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BATTERIES, CHARGERS & ALTERNATORS

Excerpt from Inverter Charger Series Manual

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The Inverter Charger Series will require Deep Cycle Lead Acid Batteries of appropriate capacity. Lead-acid batteries can be categorized by the type of application: Automotive service¬Starting / Lighting / Ignition (SLI, a.k.a. cranking) and Deep cycle service.

1.0 BATTERY TYPES

There are several types of battery chemistries like Lead-Acid, Nickel-Iron (Ni-Fe), Nickel-Cadmium (Ni-Cad) etc. The batteries consist of individual cells that can be connected in series or parallel to obtain the required battery voltage and capacity. Batteries are either sealed (also called Valve Regulated Lead Acid - VRLA) or non-sealed / vented / flooded / wet cell.

Nickel-Iron (Ni-Fe) and Nickel-Cadmium (Ni-Cad) Batteries

Nickel-Iron (Ni-Fe) and Nickel-Cadmium (Ni-Cad) (also called alkaline batteries) have a nominal cell voltage of 1.2 volts per cell. The nominal voltage of a Ni-Cad / Ni-Fe battery bank can be made the same as a lead acid bank just by juggling the number of cells (10 cells for 12 volts, 20 cells for 24 volts and 40 cells for 48 volt systems). However, the Ni-Cad / Ni-Fe battery bank must be charged to a higher voltage to fully recharge and will drop to a lower voltage during discharging compared to a similarly sized lead acid type battery.

2.0 CONSTRUCTION OF LEAD ACID BATTERY

A Lead Acid battery consists of a number of 2 V nominal cells (actual voltage of the cell is 2.105 V) that are connected in series e.g. a 12 V nominal battery will have six, 2 V nominal cells in series (actual voltage of the 6 cells will be 2.105 x 6 = 12.63 V). Each 2 V nominal cell in this battery consists of an independent enclosed compartment that has Positive and Negative Plates (also called Electrodes) dipped in electrolyte that is composed of diluted Sulphuric Acid – solution of 33.5% v / v Sulphuric Acid and water. In a fully charged battery, the Positive Plate is in the form of Lead Dioxide (PbO_2), the Negative Plate is in the form of Sponge Lead (Pb)and the Sulphuric Acid in the electrolyte has the maximum concentration of 33.5% v / v.

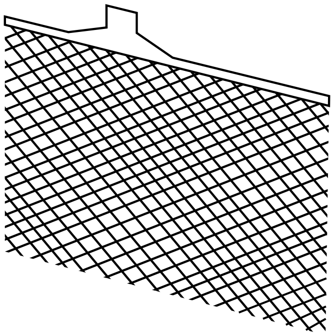

Fig 1: Grid structure of Positive and Negative Plates in a Lead Acid Battery

3.0 CONSTRUCTION OF BATTERY CELL AND CELL PLATES - LEAD ANTIMONY AND LEAD CALCIUM BATTERIES

During construction, both the Positive and the Negative plates are similar. Both the plates consist of a rectangular grid made out of alloyed Lead with rectangular holes in it as shown in Fig. 1: The holes in the grid of the plates are filled with a paste of active material made out of a mixture of Red Lead (Pb) and 33% dilute Sulphuric Acid (different manufacturers use modified mixtures). The paste is pressed into the holes in the grid. This paste remains porous and allows the Sulphuric Acid in the electrolyte to react with the lead inside the plate increasing the surface area many fold. At this stage, the Positive and Negative plates are identical. Once dry, the plates are then stacked together with suitable separators and inserted in the battery container. After the electrolyte has been added to the cell, the cell is given its first "Forming Charge. During this "Forming Charge", the Lead paste in the Positive plate gradually turns to Lead Dioxide (PbO_2) (chocolate brown color), and the Lead paste in the Negative plate turns to Sponge Lead (Pb) (slate gray color). Such charged cell is ready to be used.

The above grid structure of the plates is made from a Lead alloy. A pure Lead grid structure is not strong enough by itself to stand vertically while supporting the active material. Other metals in small quantities are alloyed with Lead for added strength and improved electrical properties. The most commonly alloyed metals are Antimony, Calcium, Tin, and Selenium.

The two most common alloys used today to harden the grid are Antimony and Calcium. Batteries with these types of grids are sometimes called "Lead-Antimony" and "Lead-Calcium" batteries. Tin is added to Lead-Calcium grids to improve cyclability.

The major differences between batteries with Lead-Antimony and Lead-Calcium grids are as follows:

- Lead-Antimony batteries can be deep cycled more times than Lead-Calcium batteries.
- Flooded Lead-Antimony batteries require more frequent maintenance as they near end-of-life since they use an increasing amount of water and require periodic equalization charges.
- Lead-Calcium batteries have lower self-discharge rates and therefore, will draw less current while kept in storage

Table 1 shows details of some popular battery sizes:

TABLE 1 TYPICAL BATTERY SIZES		
BCI* Group	Battery Voltage, Volts	Battery Capacity, Amp Hours
27 / 31	12	105
4 D	12	160
8D	12	225
GC2**	6	220
* Battery Council International ** Golf Cart		

4.0 TYPES OF LEAD ACID BATTERIES - SEALED LEAD ACID (SLA) OR VALVE REGULATED LEAD ACID (VRLA) BATTERIES

Sealed Lead Acid (SLA) batteries or Valve Regulated Lead Acid (VRLA) batteries can either be Gel Cell or AGM (Absorbed Glass Mat). In a Gel Cell battery, the electrolyte is in the form of a gel. In AGM (Absorbed Glass Mat) battery, the electrolyte is soaked in Glass Mat. In both these types, the electrolyte is immobile. There are no refill caps and the battery is totally sealed. Hydrogen and Oxygen released during the charging process is not allowed to escape and is recombined inside the battery. Hence, there is no water loss and the batteries are maintenance free. These batteries have safety valves on each cell to release excessive pressure that may be built up inside the cell. The Gel Cell is the least affected by temperature extremes, storage at low state of charge and has a low rate of self discharge. An AGM battery will handle overcharging slightly better than the Gel Cell.

4.1 Non Sealed (Vented / Flooded / Wet Cell) Lead acid Batteries

In a non-sealed / vented / flooded / wet cell battery, each individual cell compartment has a refill cap that is used to top up the cell with distilled water and to measure the specific gravity of the electrolyte using a hydrometer. When fully charged, each individual cell has a voltage of approximately 2.105 V and electrolyte specific gravity of 1.265. As the cell discharges, its voltage and specific gravity drop. Thus, a healthy, fully charged, 12 V nominal battery with each of the 6 cells fully charged to 2.105 V will measure a standing voltage of 12.63 V at 25 ° C / 77 ° F. Also, in a healthy battery, all the individual cells will have the same voltage and same specific gravity. If there is a substantial difference in the voltages (0.2 V or higher) and specific gravities of the individual cells(0.015 or more), the cells will require equalization.

4.2 SLI (Starting, Lighting, Ignition) Batteries

Everybody is familiar with the SLI batteries that are used for automotive starting, lighting, ignition and powering vehicular accessories. SLI batteries are designed to produce high power in short bursts for cranking. SLI batteries use lots of thin plates to maximize the surface area of the plates for providing very large bursts of current (also specified as Cranking Amps). This allows very high starting current but causes the plates to warp when the battery is cycled. Vehicle starting typically discharges 1%-3% of a healthy SLI battery's capacity. The automotive SLI battery is not designed for repeated deep discharge where up to 80 % of the battery capacity is discharged and then recharged. If an SLI battery is used for this type of deep discharge application, its useful service life will be drastically reduced.

This type of battery is not recommended for the storage of energy for inverter applications. However, they are recommended as starting battery for the back-up generator.

4.3 Deep Cycle Lead Acid Batteries

Deep cycle batteries are designed with thick-plate electrodes to serve as primary power sources, to have a constant discharge rate, to have the capability to be deeply discharged up to 80 % capacity and to repeatedly accept recharging. They are marketed for use in recreation vehicles (RV), boats and electric golf carts – so they may be referred to as RV batteries, marine batteries or golf cart batteries.

5.0 SPECIFYING BATTERY CAPACITY

Battery capacity “C” is specified in Ampere-hours (Ah). An Ampere is the unit of measurement for electrical current and is defined as a Coulomb of charge passing through an electrical conductor in one second. The Capacity “C” in Ah relates to the ability of the battery to provide a constant specified value of discharge current (also called “C-Rate”) over a specified time in hours before the battery reaches a specified discharged terminal voltage (Also called “End Point Voltage”) at a specified temperature of the electrolyte.

5.1 Rated Capacity in Ampere-hour (Ah)

As a benchmark, the automotive battery industry rates batteries at a “Discharge Rate” / C-Rate of 0.05C / C20 / C / 20 Amperes corresponding to 20 Hour discharge period. The rated capacity “C” in Ah in this case will be the number of Amperes of current the battery can deliver for 20 Hours at 80 ° F (26.7 ºC) till the voltage drops to 1.75 V / Cell i.e. 10.5 Volts for 12 V battery, 21 V for 24 V battery and 42 V for a 48 V battery. For example, a 100 Ah battery will deliver 5 A for 20 Hours.

5.2 Rated Capacity in Reserve Capacity (RC)

Battery capacity may also be expressed as Reserve Capacity (RC) in minutes typically for automotive SLI (Starting, Lighting and Ignition) batteries. It is the time in minutes a vehicle can be driven after the charging system fails. This is roughly equivalent to the conditions after the alternator fails while the vehicle is being driven at night with the headlights on. The battery alone must supply current to the headlights and the computer / ignition system. The assumed battery load is a constant discharge current of 25 A.

Reserve capacity is the time in minutes for which the battery can deliver 25 Amperes at 80 ° F (26.7 ° C) till the voltage drops to 1.75 V / Cell i.e. 10.5 Volts for 12 V battery, 21 V for 24 V battery and 42 V for 48 V battery. Approximate relationship between the two units is:

Capacity "C" in Ah = Reserve Capacity in RC minutes x 0.6

6.0 SPECIFYING CHARGING / DISCHARGING CURRENT: C-RATE

As explained above, electrical energy is stored in a cell / battery in the form of DC power. The value of the stored energy is related by the amount of the active materials pasted on the battery plates, the surface area of the plates and the amount of electrolyte covering the plates. The amount of stored electrical energy is also called the Capacity of the battery and is designated by the symbol "C".

The time in Hours over which the battery is discharged to the "End Point Voltage" for purposes of specifying Ah capacity depends upon the type of application. Let us denote this discharge time in hours by "T". Let us denote the discharge current of the battery as the "C-Rate". If the battery delivers a very high discharge current, the battery will be discharged to the "End Point Voltage" in a shorter period of time. On the other hand, if the battery delivers a lower discharge current, the battery will be discharged to the "End Point Voltage" after a longer period of time.
Mathematically: Discharge current "C-Rate" = Capacity "C" in Ah ÷ Discharge Time "T"……….Equation 1

Table 2 gives some examples of C-Rate specifications and applications:

Table 2: C-Rates

Hours of discharge time "T" till the "End Point Voltage"	C-Rate Discharge Current in Amps			Example of C-Rate Discharge Currents for 100 Ah battery
	Fraction	Decimal	Subscript	
0.5 Hrs.	2C	2C	2C	200 A
1 Hrs.	1C	1C	1C	100 A
5 Hrs.	C / 5	0.2C	C5	20 A
8 Hrs. (UPS application)	C / 8	0.125C	C8	12.5 A
10 Hrs. (Telecom application)	C / 10	0.1C	C10	10 A
20 Hrs. (Automotive application)	C / 20	0.05C	C20	5 A
100 Hrs.	C / 100	0.01C	C100	1 A

NOTE: When a battery is discharged over a shorter time, its specified "C-Rate" discharge current will be higher. For example, the "C-Rate" discharge current at 5 Hour discharge period i.e. 0.2C / C5 / C / 5 Amps will be 4 times higher than the "C-Rate" discharge current at 20 Hour discharge period i.e. 0.05C / C20 / C / 20 Amps.

7.0 CHARGING / DISCHARGING CURVES

Fig. 2 shows the charging and discharging characteristics of a typical, 6 cell, 12 V, Lead Acid battery. The curves show capacity of the battery versus its terminal voltage during charging and discharging conditions at different charge and discharge C-Rates. These curves will be referred to in the subsequent explanations.

8.0 ELECTROCHEMICAL REACTIONS DURING CHARGING AND DISCHARGING OF LEAD ACID BATTERY

Electrical power in the Lead Acid Battery is produced by reversible (shown as $\longleftrightarrow$) electro-chemical reactions. A reversible reaction is shown as $\longleftrightarrow$ which means that the reaction can take place in both the directions. The following "Half Reactions" will be used to explain the charging and discharging reactions:

1. **Creation of Sulfate and Hydrogen Ions in the Electrolyte**
   2 molecules of Sulphuric Acid ($2H_2SO_4$) $\longrightarrow$
   4 Hydrogen Ions ($4\,H^+$) + 2 Sulfate Ions 2 $(SO_4)^{2-}$
2. **Half Reaction at the Negative Battery Plates**
   Sponge Lead (Pb) + Sulfate Ion $(SO_4)^{2-}$ $\longleftrightarrow$ Lead Sulfate ($PbSO_4$)

+ Electrons (2e-)

3. Half Reaction at the Positive Battery Plates

Lead Dioxide (PbO_2) + 4 Hydrogen Ions ($4H^+$) + Sulfate Ion $(SO_4)^{2-}$
+ 2 Electrons (2e-) $\longleftrightarrow$ Lead Sulfate ($PbSO_4$) + 2 molecules of
Water ($2H_2O$)

Equation #1 shows that 2 molecules of Sulphuric Acid ($2H_2SO_4$) in the water break up into 4 Positive Hydrogen Ions ($4\ H^+$) and 2 Negative Sulfate Ions 2 $(SO_4)^{2-}$. The electrolyte (mixture of Sulphuric acid and water) will thus contain negatively charged Sulfate ions $(SO_4)^{2-}$ and positively charged Hydrogen ions (H+).

Equation #2 shows the "Half Reaction" at the Negative Battery Plates and Equation #3 shows the "Half Reaction" at the Positive Plates.

During discharging, negatively charged Sulfate Ions $(SO_4)^{2-}$ move to the Negative Battery Plates and convert the Sponge Lead (Pb) in the Negative Battery Plates to soft Lead Sulfate ($PbSO_4$) crystals and give up their Negative charge i.e. 2 electrons (2e-). The electrons thus generated on the Negative Battery Plates flow as electric current to the Positive Battery Plates through the external electrical load circuit. At the Positive Battery Plates, these electrons combine with the Oxygen in the Lead Dioxide (PbO_2), Hydrogen Ion(4H+) and Sulfate Ion (SO_4^{2-}) to form soft Lead Sulfate ($PbSO_4$) crystals and Water ($2H_2O$). Thus, soft Lead Sulfate ($PbSO_4$) crystals are formed on both the plates during discharging. The soft Lead Sulfate ($PbSO_4$) crystals formed on the two plates act as insulator and consequently, the internal resistance of the battery increases. The concentration of Sulphuric Acid in the electrolyte is reduced as the battery gets discharged (the electrolyte becomes pure water when the battery is fully discharged).

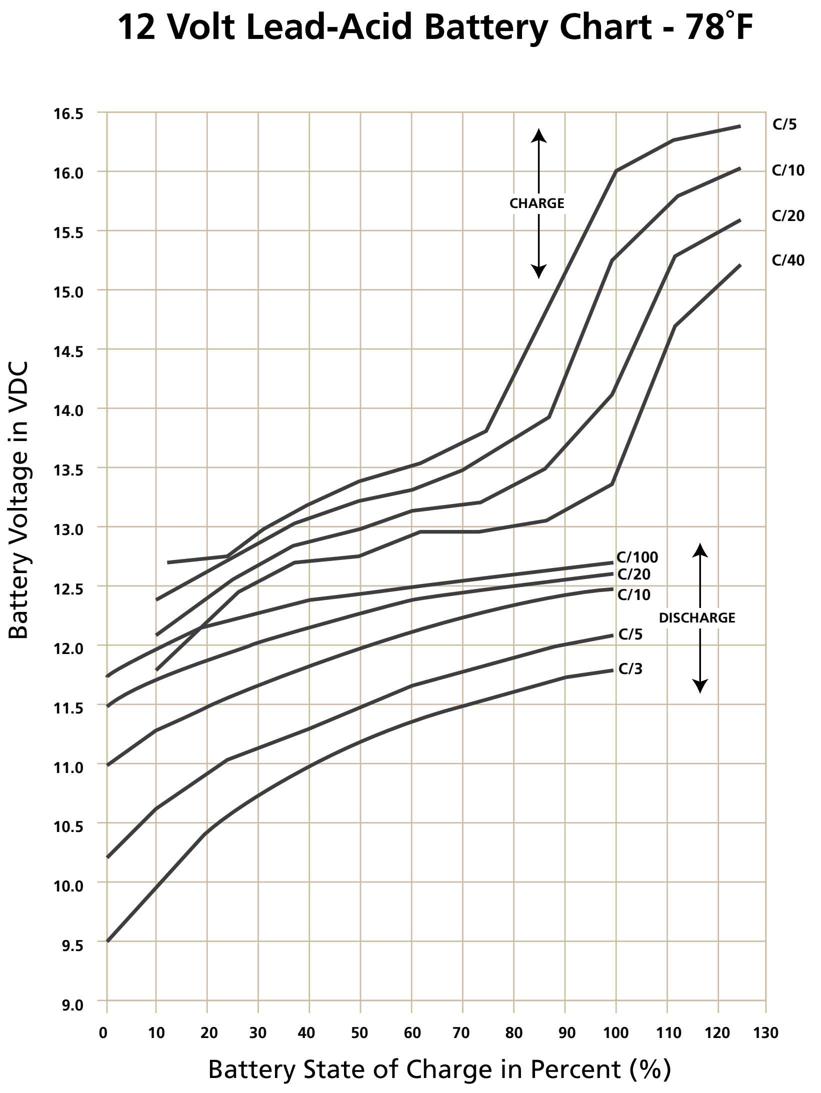

Fig. 2: Charging / Discharging Curves for 12 V Lead Acid Battery

During charging, reverse electrochemical reactions take place. Under the influence of the charging voltage fed to the battery by the external battery charger / charge controller, electrons are fed to the Negative Battery Plates. 2 electrons combine with the soft Lead Sulfate ($PbSO_4$) crystal to create Sponge Lead (Pb) and Sulfate Ion (SO_4^{2-}). At the Positive Battery Plates, soft Lead Sulfate ($PbSO_4$) crystals and Water ($2H_2O$) combine to form Lead Dioxide (PbO_2), Hydrogen Ion($4H^+$) and Sulfate Ion (SO_4^{2-}). The concentration of Sulphuric Acid is restored (will revert to 33.5% v / v when the battery is fully charged).

8.1 Effects of charging and discharging at very high rates

The negatively charged Sulfate ions (SO_4^{2-})and positively charged Hydrogen ions ($4H^+$) moving around (diffusing) in the electrolyte are responsible for the charging / discharging process. As the cells become charged / discharged, the number of these ions in the electrolyte increases (during charging) / decreases (during discharging) and the area of active material available to accept them also increases (during charging) / decreases (during discharging) because it's getting uncoated (during charging) / coated (during discharging) with soft Lead Sulfate ($PbSO_4$) crystals. Remember, the chemical reaction takes place in the pores on the active material that is bonded to the plates.

It is seen that if a battery is discharged very rapidly at a very high current, its voltage and current drop but recover after discharging has been stopped for some time. This effect is due to the time lag in the diffusion (movement) of the Sulfate and the Hydrogen ions towards the plates and to the inner sections of the active material. When discharging takes place very rapidly, the above electrochemical reactions will be very active around the outer surfaces of the plates and the ions will not have enough time to be replaced from the areas of the electrolyte farther away from the plates. Also, the ions are not able to penetrate the pores towards the inner areas of the active material. Thus, the ions will be depleted in the area around the plates, the concentration of the Sulphuric acid around the vicinity of the plate surface will decline temporarily and the voltage and the discharge current will drop. Once the discharging is interrupted, the ions are able to travel to the depleted regions to re-activate charging

Similarly, when the battery is charged at a very high current, its voltage rises but drops after the charging is stopped. Also, the battery capacity is not restored fully. Here again, the electrochemical reactions are concentrated in the vicinity of only the surface of the plates due to the slow mobility of the Sulfate and the Hydrogen ions.

9.0 GASSING DURING CHARGING

During charging, the battery is required to be charged in a controlled manner in the final Boost (Absorption) Stage (2.4 V per cell at 25 ° C / 77 ° F or 14.4 V for a 12 V battery at 25 ° C / 77 ° F) that restores the last 20% to 30% of the capacity. On successful completion of this stage of charging, the soft Lead Sulfate ($PbSO_4$) crystals at the Positive and Negative Plates should have fully converted back to Lead Dioxide at the Positive Plate and Sponge Lead at the Negative Plate. Any further charging at this voltage or higher than this voltage results in electrolysis of water in the electrolyte to Hydrogen and Oxygen as shown in the equations given below:

- **At Positive Plates:** Water ($2H_2O$) $\longleftrightarrow$ Oxygen gas (O_2)
  + Hydrogen Ion ($4H^+$) + 4 Electrons (4e-) **(Oxygen evolution)**
- **At Negative Plates:** Hydrogen Ion ($4H^+$) + 4 electrons (4e-) $\longleftrightarrow$Hydrogen gas ($2H_2$) **(Hydrogen evolution)**

The above undesirable condition contributes to waste of energy. This process is known as "gassing". Gassing is also produced during the timed Equalization Stage when the battery is intentionally overcharged (2.5 to 2.7 V per cell / 15 to 16 V for 12 V batteries) so that the weaker cells are fully charged too (equalized) and stratification is removed.

Non-sealed / vented / flooded / wet cell batteries have open vents to release Hydrogen and Oxygen produced during gassing. The above un-intentional electrolysis of water during overcharging results in loss of water and reduces the level of the electrolyte in this type of batteries. When the level of the electrolyte is reduced, the upper portion of the plates in the cells will not be immersed in the electrolyte and will result in loss of battery capacity. **Hence, this type of battery is required to be topped up with distilled water periodically to ensure that the plates in the cells are fully immersed in the electrolyte.** Some non-sealed / vented / flooded / wet cell batteries come with catalytic caps to recombine any emitted Hydrogen and Oxygen.

Sealed / VRLA batteries are designed to recombine the Hydrogen and Oxygen back into water and hence, Sealed / VRLA batteries are not required to be topped up with distilled water. That is why these batteries are also called maintenance free batteries. Sealed / VRLA batteries use safety valves to release any excessive gas pressure built up inside the battery due to malfunction or overheating. If this happens (e.g., by overcharging) the valve vents the gas and normalizes the pressure, producing a characteristic acid smell. Valves can sometimes fail however, if dirt and debris accumulate, allowing pressure to build up that will result in damage to the battery.

10. BATTERY CHARGING STAGES

Normally, following 4 stages of charging process are used to fully charge a battery:

10.1 Constant Current Bulk Charge Stage

In the first stage, known as the Bulk Charge Stage, the charger delivers a constant, maximum charging current that can be safely handled as specified by the battery manufacturer. The value of the Bulk Charge Current depends upon the total Ampere Hour capacity of the battery or a bank of batteries. A battery should never be charged at very high charging current as very high rate of charging will not return the full 100% capacity as the Gassing Voltage rises with higher charging current due to"Peukert Effect". Also, very high charging current produces higher temperature in the active material of the plates resulting in loss of cohesion and shedding of the active material that settles on the bottom of the plates. Shedding of the active material results in loss of capacity. If the quantity of the shedded active material at the bottom of the plates rises, it may short the cells. Further, rise in the temperature of the electrolyte will require temperature compensation (charging voltages will be required to be reduced) and hence, a temperature compensated charger will be mandatory otherwise, the battery will be overcharged, will boil and is likely to be damaged. As a general thumb rule, the Bulk Charging Current should be limited to 10% to 13% of the AH capacity of the battery (20 Hour discharge rate). Higher charging current may be used if permitted by the battery manufacturer.

This current is delivered to the batteries until the battery voltage approaches its Gassing Voltage of around 2.4 V per cell at 25° C / 77° F or 14.4 V for a 12 V battery and 28.8 volts for a 24 volt battery. The Bulk Charge Stage restores about 75% of the battery's capacity. The Gassing Voltage is the voltage at which the electrolyte in the battery begins to break down into Hydrogen and Oxygen gases. Under normal circumstances, a battery should not be charged at a voltage above its Gassing Voltage (except during Equalization Stage) since this will cause the battery to lose electrolyte and dry out over time. Once the Gassing Voltage is approached, the charger transfers to the next stage, known as the Boost (Absorption) Stage.

NOTE: As the Bulk Charge Stage is a constant current stage, the charger does not control the voltage and the voltage seen at the output terminals of the charger will be the actual battery voltage (this will rise slowly towards the Gassing Voltage under the influence of the constant charging current).

10.2 Constant Voltage Boost (Absorption) Stage

During the Boost (Absorption) Stage, the charger changes from a constant current to constant voltage charging. The charging voltage is held constant near the Gassing Voltage to ensure that the battery is further charged to the full capacity without overcharging. The Boost Stage feeds additional 40% of the capacity that adds up to a total charged capacity of around 115% to take care of around 15% loss of charging efficiency. As the output voltage of the charger is held constant, the battery absorbs the charge slowly and the current reduces gradually till all of the soft Lead Sulfate ($PbSO_4$) crystals have been converted to Lead Dioxide (PbO_2) on the Positive Plates and Sponge Lead (Pb) on the Negative Plates. The time the charger is held in the Boost / Absorption Stage before it transitions to the next Float Stage is determined in one or more of the following conditions:

- By a fixed timer (e.g. 4 to 8 Hours). This may result in overcharging of almost fully charged batteries
- By sensing the value of charge current and then switching over to the Float Stage when the charge current drops below a certain threshold (e.g. 10% of the charger Bulk Charge Current). This may result in overcharging and locking in the Boost (Absorption) Mode if the battery is feeding an external load that has a value > the specified threshold
- Using an automatic Adaptive Charging Algorithm that ensures that the battery is completely charged in a safe manner for longer battery life. In this algorithm, the time the battery remains in Boost (Absorption) and Equalization Stages is automatically made proportional to the time the battery remains in the Bulk Charge Stage. A battery that is deeply discharged will remain in Bulk Stage for a longer duration and will require longer time in the Boost (Absorption) and Equalization Stages for complete charging. On the other hand, a battery that is almost completely charged will remain in the Bulk Stage for a shorter duration and consequently, will remain in Boost (Absorption) and Equalization stages for a shorter duration. This will prevent overcharging / boiling of the battery. **The Inverter Charger Series uses this Adaptive Charging Algorithm.**

10.3 Constant Voltage Float Stage

The Float Stage is a maintenance stage in which the output voltage is reduced to a constant lower level, typically about 13.5 V for a 12 V battery and 27 V for a 24V battery to maintain the battery's charge without losing electrolyte through gassing and also to compensate for self discharge.

10.4 Equalization Stage

The fourth Charging Stage, known as the Equalization Stage, is normally initiated manually because it is not required every time the battery is recharged. Normally, only the vented / wet cell / flooded batteries are equalized. Some sealed AGM batteries may be equalized if recommended by the manufacturer (e.g. Life Line brand of sealed, AGM batteries). The Equalization Stage should be carried out only after completion of the Bulk and Absorption Stages. During the Equalization Stage, the battery is intentionally held above the Gassing Voltage which is normally in the region of 2.5 to 2.7 V per cell at 25° C / 77° F (e.g. 15 to 16 V for 12 V batteries and 30 to 32 V for 24 V batteries). The time the battery remains in this stage is determined as follows:

- By a fixed timer (e.g. 4 to 8 Hours). This may result in overcharging of almost fully charged batteries
- Using an automatic Adaptive Charging Algorithm that ensures that the battery is equalized in a safe manner for longer battery life. In this algorithm, the time the battery remains in Boost (Absorption) and Equalization Stages is automatically made proportional to the time the battery remains in the Bulk Charge Stage. A battery that is deeply discharged will remain in Bulk Stage for a longer duration and will require longer time in the Boost (Absorption) and Equalization Stages for complete charging. On the other hand, a battery that is almost completely charged will remain in the Bulk Stage for a shorter duration and consequently, will remain in Boost (Absorption) and Equalization stages for a shorter duration. This will prevent overcharging / boiling of the battery. **The Inverter Charger Series uses this Adaptive Charging Algorithm.**

Recommendations of the battery manufacturer are to be followed for equalizing the batteries as the equalization voltage, current, time and frequency will depend upon the specific design of the battery. **As a guide, a heavily used flooded battery may need to be equalized once per month and a battery in light duty service, every two to four months.** The Equalization Charge Current should be a relatively low current of around 2% to 10% of the AH capacity of the battery. Such a low current prevents an overcharge condition that results in excessive gassing and excessive loss of water.

11. NECESSITY FOR EQUALIZING BATTERIES

For proper health and long life of a Lead Acid battery, it is required to undergo an Equalization Stage during the charging process to prevent / reduce the following undesirable effects:

Sulfation: If the charging process is not complete due to the inability of the charger to provide the required voltage levels or if the battery is left uncharged for a long duration of time, the soft Lead Sulfate ($PbSO_4$) crystals on the Positive and Negative plates that are formed during discharging / self discharge are not fully converted back to Lead Dioxide on the Positive plate and Sponge Lead on the Negative plate and get hardened and are difficult to dislodge through normal charging. These crystals are non-conducting and hence, introduce increased internal resistance in the battery. This increased internal resistance introduces internal voltage drop during charging and discharging. Voltage drop during charging results in overheating and undercharging and formation of more Lead Sulfate ($PbSO_4$) crystals. Voltages drop on discharging results in overheating and excessive voltage drop in the terminal voltage of the battery. Overall, this results in poor performance of the battery. To dislodge these hardened Lead Sulfate crystals, some chargers are designed to detect a sulfated condition at the start of the charging process and go through an initial De-sulfation Mode that sends high frequency, high voltage pulses at the natural oscillation frequency of the crystals to dislodge the hardened crystals. Sulfation may also be reduced partially by the stirring / mixing action of the electrolyte due to gassing and bubbling because of intentional overcharging during the Equalization Stage.

Electrolyte Stratification: Electrolyte stratification can occur in all types of flooded batteries. As the battery is discharged and charged, the concentration of acid becomes higher at the bottom of the cell and lower at the top of the cell. The low acid concentration reduces capacity at the top of the plates, and the high acid concentration accelerates corrosion at the bottom of the plates and shortens the battery life. Stratification can be minimized by the Equalization Stage by raising the charging voltage so that the increased gassing and bubbling agitates / stirs the electrolyte and ensures that the electrolyte has uniform concentration from top to bottom. The stirring action also helps to break up any Lead Sulfate crystals, which may remain after normal charging.

Unequal charging of cells: During normal charging, temperature and chemical imbalances prevent some cells from reaching full charge. As a battery is discharged, the cells with the lower voltage will be drained further than the cells at the higher voltage. When recharged, the cells with the higher voltage will be fully charged before the cells with the lower voltage. The more a battery is cycled, the more cell voltage separation takes place. In a healthy battery, all the individual cells will have the same voltage and same specific gravity. If there is a substantial difference in the cell voltages (0.2 V or more) and in the specific gravities (0.015 or more) of the individual cells, the cells will require equalization. Equalizing batteries helps to bring all the cells of a battery to the same voltage. During the Equalization Stage, fully charged cells will dissipate the charging energy by gassing while incompletely charged cells continue to charge.

12. BOOST (ABSORPTION), EQUALIZATION AND FLOAT VOLTAGES OF TYPICAL BATTERIES / CHARGERS

Table 3 gives the Absorption, Float and Equalization voltage settings for common batteries used in North America:

TABLE 3: TYPICAL CHARGING VOLTAGES

Battery Type	Inverter Voltage	Absorption Voltage	Float Voltage	Equalization Voltage
Gel	12 VDC	14.1 VDC	13.6 VDC	14.1 VDC@
	24 VDC	28.2 VDC	27.2 VDC	28.2 VDC@
	48 VDC	56.4 VDC	54.4 VDC	56.4 VDC@
Flooded	12 VDC	14.6 VDC	13.4 VDC	15.5 VDC
	24 VDC	29.2 VDC	26.8 VDC	31.0 VDC
	48 VDC	58.4 VDC	53.6 VDC	62.0 VDC
AGM 1 Lifeline brand	12 VDC	14.3 VDC	13.1 VDC	15.5 VDC
	24 VDC	28.6 VDC	26.2 VDC	31.0 VDC
	48 VDC	57.2 VDC	52.4 VDC	62.0 VDC
AGM 2 East Penn / Deka / Discover / Trojan brand	12 VDC	14.5 VDC	13.5 VDC	14.5 VDC@
	24 VDC	29.0 VDC	27.0 VDC	29.0 VDC@
	48 VDC	58.0 VDC	54.0 VDC	58.0 VDC@

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TABLE 3: TYPICAL CHARGING VOLTAGES

Battery Type	Inverter Voltage	Absorption Voltage	Float Voltage	Equalization Voltage
Programmable Chargers⁎	12 VDC	12.0-16.0 VDC	12.0-16.0 VDC	12.0-16.0 VDC
	24 VDC	24.0-32.0 VDC	24.0-32.0 VDC	24.0-32.0 VDC
	48 VDC	48.0-64.0 VDC	48.0-64.0 VDC	48.0-64.0 VDC

@ Gel and the AGM 2 Group (East Penn / Deka / Discover / Trojan brand) batteries are not equalized. Hence, their Equalization Voltages are same as the Absorption Voltages.

⁎ May be selected by the customer based on the manufacturers' recommendations, if available. When using the Custom setting, the EQ (Equalization) voltage setting should not be lower than the Absorption Voltage setting. Also, the Equalization Voltage setting should not be higher than 2-volts (for 12V systems), 4-volts (for 24V systems), or 8-volts (for 48V systems) above the Absorb Voltage setting.

13. BATTERY EFFICIENCY

A lead-acid battery has an efficiency of only 75% -85%. The energy lost appears as heat and warms the battery. This means that the Ampere Hour energy required to charge a battery to its full rated capacity will be approximately 120% to 130% higher than the AH capacity rating of the battery.

14. REDUCTION IN USABLE CAPACITY AT HIGHER DISCHARGE RATES

As stated above, the rated capacity of the battery in AH is normally applicable at a discharge rate of 20 Hours. As the discharge rate is increased, the usable capacity reduces due to “Peukert Effect”. This relationship is not linear but is more or less according to the Table 12.4:

TABLE 4: Battery Capacity versus Rate of Discharge – "C-Rate"

C-Rate discharge current	Usable Capacity
C / 20	100%
C / 10	87%
C / 8	83%
C / 6	75%
C / 5	70%
C / 3	60%
C / 2	50%
1C	40%

Using the above Table will show that a 100 AH capacity battery will deliver 100% (i.e. full 100 AH) capacity if it is slowly discharged over 20 hours at the rate of 5 Amperes. However, if it is discharged at a rate of 50 Amperes then theoretically, it should provide 100 AH ÷ 50 = 2 hours. However, the Table above shows that for 2 hours discharge rate, the capacity is reduced to 50% i.e. 50 AH. Therefore, at 50 Ampere discharge rate the battery will actually last for 50 AH ÷ 50 Amperes = 1 Hour.

15. STATE OF CHARGE (SOC) OF A BATTERY – "STANDING" OR OPEN CIRCUIT CONDITION

TABLE 5: State of Charge versus Standing Voltage – 12 V Battery

Percentage of Full Charge	Standing Voltage of 12 V Nominal Battery	Cell Voltage (12 V battery has 6, 2 V Nominal cells in series)
100%	12.63 V	2.105 V
90%	12.6 V	2.10 V
80%	12.5 V	2.08 V
70%	12.3 V	2.05 V
60%	12.2 V	2.03 V
50%	12.1 V	2.02 V
40%	12.0 V	2.00 V
30%	11.8 V	1.97 V
20%	11.7 V	1.95 V
10%	11.6 V	1.93 V
0%	= / < 11.6 V	= / < 1.93 V

The "Standing Voltage"of a battery under open circuit conditions can approximately indicate the State of Charge (SOC) of the battery. The "Standing Voltage" is measured after disconnecting any charging device(s) and the battery load(s) and letting the battery "stand" idle for 3 to 8 hours before the voltage measurement is taken. The Table given below shows the State of Charge versus Standing Voltage for a 12 volt battery system at around 80 F (26.7° C). For 24-volt systems, multiply by 2; for 48-volt systems, multiply by 4.

Check the individual cell voltages / specific gravity. If the inter-cell voltage difference is more than a 0.2 V, or the specific gravity difference is 0.015 or more, the cells will require equalization. **Please note that only the non-sealed / vented / flooded / wet cell batteries are equalized. Do not equalize sealed / VRLA type of AGM or Gel Cell Batteries.**

16. STATE OF DISCHARGE OF A LOADED BATTERY

The State of Discharge of a battery is normally estimated based on the measured terminal voltage of the battery. The terminal voltage of the battery is dependent upon the following:

Temperature of the battery electrolyte: Temperature of the electrolyte affects the electro-chemical reactions inside the battery and produces a Negative Voltage Coefficient – during charging / discharging, the terminal voltage drops with rise in temperature and rises with drop in temperature

The amount of charging / discharging current or "C-Rate": For the present discussion, we will mainly consider discharging characteristics of the battery. A battery has non linear internal resistance and hence, as the discharge current increases, the battery terminal voltage decreases non linearly

The charge / discharge curves at Fig. 12.2 show the % State of Charge versus the terminal voltage of a 12 V battery under different charge / discharge currents i.e. "C-Rates" and fixed temperature of 78° F. (By convention, battery data is normally presented at 78° F). ***Please consider the Discharge Curves for the present.***

Please note that the terminal voltage relative to a particular of State Discharge will decrease with the rise in the value of the discharge current. For example, terminal voltages for a State of Discharge of 80% (State of Charge of 20%) for various discharge currents will be as follows:

At highest discharge current of C / 3 A	10.45 V
At discharge current of C / 5 A	10.9 V
At discharge current of C / 10A	11.3 V
At discharge current of C / 20 A	11.85 V
At the lowest discharge current of C / 100 A	12.15 V

In the example given above, a "Low Battery Alarm" set at 11 V would trigger at around 80% discharged state (78% as per the calculation) when the C-Rate discharge current is C / 5 Amps.

However, for lower C-Rate discharge current of C / 10 Amps and lower, the battery will be almost completely discharged when the alarm is sounded. Hence, if the C-Rate discharge current is lower than C / 5 Amps, the battery may have completely discharged by the time the Low DC Input Alarm is sounded.

17. LOW BATTERY / DC INPUT VOLTAGE ALARM & LOW BATTERY / DC INPUT VOLTAGE SHUTDOWN

Ambiguity In Inverters With Fixed Voltage Thresholds For Low Battery / DC Input Voltage Alarm And Shutdown Of Loaded Batteries

NOTE: The discussion below regarding voltage values for alarms and shutdown pertain to loaded condition of the battery. The State of Charge relative to the no load voltage (also called the "Standing Voltage") are different.

17.1 Low battery / DC input voltage alarm

Most inverter and UPS hardware estimate the State of Charge of the loaded battery by measuring the voltage at the inverter's / UPS's DC input terminals (considering that the DC input cables are thick enough to allow a negligible voltage drop between the battery and the inverter)

Inverters are normally provided with a buzzer alarm to warn that the loaded battery has been deeply discharged to 80% of the rated capacity (or the State of Charge has reduced to 20%). Normally, the buzzer alarm is triggered when the voltage at the DC input terminals of the inverter has dropped to around 11 V for a 12 V battery at C-Rate discharge current of C / 5 Amps. Referring to the Discharge Curves given in Fig. 12.2, the State of Discharge for various C-Rate discharge currents for a battery voltage of
11 V is as follows:

- 40% discharged or 60% charged at very high C-rate discharge current of C / 3 Amps
- 78% discharged or 22% charged at high C-Rate discharge current of C / 5 Amps
- 99% discharged or 1% charged at lower C-rate Discharge current of C / 10 Amps
- 100% discharged or 0% charged at lower C-rate Discharge current of C / 20 Amps

17.2 Low Battery / input voltage shut-down

As explained above, at around 80% discharge condition of the battery at C-Rate discharge current of around C / 5 Amps, the Low DC Input Voltage Alarm is sounded at around 11 V for a 12 V battery to warn the user to disconnect the battery to prevent further draining of the battery. If the load is not disconnected at this stage, the batteries will be drained further to a lower voltage and to a completely discharged condition which is harmful for the battery and for the inverter.

Inverters are normally provided with a protection to shut down the output of the inverter if the DC voltage at the input terminals of the inverter drops below a threshold of around 10 V for a 12 V battery. Referring to the Discharge Curves given in Fig. 12.2, the State of Discharge for various C-Rate discharge currents for battery voltage of 10 V is as follows:

- 85% discharged or 15% charged at very high C-rate discharge current of C / 3 Amps
- 100% discharged or 0 % charged at high C-Rate discharge current of C / 5 Amps
- 100% discharged or 0% charged at lower C-rate Discharge current of C / 10 Amps

It is seen that at DC input voltage of 10 V, the battery is completely discharged for C-rate discharge current of C / 5 and lower.

In view of the above, it will be seen that a fixed Low Battery / DC Input Voltage Alarm is very deceptive. Temperature of the battery further complicates the situation. All the above analysis is based on battery electrolyte temperature of 78° F. The battery capacity varies with temperature. Battery capacity is also a function of age and charging history. Older batteries have lower capacity because of shedding of active materials, sulfation, corrosion, increasing number of charge / discharge cycles etc. Hence, the state of charge of a battery under load cannot be estimated accurately

18. USE OF EXTERNAL PROGRAMMABLE LOW VOLTAGE DISCONNECTS

The above ambiguity can be removed by using an external, programmable Low Voltage Disconnect where more exact voltage threshold can be set to disconnect the battery based on the actual application requirements

Please consider using the following Programmable Low Battery Cut-off / "Battery Guard" Models manufactured by Samlex America, Inc., www.samlexamerica.com:

- BG40 (40 A) – For up to 400 W, 12 V inverter or 800 W, 24 V inverter
- BG-60 (60 A) - For up to 600 W, 12 V inverter or 1200 W, 24 V inverter
- BG-200 (200 A) - For up to 2000 W, 12 V inverter or 4000 W,24 V inverter

19. DEPTH OF DISCHARGE AND BATTERY LIFE

The more deeply a battery is discharged on each cycle, the shorter the battery life. Using more batteries than the minimum required will result in longer life for the battery bank. A typical cycle life chart is given in Table6:

TABLE 6: TYPICAL CYCLE LIFE CHART

Depth of Discharge % of AH Capacity	Cycle Life of Group 27 / 31	Cycle Life of Group 8D	Cycle Life of Group GC2
10	1000	1500	3800
50	320	480	1100
80	200	300	675
100	150	225	550

Recommended that the depth of discharge should be limited to 50%.

20. LOSS OF BATTERY CAPACITY AT LOW TEMPERATURES

Batteries lose capacity in low temperatures. At 32 ° F (0 ° C), a battery will deliver about 70 to 80 % of its rated capacity at 80 ° F (26.7 ° C). If the electrolyte temperature of the battery bank is lower than 80 ° F (26.7 ° C), additional batteries will be needed to provide the same usable capacity. For very cold climates, an insulated / heated battery compartment is recommended.

21. FREEZING OF ELECTROLYTE

For applications with low ambient temperature, the lead-acid battery must also be protected against freezing of the electrolyte. The risk of freezing depends on the state of charge. The chart given below illustrates the freezing limit as a function of the state of charge.

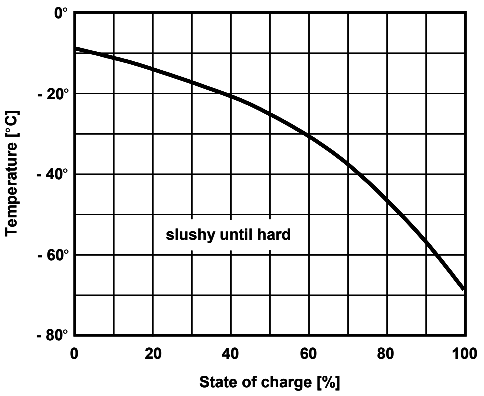

Fig 3.

22. SERIES AND PARALLEL CONNECTION OF BATTERIES

22.1 Series Connection

When two or more batteries are connected in series, their voltages add up but their AH capacity remains the same. Fig. 4 shows 4 pieces of 6 V, 200 AH batteries connected in series to form a battery bank of 24 V with a capacity of 200 AH. The Positive terminal of Battery 4 becomes the Positive terminal of the 24 V bank. The Negative terminal of Battery 4 is connected to the Positive terminal of Battery 3. The Negative terminal of Battery 3 is connected to the Positive terminal of Battery 2. The Negative terminal of Battery 2 is connected to the Positive terminal of Battery 1. The Negative terminal of Battery 1 becomes the Negative terminal of the 24 V battery bank.

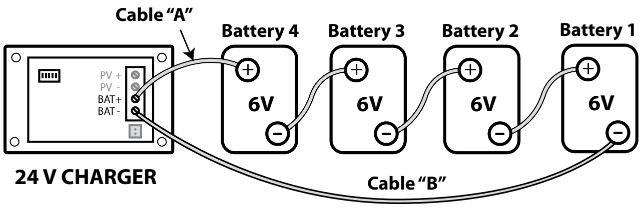

Fig 4: Series Connection

22.2 Parallel Connection

When two or more batteries are connected in parallel, their voltage remains the same but their AH capacities add up. Fig. 5 shows 4 pieces of 12 V, 100 AH batteries connected in parallel to form a battery bank of 12 V with a capacity of 400 AH. The four Positive terminals of Batteries 1 to 4 are paralleled (connected together) and this common Positive connection becomes the Positive terminal of the 12 V bank. Similarly, the four Negative terminals of Batteries 1 to 4 are paralleled (connected together) and this common Negative connection becomes the Negative terminal of the 12 V battery bank.

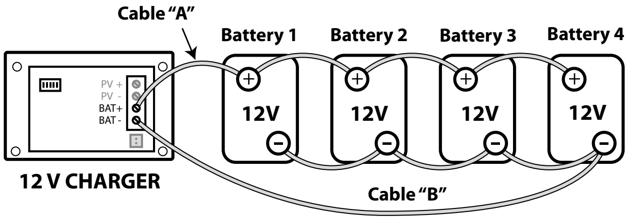

Fig 5: Parallel Connection

22.3 Series – Parallel Connection

Fig 6 shows a series – parallel connection consisting of four 6V, 200 AH batteries to form a 12 V, 400 AH battery bank. Two 6 V, 200 AH batteries, Batteries 1 and 2 are connected in series to form a 12 V, 200 AH battery (String 1). Similarly, two 6 V, 200 AH batteries, Batteries 3 and 4 are connected in series to form a 12 V, 200 AH battery (String 2). These two 12 V, 200 AH Strings 1 and 2 are connected in parallel to form a 12 V, 400 AH bank.

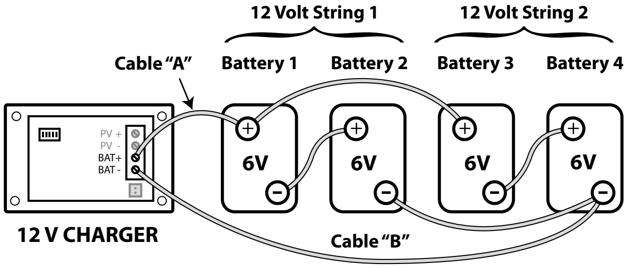

Fig. 6: Series-Parallel Connection

CAUTION!

When 2 or more batteries / battery strings are connected in parallel and are then connected to a charger (See Figs 5 and 6), attention should be paid to the manner in which the charger is connected to the battery bank.

Please ensure that if the Positive output cable of the battery charger (Cable "A") is connected to the Positive battery post of the first battery (Battery 1 in Fig 5) or to the Positive battery post of the first battery string (Battery 1 of String 1 in Fig. 6), then the Negative output cable of the battery charger (Cable "B") should be connected to the Negative battery post of the last battery (Battery 4 as in Fig. 5) or to the Negative Post of the last battery string (Battery 4 of Battery String 2 as in Fig. 6). This connection ensures the following:

- The resistances of the interconnecting cables will be balanced.
- All the individual batteries / battery strings will see the same series resistance.
- All the individual batteries will charge at the same charging current and thus, will be charged to the same state at the same time.
- None of the batteries will see an overcharge condition.

⚠ CAUTION!

If the Positive output cable of the battery charger (Cable "A") is connected to the Positive battery post of the first battery (Battery 1 in Fig. 5) or to the Positive battery post of the first battery string (Battery 1 of String 1 in Fig. 6), and the Negative output cable of the battery charger (Cable "B") is connected to the Negative battery post of the first battery (Battery 1 as in Fig. 5) or to the Negative Post of the first battery string (Battery 1 of Battery String 1 as in Fig 6), the following abnormal conditions will result:

- The resistances of the connecting cables will not be balanced.
- The individual batteries will see different series resistances.
- All the individual batteries will be charged at different charging current and thus, will reach fully charged state at different times.
- The battery with lower series resistance will take shorter time to charge as compared to the battery which sees higher series resistance and hence, will experience over charging and its life will be reduced.

23. EFFECT OF TEMPERATURE ON BATTERY VOLTAGE

The temperature of the electrolyte affects the rate of chemical reactions in the batteries as well as the rate of diffusion and the resistivity of the electrolyte. Therefore, the charging characteristics of the battery will vary with temperature. This is nearly linear and the Voltage Coefficient of Temperature Change is normally taken as -3 mV to -5 mV / ºC / Cell. Please note that the Voltage Coefficient of Temperature Change is negative which means that as the temperature rises, the charging voltage is required to be reduced and as the temperature is decreased, the charging voltage has to be increased. All charging voltage set points are normally specified at 25º C / 77º F.
For example, in PV systems, battery temperatures often vary up to 15º C from the 25º C reference. The Absorption Voltage for a 12 V battery must then be adjusted as shown in the Table 7 or a controller with Temperature Sensor should be used (assuming Voltage Coefficient of Temperature Change as -5 mV / ºC / Cell or -30 mV (.03 V) for a 6 cell, 12 V battery):

TABLE 7: TEMPERTURE VS. VOLTAGE

Battery Temperature	Absorption Voltage
40º C	13.95 V
25º C (Reference)	14.4 V (Reference)
10º C	14.85 V

In case temperature compensation is not provided, the warmer battery at 40 ºC will begin to heat and out gas at 13.95 V and will continue to overcharge until the non-compensated Absorption Voltage set point is reached (14.4 V). In cooler temperatures, the 10 ºC battery will experience severe undercharging resulting in sulfation.

It is recommended that a battery charger / charge controller with a provision for temperature sensing and compensation should be used if the battery electrolyte temperature varies more than 5º C to 10º C(9º F to 18ºF).

24. SELF-DISCHARGE

The battery discharges itself even without any load connected to it. This effect is caused by secondary reactions at its electrodes and proceeds faster with higher temperature or in older batteries. Thermodynamic instability of the active materials and electrolytes as well as internal and external short-circuits lead to capacity losses, which are defined as self-discharge.

This loss should be small,particularly in respect of annual storage. Self discharge (% of loss of capacity per month) for various types of batteries is as follows:

- Lead Acid - 3% to 4%
- Ni-Cd - 6% to 20%
- Ni-Fe - 40%

25. SIZING THE INVERTER BATTERY BANK

One of the most frequently asked question is, "how long will the batteries last?" This question cannot be answered without knowing the size of the battery system and the load on the inverter. Usually this question is turned around to ask "How long do you want your load to run?", and then specific calculation can be done to determine the proper battery bank size.

There are a few basic formulae and estimation rules that are used:

Formula 1	Power in Watts (W) = Voltage in Volts (V) x Current in Amperes (A).
Formula 2	For an inverter running from a 12 V battery system, the DC current required from the 12 V batteries is the AC power delivered by the inverter to the load in Watts (W) divided by 10 & for an inverter running from a 24 V battery system, the DC current required from the 24 V batteries is the AC power delivered by the inverter to the load in Watts (W) divided by 20.
Formula 3	Energy required from the battery = DC current to be delivered (A) x time in Hours (H).

The first step is to estimate the total AC watts (W) of load(s) and for how long the load(s) will operate in hours (H). The AC watts are normally indicated in the electrical nameplate for each appliance or equipment. In case AC watts (W) are not indicated, Formula 1 given above may be used to calculate the AC watts by multiplying 120 VAC / 230 VAC by the AC current in Amperes. The next step is to derive the DC current in Amperes (A) from the AC watts as per Formula 2 above. An example of this calculation for a 12V inverter is given below:

Let us say that the total AC Watts delivered by the 12 V inverter = 1000 W. Then, using Formula 2 above, the DC current to be delivered by the 12 V batteries = 1000 W ÷10 = 100 Amperes.

Next, the energy required by the load in Ampere Hours (AH) is determined. For example, if the load is to operate for 3 hours then as per Formula 3 above, the energy to be delivered by the 12 V batteries = 100 Amperes × 3 Hours = 300 Ampere Hours (AH).

Now, the capacity of the batteries is determined based on the run time and the usable capacity. From ***Table 12.4: Battery Capacity versus Rate of Discharge***, the usable capacity at 3 Hour discharge rate is 60%. Hence, the actual capacity of the 12 V batteries to deliver 300 AH will be equal to: 300 AH ÷ 0.6 = 500 AH.

And finally, the actual desired rated capacity of the batteries is determined based on the fact that normally only 80% of the capacity will be available with respect to the rated capacity due to non availability of ideal and optimum operating and charging conditions. So the final requirements will be equal to: 500 AH ÷0.8 = 625 AH (note that the actual energy required by the load was 300 AH). It will be seen from the above that the final rated capacity of the batteries is almost 2 times the energy required by the load in AH. **Thus, as a thumb rule, the AH capacity of the batteries should be twice the energy required by the load in AH.**

For the above example, the 12 V batteries may be selected as follows:

- Use 6 Group 27 / 31, 12 V, 105 AH batteries in parallel to make up 630 AH, or
- Use 3 Group 8D, 12 V, 225 AH batteries in parallel to make up 675 AH.

26. BATTERIES AND BATTERY CHARGING IN VEHICLES / RVS –ALTERNATORS, BATTERY ISOLATORS, INVERTERS, LOW VOLTAGE DISCONNECTS

26.1 Battery Isolators

It is recommended that for powering an inverter, one or more auxiliary deep cycle batteries should be used that are separate from the starter SLI batteries.

The inverter should be powered from deep cycle batteries. For charging the starter SLI and the auxiliary deep cycle batteries, the output from the alternator should be fed to these two sets of batteries through a Battery Isolator of appropriate capacity.

The Ampere rating of the Battery Isolator should be 10% more than the Amp rating of the alternator or the maximum DC Amps pulled by the inverter, whichever is higher The Battery Isolator is a device that will allow the alternator to charge the two sets of batteries when the engine is running. The Battery Isolator will allow the inverter to be operated from the auxiliary batteries and also prevent the starter SLI batteries from charging the auxiliary deep cycle batteries when the engine is not running. Battery Isolators are available from auto / RV / marine parts suppliers.

26. 2 Alternators

A majority of smaller vehicles have 40 to 105 Ampere alternator and RVs have 100 to 130 Ampere alternator. When in use, the alternators heat up and their output current capacity can drop by up to 25%. When heated up, their charging voltage may also not reach the desired Absorption Voltage and will result in return of only about 80% of the battery capacity.

In case the current output of the standard alternator is not adequate to charge the two sets of batteries rapidly and fully to 100% of their capacity, use heavy duty alternator that can produce higher current and voltage required to charge multiple battery systems. These alternators are available with auto / RV parts suppliers.