need for water additions.

6.1.3 Gelled batteries
The addition of silicon dioxide to the electrolyte forms a warm liquid which is added to the battery and become gel after cooling. The hydrogen and oxygen produced during charging process are transported between positive and negative plates through the cracks and voids in the gelled electrolyte during the process of charge and discharge.

6.1.4 Absorbed GAS MAT [AGM] batteries
In AGM batteries the glass mats are sandwiched between plates. These glass plates absorb the electrolyte. The oxygen molecules from positive plate moves through the electrolyte in the glass mats and recombine hydrogen at the negative plate to form water**.**

Both gel and AGM batteries require controlled charging. In this batteries generally Lead calcium electrode are used to minimize gassing and water loss. Voltage and current must be controlled below C/20 rate.

Characteristics of Lead Acid Batteries:

Specific energy : 25 – 35Wh/kg

Life time : 250 -750 cycles

Advantages :low cost, high efficiency, simple operation

Disadvantages : relatively low lifetime

6.2 Nickel –Cadmium (Ni - Cd) batteries
In Ni-Cd battery positive electrode is made up of cadmium and the negative electrode by Nickel hydroxide separated by Nylon separators immersed in potassium hydroxide electrolyte placed in a stainless steel casing. It has longer deep cycle life and temperature tolerant compared lead-acid battery. Cadmium is replaced by metal hydrides due to environmental regulatory rules. Memory effect degrades the battery capacity when the battery is idle for long time.

Memory effect is the process of remembering the depth of discharge in the past. If the battery is discharged to 25% repeatedly, it will remember it, and if the discharge is greater than 25%, the cell voltage will drop as shown in figure 4. To recover the full capacity the battery, it should be reconditioned by fully discharging and then fully charging once in few months.

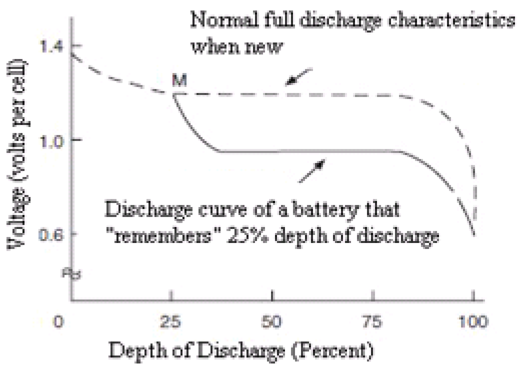

Fig 4. Memory effect of Ni-Cd battery

6.3 Nickel – Metal hydride (Ni MH) batteries
It is an extension of NiCd batteries with high energy density. The anode is made up of metal hydride instead of NiCd. It has less memory effect and delivers high peak power. It is expensive than NiCd batteries and overcharging damages the battery easily.

Characteristics of Nickel-metal hydride Batteries:

Specific energy : 65 – 75Wh/kg

Life time : 700 cycles

Advantages : high specific energy, good deep discharge, environmental friendly

Disadvantages : High cost, high self discharge and low efficiency

6.4 Lithium ion batteries
The energy density of Li-ion batteries is 3 times that of Pb-acid batteries. The cell voltage will be 3.5V, and few cells in series will give the required battery voltage. The lithium electrode reacts with the electrolyte creates a passivation film during every discharge and charge operation. This is compensated by the usage of thick electrodes. Because of this fact the cost of Li-ion battery is higher than NiCd batteries. Further overcharging damages the battery.

6.5 Lithium polymer batteries
In this battery solid polymer electrolyte acts as both electrolyte and separator and the lithium electrode reaction with the electrolyte is less.

Characteristics of Lithium Batteries:

Specific energy	: 100-150Wh/kg
Life time	: 1000 cycles
Advantages	: high specific energy, long life time
Disadvantages	: High cost, low safety

7. BATTERY AGEING FACTORS [1], [3]

7.1 Acid stratification

In lead acid batteries there is a slight difference in density between water and acid. If the battery is left idle for a long time, the mixture of water and acid can separate into layers with water rising up and acid sinking down because of gravimetric effects. This can lead to corrosion of the plates at the bottom side.

The stratification can be removed by stirring the electrolyte with air pumps or nature gassing of the battery at high voltages.

7.2 Sulphation

Sulphation forms during normal operation of battery. During discharging process a thin layer of sulphate forms on the battery plates. The layer dissolves into the battery acid during charging. When a hard crystalline layer is formed it cannot dissolve during charging. When the sulphate crystals cover the surface area of the plates, it will reduce the battery efficiency by holding less charge. Sulphation occurs if the battery is kept idle for a long time or if the charging is not enough to dissolve the sulphate formed during charging cycle. Incomplete charging for long time and high temperature will also lead to sulphation.

Desulphation can be carried out by equalization which is the process of overcharging the battery. Desulphation can also be done by pulse conditioning by simply controlling the pulses or frequency components of frequency ranging 2-6 MHz.

7.3 Corrosion

The application high positive potential at the positive electrode causes the corrosion of the lead grid. It is an irreversible process and results in the decrease of cross section of grid which leads to the increase in grid resistance. Further formation of layers of lead oxide and sulphates between grid and active material increases the contact resistance which results in increased voltage drop during charging and discharging process. The factors on which corrosion depends are electrode potential, temperature, grid alloy and quality of grid. For PV applications batteries having thicker grid are suitable to minimise the corrosion effect and to increase the lifetime.

7.4 Erosion

The electrodes subjected to strong mechanical loads during cycling operation due to the conversion of active material into lead sulphate during discharge. Lead sulphate has 1.94 times larger than lead dioxide in volume per mole. Because of the change in volume, the active material loosens and gets separated from the electrode and forms sludge at the base of the battery. If the sludge volume becomes large then it may cause short circuit between electrodes.

7.5 Short circuit

The plate connectors from the positive electrodes can also be subjected to corrosion and cause detachment of small layers of the connectors, which when fall on the electrodes will result in short circuit. To avoid these problem separators should extend upward over the electrodes. In case of lead acid batteries dendrites growing from positive to negative electrode through the separators. This growth can be accelerated by low state of charge for long periods which leads to low acid concentrations. This dendrite growth causes microscopic short circuit which will lead to sudden and complete breakdown of the battery.

7.6 Low temperature

Low temperature will not accelerate any irreversible aging effect. Formation of ice must be prevented. Once ice is formed, then it is difficult to operate the battery and the cell housing may burst due to the increased volume and the surroundings will be affected by the scattering of sulphuric acid.

7.7 High temperature

Increase of battery temperature by high ambient temperature or by high current rate charging/discharging increase corrosion, sulphation, gassing and self discharge etc. For every 10°K rise of temperature the life time battery is reduced by 50%. The normal operating temperature for batteries is 10° - 20° C.

8. BATTERY PROTECTION AND REGULATION

Proper voltage regulation circuit must be used to prevent overcharging and excessive discharging of the battery. Charging of the battery too fast or too long will cause permanent damage to the battery. Gassing occurs while permitting higher charging current to a fully charged battery. Excessive discharging should also be avoided to prevent the disintegration of the plates. Hence the usage of voltage regulating circuits to maintain battery voltage within the specified range becomes necessary.

8.1 Shunt regulator

This regulator will be connected in parallel to the PV generator to dissipate excess energy. Battery charging will not be affected by the failure of the regulator. During non regulation period there is no voltage drop in the charging unit and hence power consumption is negligible.

8.2 Series regulator

The regulator will be connected in series with the PV generator. During non regulation period also there will be a voltage drop in the regulator causing current consumption in the circuit.

8.3 Electromagnetic series regulator

Battery charging stopped by electromechanical device when the voltage reaches maximum acceptable level and reset automatically when the threshold level is returned back.

8.4 Automatic circuit breaker

Due to weak sunshine and overloading, it will become necessary to cut off the load to limit the depth of discharge of the battery. This regulator cut off load at certain threshold voltage level and reset automatically while the battery gets charged to the required level.

9. BATTERY INSTALLATION

The commonly used PV battery is flooded type of battery. The flooded battery must be installed in a separate room having sufficient ventilations and moderate temperature to avoid accidents due to the formation of hazardous gases. Batteries may be placed over wooden or plastic planks on the floor. Maintenance free sealed batteries can be installed in the working area with normal ventilation on slotted iron racks. The IEEE European standard can be referred [2].

10. CLASSIFICATION OF BATTERIES BASED ON THE DEPTH OF DISCHARGE [3]

10.1 Shallow cycle batteries

These batteries will have thin plates with large surface area, providing large current for a short period for starting vehicles, discharging only 20% or less and recharging back to full. Shallow cycle batteries are not suitable for PV system.

10.2 Deep cycle batteries

These batteries will have thicker plates with small surface area, providing small current for longer periods and discharging up to 80%. Deep cycle batteries are suitable for PV systems.

Table 1.Comparison of performance parameters of batteries for PV applications [3]

Battery type	Cell nominal voltage(v)	Self discharge(% per month)	Life (no of cycles)	Energy Density (Wh/Kg)
Lead-acid	2	5	700	30
Ni – Cd	1.2	10	1000-1500	45
Lithium -ion	3.7	3-5	500-1000	90

11. SAFETY MEASURES WHILE USING BATTERIES [7]

- The tools used for connecting batteries must be insulated to avoid potential shorting of batteries.
- Safety goggles must be worn when working with batteries.
- Rubber Gloves should be used to avoid contact of skin with the electrolyte.
- To avoid destruction of normal dress by acid droplets Special clothing can be used.
- Suitable acid-neutralizing agent such as bicarbonate of soda should be made available.
- Lifting device of suitable capacity should be used.
- Class C fire extinguisher should be there in the battery room.

12. BATTERY RECYCLING

Batteries contain toxic materials like lead, acid and plastics which are harmful to human life and environment. So the batteries after usage should not be disposed like house wastages. They must be send to the recycling centers. The battery manufacturers must give guidelines through their distributors either to send them to the recycling center or to recycle the batteries by themselves.

13. CONCLUSION

Utilization of renewable energy sources for power generation is growing in a fast rate due to the depletion of fossil fuels and the environmental pollutions produced by the usage of fossil fuels. The power generation using renewable energy sources such as wind and solar are intermittent in nature and hence to provide continuous supply of power to load the battery backup becomes essential. To reduce the cost of the system it is essential to know about the types, requirements, protective methods, aging problems of batteries and this paper provides the basic information about batteries for PV system designers.

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