A DETAILED MANUAL ON LEAD ACID BATTERY OPERATION & MAINTENANCE FOR SOLAR PV PLANTS

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Solar PV Battery Manual

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PREFACE

In India over 14,000 Micro/Mini grids (DC and AC) are under operation. These micro and mini grids are complementing the efforts of Government of India's ambitious target of providing 24/7 access to electricity to every Indian citizen by 2022. Micro/mini grids entrepreneurs are deploying innovative off grid solutions that are powered by renewable energy to provide energy access for all. All these plants have solar PV capacity generally in range of 250 W to 100 kW with battery backup for providing backup for almost couple of hours to over twelve hours.

Private and public sectors have struggled while operating these mini grids which are located in remote location for a planned period. The major cause for premature failure of the mini grids has been poor performance of the batteries and lesser know-how to maintain and operate them. Taking lead from this sectoral issue, Clean Energy Access Network (CLEAN) along with India Energy Storage Alliance (IESA) and Customised Energy Solution, attempted to develop a comprehensive O&M manual for Solar PV battery. This manual will address the current issues like battery bank selection, identification of failure modes in the mini grids, charging and discharging rates and relevant cut-off voltages etc.. The manual will be ready reckoner for Micro/mini grid operators for improving the life of the batteries in their plants. The manual gives comprehensive guidelines around equalization charge process and annual maintenance procedures for lead acid batteries.

Our heartfelt thanks to the United States Agency for International Development (USAID), without whose funding support none of our work would have been accomplished.

Hope this manual will be useful for Micro/Mini grid operators for better understanding the operational issues around lead acid batteries and taking corrective actions accordingly.

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1. Introduction

Countries across the world including India are deploying - thousands of off-grid solar power system and minigrids with lead acid batteries. The- solar plants are mainly deployed for gaining energy access- and are established at rural communities as well as at commercial facilities like rural banks, gas stations and government institutes where power supply is limited or is of poor quality. These plants have solar PV capacity generally in range of 250 W to 100 kW with battery sized for providing backup for two hours to over twelve hours.

As most of these sites are deployed for bottom of pyramid and for remote locations; installation, commissioning and O&M procedures of these plants are often sub-standard. During the last two years, the (mention the team name) team involved in writing of this manual have at large studied performance of over fifty solar off-grid plants across India. During the site visits, a lot of common issues with the performance of the solar PV plants especially the battery bank was witnessed. Hence developing a designer manual cum user handbook for operations and maintenance of lead acid batteries was conceptualized.

Figure 3 Image collage of an off-grid solar PV microgrid (source: CES)

At most of the sites, the battery bank was not supplying the rated output. With passage of time, a rapid capacity degradation of the battery bank was noticeable. Sizing of the battery bank at the plants was dependent on a general understanding on operation and sometimes on commercial conditions. At many plants, the battery bank was not able to supply even half of its capacity and at other plants, battery was failing after a few minutes of discharge. The reason lies in the design of the system, sizing of battery, installation, and most importantly the operation & maintenance (O&M).

These issues were seen at all the sites which were more than eighteen months old and customers are often demoralized by early degradation of the SPV & failure of battery within 4 years. With such observations & concerning knowledge of system design, battery type & capacity, -installation and O&M of the lead acid battery used for off-grid solar PV plants, a need was felt for a designer manual cum practitioner's handbook. This manual is an attempt to be a guide for the people involved in sizing, designing, installing, operating and maintaining solar PV plants with lead acid batteries which will result in increasing output of power plants & life of batteries by 30% to 50%.

During our extensive survey of off grid power plants & revival of some of them, it was found that most of the degradation ha-s been due to lack of operating information on batteries. While selection of battery type & sizing were a part of the cause, the bigger problem was in understanding battery operation & maintenance in solar PV. This - manual is the result of 20 years' experience in design, installation, operation & maintenance of battery based solar/wind solar hybrid power plants. Most of the recommended operating procedures are validated by field experiments conducted on new and old solar power plants and laboratory experiments on operation of charge controllers, inverters and most importantly, on lead acid batteries of different types. In this manual we have focused on the following parameters:

- Understanding the function & effects of battery components and its performance in off-grid solar PV plant.
- Optimization of input and output of the battery
- Sizing and selection among various types of Lead Acid batteries
- Installation and commissioning of the battery/DC system
- Operation and Maintenance of the battery

"At some point, if you don't take care of the roads today, it's like any other maintenance issue: you're going to end up paying a lot more down the road" – Matt Mead, Wyoming's 32nd Governor

2. System Layout and Components

To understand the performance of batteries in off-grid solar PV system, it is very important to understand the input and the output of the battery which can affect performance & life of the energy storage component as well as that of the complete generation plant. Following are the block diagrams to understand the functioning of the complete system. Figure 4 is a block diagram of a solar PV plant where battery and solar PV are connected on the DC side. This kind of system is generally adopted for DC microgrids, pico-grids or at the plants with lower day load.

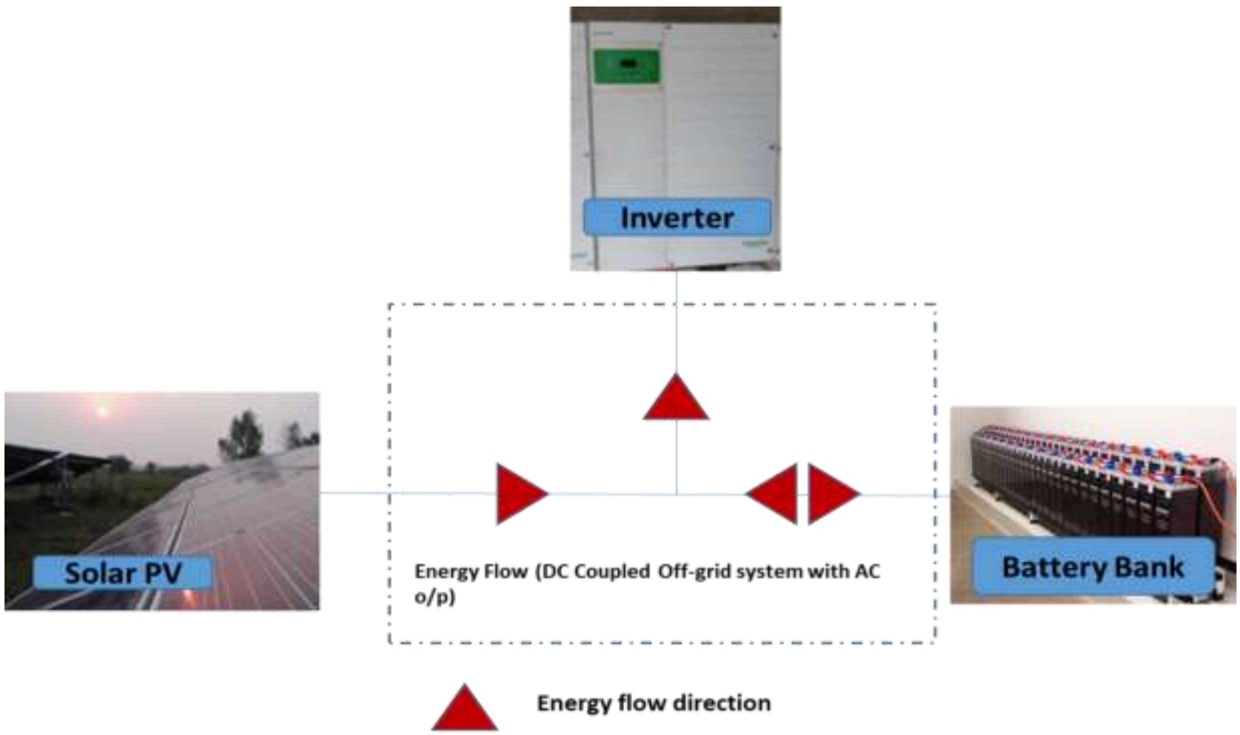

Figure 4 Block diagram of a DC coupled off-grid solar PV Power Plant

There are also AC coupled microgrids as shown in Figure 5 but -are very few in numbers. These microgrids should be designed for plants where day load is higher.

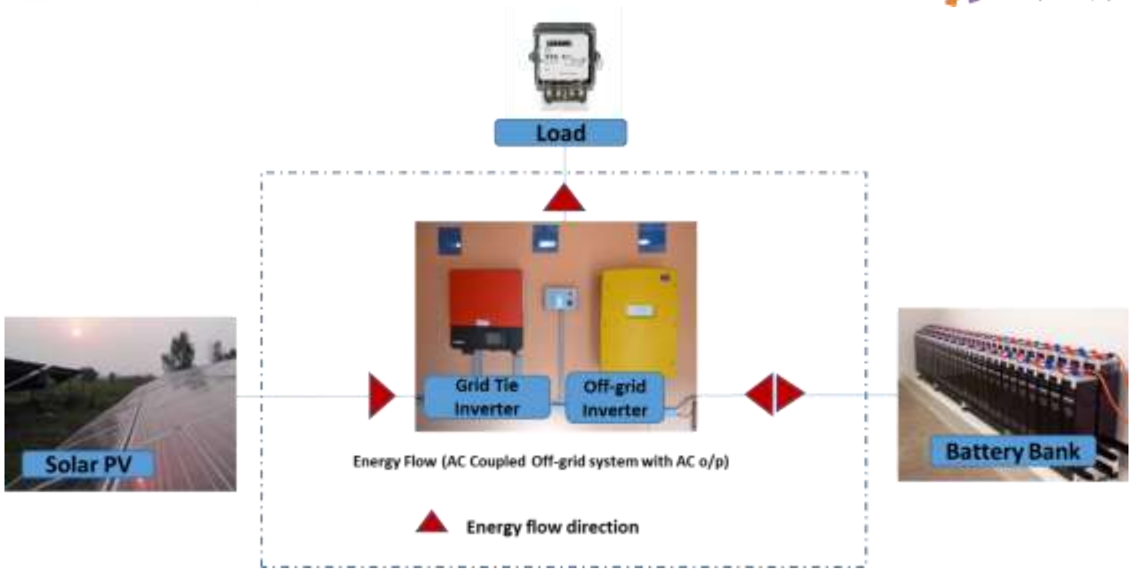

Figure 5 Block diagram of an AC coupled off-grid solar PV Power Plant

In both the above diagrams, it can be seen that maximizing performance of the plant depends upon optimization of input and output of the battery. For this, function of all the components in both these systems should be understood.

Generation

An off-grid or stand alone solar power plant consists of following components:

Solar modules: The solar photovoltaic modules are connected in series or parallel, depending on the Total Voltage and Current required to be supplied (Voltage X Current = Power). The power from the solar array are collected in one or more junction boxes and thereafter, fed into one or multiple solar charge controllers.

Figure 6 Solar PV panel array at a rural microgrid (source: CES)

Module Inter-connect cables: These connect the solar modules in series or parallel as per the system voltage and current requirement and sized for maximum current output from each solar module.

Figure 7 Solar PV module interconnection cable (source: http://www.wegosolar.com/products)

Solar module support structure: These are metallic structures, normally made of galvanized steel channels which are adequate to not only carry the weight of solar modules but also resist high wind loads and corrosion or rusting over their lifetime.

Figure 8 Solar PV Mounting Structure (source: IndiaMart)

Cable Junction Box/Boxes: These collect the power from a batch of solar modules and ensure that electrical contacts are safe from the access of dust, moisture and other atmospheric elements. Multiple junction boxes are all connected to a main junction box.

Figure 9 Solar PV Cable Junction Box (source: IndiaMart)

Main D.C cable from solar array to charge controller: The main cable connects the main junction box to the solar charge controller and delivers all the generated solar power to the solar charge controller or controllers. It consists of a positive and a negatively charged cable of sufficient current carrying capacity to ensure minimal voltage drop at delivery point. It is armored or conduits are used for underground routing. Precious power for battery charging flows through this cable & loss of power by voltage drop can be reduced by correctly sizing the cross section of conductor, based on the length of its run.

Figure 10 Solar cable piece crimped with termination lugs (source: The 12 V shop)

Solar Charge Controller: The functions were originally to obstruct reverse flow of current from battery to solar module during the night. Ideally, they should also control charging voltage & current for battery safety and improving the efficiency of solar power input to and acceptance of same by the battery. Controllers provide various protections to the upstream and downstream electrical circuit.

Pulse Width Modulation(PWM). The solar charge controllers use pulse width modulation technique for voltage regulation. This allows a larger amount of power supply after the regulation point without crossing the gassing voltage of the battery. However, the maximum power that solar panel can supply (V_{max} X A) is not fully utilized, since the power fed to battery is Battery Voltage $V_{Battery}$ X A, Where $V_{Battery} < V_{max}$ of solar panel.

Maximum Power Point Tracking(MPPT) charge controllers on the other hand, use a DC – DC converter for converting the full power (V_{max} X A) of solar panel to AC power which is then stepped down to battery voltage while increasing the current so that (Vmax X A) = $V_{Battery}$ X Ā Where Ā > A. However, most of the mid-sized MPPT controllers - in the market track only the battery voltage and -not –change the - solar panel voltage which changes with change in panel temperature. This could have been made better.

It was seen that standard brands of mid sized MPPT operate more efficiently than PWM controllers upto 80% charge level of battery while the later is more efficient after battery reaches 80% charge level.

Their operations can mark effect on battery charge efficiency, service life & performance of solar power plant. The vital functions should be (i) Regulate voltage to avoid overcharge/gassing (ii) Save battery from capacity loss by undercharge (iii) Protect battery from deep discharge (iv) Ensure maximum charging efficiency & (v) Ensure full capacity & service life.

Figure 11 MPPT Charger Controller (Source: OEM)

Power Convertor (DC to AC Inverters)

D.C power from battery is converted to A.C by an inverter. The need arises from the fact that most of the electrical appliances work on A.C and it also helps in distributing power at a higher voltage, thus reducing the line losses. Inverter has an important function of cutting off the power supply before battery is over discharged. Since this function is one of the key aspects in the performance & life of batteries in a solar power plant. this problem & solution - is discussed in detail under the caption of " Battery failure by Deep Discharge".


Figure 12 Solar PV Inverters and Battery Inverters at DC coupled (L) and AC coupled (R) Microgrids (Source: CES)

Introduction to Solar Lead Acid Batteries

The primary function of storage battery in an off-grid solar PV system is to balance the power flow by absorbing excess/un-utilized power from solar PV or delivering power when demand is more than the supply from solar PV.

Understanding its features & functions will help in improving its performance & life.

Capacity rating and C Rate: Stationary batteries are rated for a particular capacity in terms of Ampere-hour(Ah) normally at C10 (10 hour rate of discharge), which means that a battery rated 100Ah will provide 10 Amperes for 10 Hours or 100% of its capacity at 10 hour rate of discharge. At any higher rate of discharge, the output will be less than rated output in AH. Conversely, at lower discharge rates, the output will be higher than rated output at C10. Table 1 indicates the approximate output, as a percentage of C10 capacity.

Table 1 Battery output capacity as a percentage of C10 capacity

Maximum Discharge Duration in Hours for flooded tubular Battery (IS13369: 1992)	Maximum Discharge Duration in Hours for VRLA Battery (IS15549:2005)	% Output	Eg. Discharge rate of a 100Ah battery for this duration (Amps)
10 Hours (C10)	10 Hours	100	10
8 Hours (C8)	8 Hours	95	11.9
5 Hours (C5)	5 Hours	83.3	16.7
4 hours (C4)	4 hours	78.2	19.5

3 Hours (C3)	3 Hours	71.7	24
2 Hours (C2)	2 Hours	63.3	31.5
1 Hour (C1)	1 Hour	50	50

Example 1: If 20 A is discharge for 3 hours - from a battery then to determine the capacity that need to be installed (available at C10 in the market), the following procedure should be followed

- Determine output required by the battery = 20 A X 3 Hours = 60 Ampere Hours (Ah)
- As the discharge time is three hours, discharge rate will be C3. Referring to Table 1, at C3, 71.7% of the output can be attained if 100% is at C10.
- Therefore, C10 capacity required = 60Ah ÷ 0.717 = 83.7 Ah
- Hence battery more than 83.7 Ah capacity (at C10) should be procured for this application.

It is seen, although infrequently, that some solar batteries are rated at C100 or 100 hour rate of discharge. A regular 100 Ah battery at C10 will provide 130Ah – 140Ah (i.e. 30% to 40% more than the rated capacity) at C100 discharge rate. Full-discharging 130 Ah at a slow rate, from a 100Ah battery can be very harmful to its life. On the contrary, if a 100 Ah battery is rated at C 100, it is actually a 77 Ah battery at C10. Please note, all capacity calculations are done on C10 capacity.

Temperature Correction Factor: The capacity of a battery is rated at a standard temperature of 27°C. The available capacity decreases when operating temperature is lower and vice-versa when higher. IS 13369 (flooded monoblock tubular) and IS 15549 (for VRLA batteries) indicate capacity reduction 0.43% for every 1°C drop in temperature from 27°C & vice-versa, when battery is discharged at C10 rate. This variation increases to 0.58% when discharge is at C5 rate. Since, solar batteries operate between 5 & 10 hours per day, temperature correction factor of 0.5% for every 1°C temperature variation can be safely assumed for any temperature related derating calculations.

Example 2: To apply this derating in practice, an example can be considered where battery capacity at C10 needs to be determined at 27°C for a microgrid demanding 48 V, 20A discharge in 3 hours at 0°C operating temperature. To arrive at the capacity, following steps should be followed:

- Capacity Required at C10 at 27°C : From Example 1, it is observed that battery capacity at C10 for 20A and 3 hour discharge is 83.7Ah

- **Temperature Derating:** Battery capacity drop from 27°C to 0°C = (27 – 0) X 0.5% = 13.5%
- So, effective capacity of battery at 0°C is 86.5% of rated capacity at 27°C
- Therefore battery capacity required at C10/27°C is 83.7 Ah ÷ 0.865 = 96.8 Ah

Self Discharge Loss / Retention of Charge: All types of batteries- even when unused, discharge slowly but continuously by a phenomenon called self discharge. This energy loss is due to local action inside the battery & depends on level of minute impurities in battery elements & accuracy of manufacturing process control. A rise in the operating temperature is an external factor which increases the self discharge loss.

Self discharge loss is measured by "Retention of charge test" which checks the amount of charge retained by a battery after free standing for 28 days at a standard temperature. The R.O.C test as per IS 15549 for VRLA battery and IS13369 for flooded tubular Monobloc's accepts self discharge loss within 10% & 5% respectively, for a new battery.

Customer can safely ascertain that the quality of material used & the manufacturing process control are good, simply by ensuring that the batteries meet the ROC limits as per the BIS above. A battery with poor R.O.C can have multiple deficiencies (by way of raw material input or manufacturing defects) inside and the self discharge loss can grow by 3 or 4 times over the period of its lifetime.

Ampere Hour & Watt Hour efficiency: Ampere hour efficiency of a battery is essentially, the ratio of Ah output during discharging & the AH input during charging which is expressed in percentage. Bureau of Indian Standards defines the process of measuring it as "A fully charged battery shall be discharged at I = 0.1 X C10 amperes to an end voltage of 1.80 Volts/cell (IS 13369 for 12V flooded tubular) or 1.75 Volts/cell (IS 15549 for VRLA) or 1.85 Volts/cell (IS1651 for 2 volt flooded tubular cells) careful calculations being made of the exact number of ampere hours delivered. On recharge, the same number of ampere hours are put back at the same current. A second discharge shall then be made at the same current to the same cut off voltage as before. The Ah efficiency of the battery is then calculated as the ratio of the ampere hour delivered during the second discharge to the ampere hour put in on the charge. **Ah efficiency shall not be less than 90%."**

Watt hour efficiency of a battery is calculated by multiplying the ampere hour efficiency by the ratio of average discharge and recharge voltage during the above mentioned ampere hour efficiency test. As per BIS, the Wh efficiency shall not be less than 75% for 12V flooded tubular and not less than 80% for VRLA batteries.

Ah efficiency at various state of charge: While overall Ah efficiency is 90% or more for a full recharge followed by full discharge, it also varies as per state of charge of the battery as per IS 6497

- If battery is recharged to full from 90% SOC, its efficiency is 85%
- If battery is recharged to full from 75% SOC, its efficiency is 90%
- If battery is recharged to full from 50% SOC, its efficiency is 95%

Hence, lower the state of charge, higher is the charge efficiency of the battery. **A 10% to 15% higher output can be obtained from the same solar system, if the battery is operated from partial SOC to near full charge.**

The above table in BIS relates each partial state of charge to a standard full charge level, only in order to show the comparison between charging efficiencies at each stage. Infact, in the above table, if the battery is not taken to full charged levels at each stage, then, the ampere hour efficiency is even more. Full recharge up to 100% capacity is not required and not even recommended by us at each daily cycle of the solar power plant, since, there is a possibility of overcharge and reduction of battery life.

(f) Deep discharge : Following reaction occurs in the lead acid battery during charging and discharging:

Charged Battery   Discharged Battery

$$\text{(+ve) } PbO_2 + \text{(-ve) } Pb + \text{(electrolyte) } 2H_2SO_4 = \text{(+ve) } PbSO_4 + \text{(-ve) } PbSO_4 + \text{(water) } 2H_2O$$

In the reversible reaction above, the electrolyte of dilute sulfuric acid is converted to water & the +ve & -ve plates convert to lead sulfate when the battery is discharged. Availability of surplus electrolyte & active material in the plates ensure that even after a full 100% discharge, adequate amount is leftover to conduct current into the battery on recharge. A deep discharge of much more than 100% of battery capacity, leaves no electrolyte or active material in the battery which then does not accept recharge due to very high internal resistance. Deep discharge occurs at a very low rate of discharge which can drain out more than 100% of the design capacity of battery if the discharge cut off voltage setting in the solar charge controller or the inverter is not correctly set.

e) Gassing & gassing Voltage:

The electrolyte in a lead acid battery is a dilute solution of sulfuric acid - and water. The - charging current causes electrolysis of water- which generates oxygen & hydrogen gases. In the beginning, most of the charging current is efficiently absorbed by the plates & there is hardly any electrolysis. Later, when the battery is 80% full & the voltage rises to around 2.3/2.35 volts/cell, charge acceptance is reduced-resulting in excess energy being converted to heat & electrolysis. This point of 80% state of charge, at around 2.3/2.35 Volts/cell is known as gassing voltage.

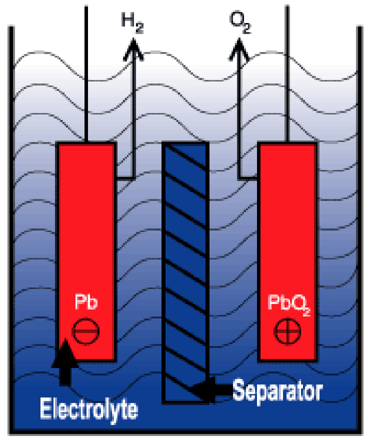

Figure 13 Gassing in flooded lead acid battery

f) Sulfation & hard sulfation:

The simple chemical formula for battery charge & discharge as shown in paragraph (f) above illustrates that lead dioxide in the positive and spongy lead in the negative plates are converted to lead sulfate when the battery is discharged. Hence, sulfate formation is a natural phenomenon during which the discharge of a battery - is re-converted to lead dioxide and spongy lead when the battery is recharged. The problem occurs when part of the lead sulfate is not converted back to active material due to insufficient recharge which - was seen during cycling of the battery when full capacity was not attained after every recharge. Other reasons for growth of sulfates are- under charging as explained earlier - and keeping the battery in discharged condition for a long duration.

The lead sulfate crystals remaining in the plates (mostly in negative plates which are more difficult to charge as compared to positives) have a tendency to grow in size & become hard crystals, impermeable to electrolyte diffusion and deterrent to normal charging current due to high resistivity. This phenomenon known as hard sulfation causes high internal resistance & refusal to accept charge.

Figure 14 A hard sulfated negative plate

g) Overcharge, Corrosion & plate shedding:

Overcharging of battery results in an increase of gassing & temperature in the batteries. Excessive or continuous overcharge leads to deformation or growth of plates (mostly positive) which leads to the active material falling off (shedding) from the grids or tubular plates. During overcharge, when all the active material have been converted & no active material is left to be charged, the extra charging can start oxidising the grid or spine of the positive plate, resulting in their corrosion and failure.

The battery not only loses capacity- but also are prone to internal short circuits caused by shedded active material which can bridge the positive and negative plates.

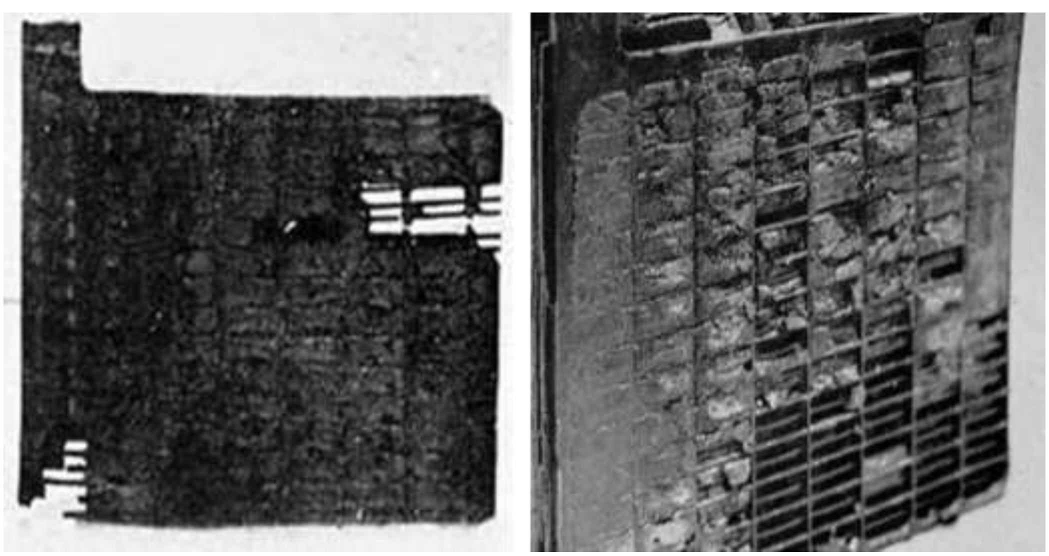

Figure 15 Corroded plates due to regular overcharging

h) Capacity degradation factor (ageing) & end of service life:

A battery- like any other equipment, continually loses a small part of its capacity right from the day it is commissioned. It is said to have reached the end of its "Service Life" once the capacity of the battery is 80% of its rated capacity or lower. It is then fit to replace the battery with a new one. For critical applications, where the backup duration cannot be compromised, even at the end of its life- a 20% extra- known as ageing/degradation factor-is added to the required capacity when sizing the battery.

i) Boost / Bulk Charge:

Boost charging means charging the battery at a high current (within the acceptable maximum current limits) till the battery reaches the gassing point or voltage. This is done, either by applying a constant voltage whereby the battery initially takes a very high current which tapers down as the battery voltage increases or by a constant current (at a rate acceptable to the battery till its gassing point is reached). Battery can be charged to 80% state of charge by this method. The last 20% charge in a flooded battery is imparted at a constant current or finishing rate which is half of the boost rate. For VRLA batteries, the final part charging is done at a constant voltage, preferably at gassing point, whereby the current tapers down to almost nil as the battery reaches a fully charged state.

j) Trickle charge & Float -charge:

Self discharge loss of a fully charged battery, as explained above can be replenished by applying a voltage of 2.25 volts/cell across the battery , for example, 2.25 Vpc X 24 = 54 volts for a 48 volt battery. At this voltage the battery is charged with a current which is the same as the self discharge loss and the battery remains in fully charged condition. This is known as trickle charge.

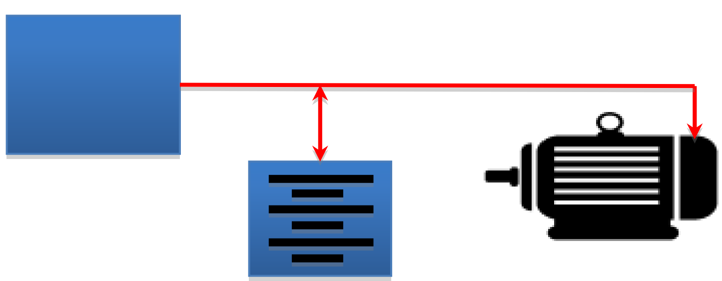

Figure 16 Float charging circuit

Float charge on the other hand, is also a trickle charge process where DC power is fed to the electrical load connected in parallel with the battery. Here, a safe voltage for the load is applied, which can be lower or higher than the trickle charge voltage of 2.25 volts/cell. If the applied voltage is higher than N X 2.25 where N = number of cells- then the number of cells are to be increased to ensure that each cell does not get a voltage of more than 2.25 volts, since it will overcharge & damage the battery. A voltage less than 2.25 Vpc is safe for the battery but does not fully compensate for the self discharge loss and hence the battery is to be given a freshening charge at some intervals.

k) Equalizing charge:

When a battery is subject- to repeated discharge and recharge cycles, it is unable to get full recharge every time, due to limitations of charging time-especially in solar PV power plants. All the cells of a battery don't - have - the same recharge efficiency and over a period of time- some cells are less charged than the others. The lowest capacity cell thus limits the effective capacity of the battery.

Periodic charging of the battery is required to be carried out at a high voltage (to overcome the internal resistance developed due to sulfation) but low current (so as not to overheat which can & - the battery) and for an extended duration- so as to enable each single cell in the battery to get full charge. This process- known as Equalizing charge, brings all cells to same level of charge-dissolves hard sulfates and reduces the internal resistance and the battery again operates at full capacity. The expert guidance on the periodicity of equalization and its duration is given in the O&M section of this manual.

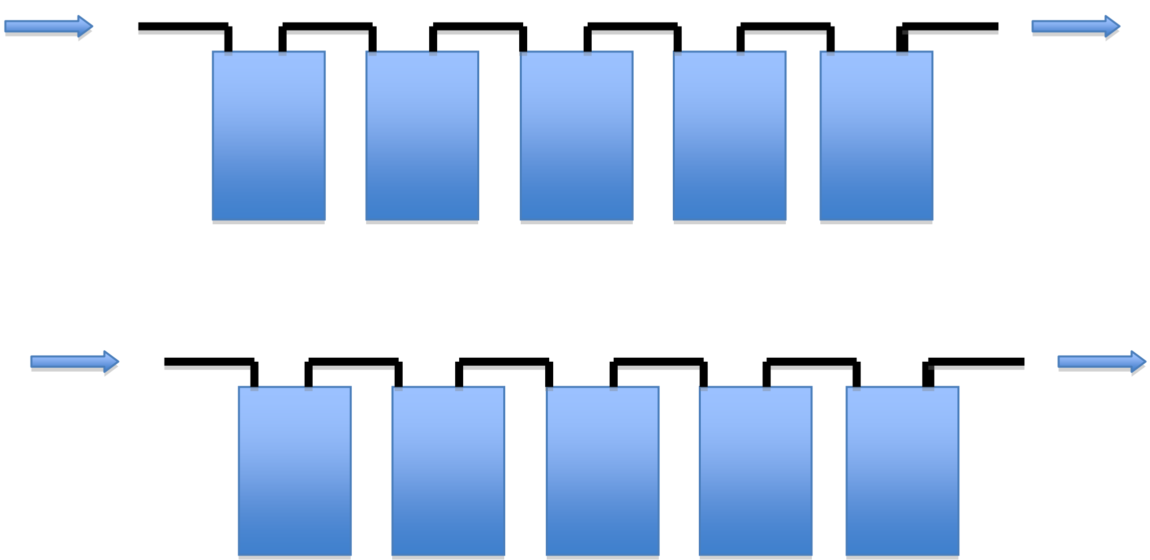

Figure 17 Cells in a battery bank at different state of charge undergoing equalization process & below – after equalizing process

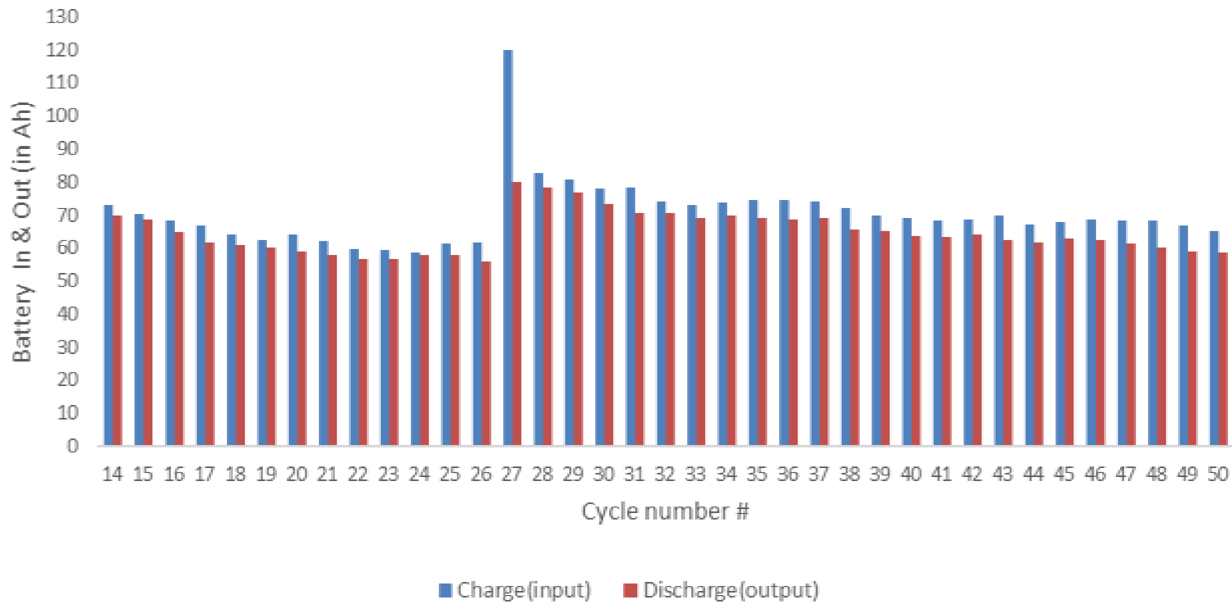

Figure 18 Tubular battery during 80% discharge under solar charging conditions demonstrating drop in capacity before and after an equalizing charge carried out at cycle #27 (source: CES)

The bar chart above shows that repeated cycling (discharge of 80% of battery capacity followed by 8 hour recharge by solar simulation) gradually reduces the effective capacity of a flooded tubular battery by 20-25% in around 25 to 30 days. It also shows that the equalizing charge imparted on 27^{th} day increased the battery capacity to 100% level.

l) Series & parallel connection:

Battery or cell voltages are added when they are connected in a series and ampere hour capacity is added when they are connected in parallel. Recommendation regarding maximum number of parallel circuits are provided in the Installation- and Operation & Maintenance section.

Cycling duty: Discharge of a battery followed by recharge is known as a cycle. Any battery that undergoes this cycle on a regular basis, can be said to undergo a cycling duty.

Depth of Discharge: It is the extent of discharge from a battery- which is measured by the energy in Ampere Hour or Watt Hour discharged, as a percentage of the battery rated capacity in AH or WH.

State of Charge: Opposite of depth of discharge, it is a measurement of AH or WH charge remaining in a battery, as a percentage of the battery capacity in AH or WH.

Partial state of charge: When a battery is cycled- but never-fully recharged-- is said to be operating in a partial state of charge. While battery charge efficiency is higher at partial state of charge, prolonged operation in such state leads to hard sulfation of battery plates.

Nominal voltage: Open circuit voltage of a battery or cell.

Top of charge voltage: Lead acid battery cells having an open circuit voltage of 2.00/2.10 tend to have an increasing voltage when put on charge, going up to the maximum voltage set in the charger system, which may be 2.25V - 2.35V for VRLA cells, or 2.35V - 2.45V for flooded cells during regular charge and 2.5V – 2.75V when equalizing charge is imparted to flooded cells. This maximum voltage reached during charging is also known as top of charge voltage.

Discharge cut off voltage: Battery/ Cell voltage goes down from open circuit voltage while being discharged. When the lowest voltage on discharge- for obtaining full capacity of the battery or that voltage beyond which the inverter/UPS/electrical load does not operate is reached, battery discharge is stopped. This is known as discharge cut off voltage.

Temperature correction: Battery capacity at C10 reduces by 0.5% for every 1°C reduction in battery temperature from the standard temperature of 27°C. The opposite happens in case of increase in temperature. Wherever, battery has to operate at lower than standard temperature, this capacity reduction has to be compensated for while sizing the battery capacity. The capacity reduction percentage is higher for higher rates of discharge.

Battery temperature: The operating temperature of the battery electrolyte & that of the plates constitute battery temperature and is measured by temperature of electrolyte in case of flooded batteries and that of the positive terminal in case of VRLA batteries.

Electrolyte specific gravity: It is the ratio of the density of the electrolyte to the density of water. Specific gravity of electrolyte in a battery has a direct & linear relationship with its state of charge.

Selection of battery for solar PV application: Several types of commercially available lead acid batteries-whose functionality & suitability for solar application are explained in Chapter 3 and Chapter 5. Recommendations are provided without reference to make or model-based on technical information available in public domain and tests carried out by solar conditions simulated in laboratory , cycling tests in laboratory & at operating several field installations. While the function, performance & life of each type of battery is elaborated- there will always be exceptions to the rule.

Battery capacity & life-are normally dependent on the amount of material used in the plates & current conductors along with matching volume of electrolyte. Hence their comparative weights- give a fair indication of their capacity & service life. Purity of material & manufacturing process control in battery making plays a major role in their performance, recharge acceptance, efficiency & life. If these are checked with care while deciding on the battery- the life and performance of solar plant is assured.

3. Classification of Lead Acid Batteries

Batteries classified by their chemistry, electrode & gut design, and electrolyte properties among others.

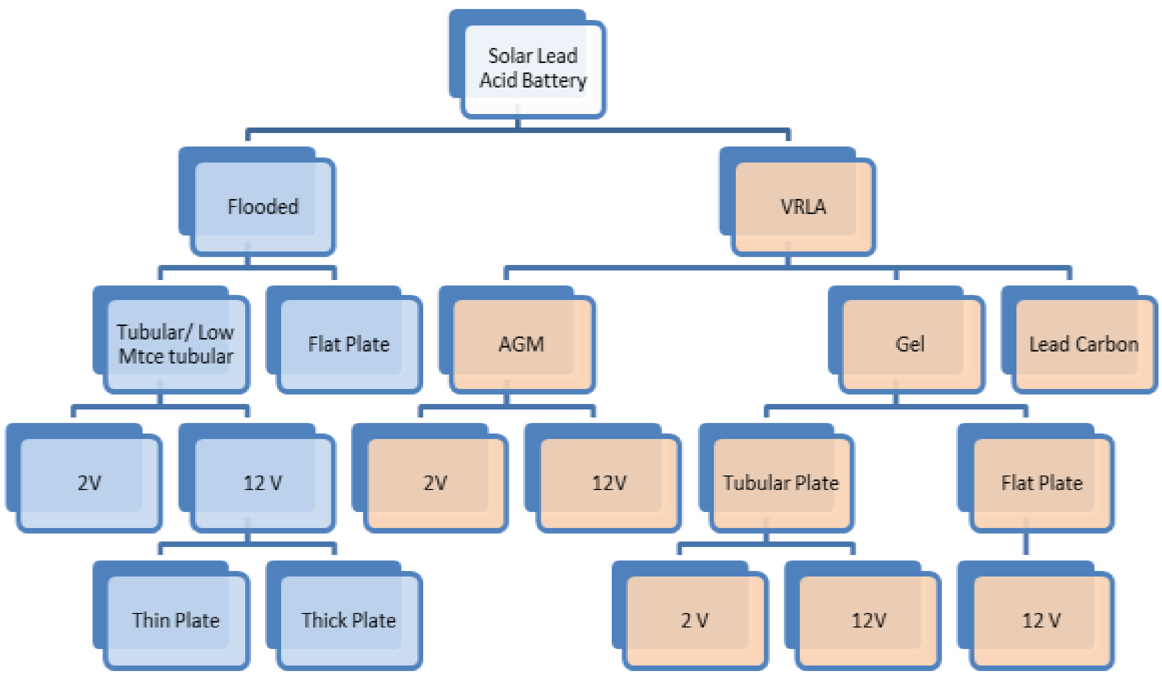

Figure 19 Classification of Solar Lead Acid Batteries

Flooded Lead Acid Battery: Flooded batteries are most popular for solar applications and are called so because the plates are immersed in electrolyte and the cells are open for topping up with DM water for replenishment of electrolyte. They consist of both tubular and flat plate construction of electrode.

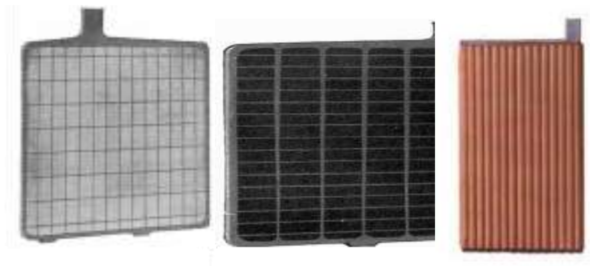

Figure 20 Construction of Flooded Lead Acid Batteries

Tubular Flooded Batteries: They consist of tubular positive plate, pasted negative plates, separators and dilute sulfuric acid electrolyte in liquid form. They are rugged in construction- that can survive abusive conditions but require distilled/ demineralized water topping up from time to time to make up for the water loss by electrolysis & evaporation. The low maintenance tubular batteries for solar are different from so called inverter batteries by way of using different chemistry in the electrodes which reduce water loss & with excess electrolyte design, require very infrequent water topping up.

Properties of different types of tubular flooded batteries:

- The larger capacity **2 volt cells** are more robust- with heavy plates for longer life and large electrolyte reservoir- acting as heat sink. Well designed - and properly manufactured cells can provide a service life of 1200 cycles at 80% D.O.D, 2500 cycles at 50% D.O.D and 5000 cycles at 20% D.O.D. (Note: (a) a cycle means a discharge followed by full recharge (b) D.O.D or Depth of discharge is the percentage of rated capacity of battery that is discharged in one cycle)

Figure 21 Photograph of a battery bank comprising of 2 V flooded tubular cells

- **12 volt monoblock** tubular batteries have the same plate design as the 2 volt cells above but are more compact in construction, lesser volume of electrolyte and lower in weight. They have a lower service life of approximately 900/1000 cycles at 80% D.O.D, 2000 cycles @50% D.O.D & 4000 cycles @20% D.O.D.

Figure 22 12 Tubular LM Lead Acid Battery for solar

- **12 volt thin-tubular** monoblock batteries have tubular positive plates that are lesser in thickness & diameter than the normal tubular. They have better charge acceptance & high discharge rates, lesser in weight & consequently price, but also lesser life than normal 12 volt units above.

Figure 23 Photos of the 6mm tubular and 8 mm tubular plates

Ideally, all the above flooded batteries, when designed for solar applications-should be low maintenance type. These batteries with very low antimony content in grids and spines (using high pressure spine casting process)- reduces the water loss and the need for frequent topping up. Batteries with larger containers & extra electrolyte content require water topping up, once in 18 months.

Flooded Lead Acid Flat Plate Battery in 12 volt monoblocks are more economical versions of their tubular cousins. These have both flat plate positives and negatives similar to automobile starting batteries but with much thicker positive and somewhat thicker negative plates. Thus, they have a much longer cyclic life than the automobile batteries but not more than half the cyclic life of tubular batteries. The life is fairly reasonable if the depth of discharge is low.

Valve Regulated Lead Acid Battery with AGM separators were originally developed for use – in UPS & telecom systems but a large number of them are currently used in solar PV applications as well. It has both positive and negatives of flat plate construction, lead calcium grids and an absorptive glass mat separator, designed for recombination of gases, thus ensuring no water loss during charge.

Figure 24 VRLA battery with AGM separator (Source: PCCOE)

Gas recombination allows the battery to be sealed & maintenance free to the extent that no water topping up is required during its lifetime. A pressure relief valve in each cell allows any excess gas pressure to be released and hence the name "Valve Regulated Lead Acid" Battery is given. Popular due to "No Maintenance" properties-these batteries have logically- a lower cycling life than that of tubular batteries due to its flat pasted positive plate design. Within the product range, there are both- long cycle life and high performance types as explained hereunder. It is to be noted that AGM VRLA batteries are not recommended to be discharged more than 50% of their capacity on a regular basis unlike tubular batteries which can be discharged up to 80% of their capacity:

- Just like, the tubular batteries-larger capacity **2 volt VRLA cells** are more robust- with plates that are thicker than their 12 volt counterparts and accordingly-a longer service life. Logically, these should have a lower cyclic life than their 2 volts tubular counterparts, although, some manufacturers claim the same life- due to their superior design. Considering both the aspects-it may not be too far-fetched to expect a life of 1800 to 2000 cycles at 50% D.O.D.

Figure 25 Photograph of a 24 V battery bank comprising of 2 V AGM cells (source: CES)

- The 12 volts AGM VRLA batteries are generally designed for high rate but shallow discharge in UPS systems and most of them are not very well suited for solar deep discharge applications. Their cycle life would be less than half of the 2 volt VRLA.

Figure 26 12 V AGM Solar Battery (source: OEM)

The AGM VRLA battery should not be discharged beyond 50% of its capacity as against 80% allowed in case of tubular batteries since recharge becomes very difficult due to its electrolyte starved design.

The other limitation is that of lower charging voltage on account of the fact that, any electrolysis or gassing caused by higher charge voltage leads to irrecoverable loss of water from battery.

Valve Regulated Lead Acid Battery with Gel Electrolyte: This battery operates on a gas recombination technology like the AGM VRLA battery-. The only differences being that tubular positive plates (of a different chemistry than those in flooded tubular) are used instead of flat pasted plates and electrolyte absorbed in silica gel is used instead of absorptive glass mats. The battery is sealed just like AGM & requires no maintenance topping up with water.

Figure 27 12V VRLA battery with gel electrolyte (source: OEM)

While the charge voltage regulation- as in AGM VRLA above remains as a limitation, the tubular positive plates provide a high cycle life as expected in flooded tubular batteries-that is 1200 cycles or more at 80% D.O.D, 2500 cycles at 50% and 5000 cycles at 20% D.O.D. These expected life cycles are for 2 volt designs, while for 12 volt monoblock batteries-it could be lower-if proportion of plate thickness & quantity of electrolyte are lesser than the 2 volt counterparts.

(a) Since these are not electrolyte starved design like AGM batteries, deep discharges up to 80% are allowed since recharging is not a problem. (b) The other advantage is its ability to withstand higher temperatures as compared to AGM VRLA due to excess water in electrolyte which acts as a heat sink (c) The recharge acceptance was found to be highest & capacity drop on cycling at 80% D.O.D lowest among flooded, AGM, GEL & Lead carbon batteries. Bar chart shows an 11% capacity drop in 21 cycles which is much less than over 20% capacity loss observed for flooded tubular batteries or AGM batteries.

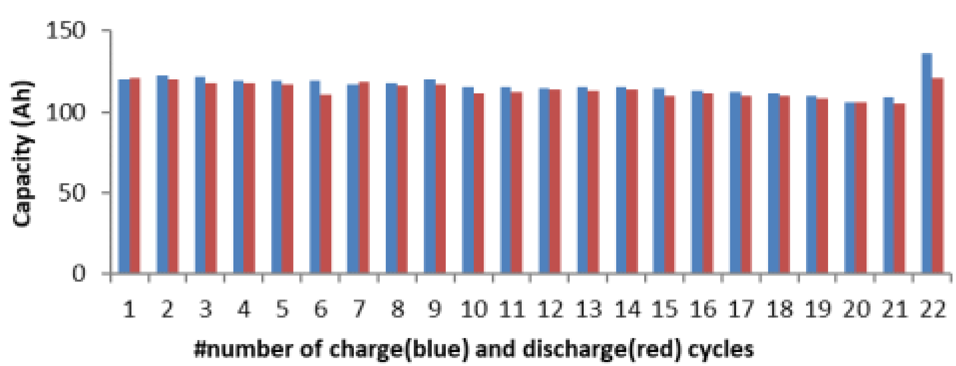

Figure 28 Capacity drop in a gel tubular battery during sola PV cycling at 80% DOD (source: CES)

Lead Carbon VRLA battery: Lead Carbon battery is similar to AGM VRLA battery- with a difference that the negative plates have a carbon foam grid which is supposed to aid in very efficient charge and discharge due to the excellent current conductivity carbon as compared to the lead antimony or lead calcium used in other batteries. Tests results in Figure 29 on lead carbon batteries available in the market did not yield any encouraging results and hence this product is not being dealt with in the manual at this stage. The concept is promising- however, market awaits suitable products after further developments in this technology or manufacturing process.

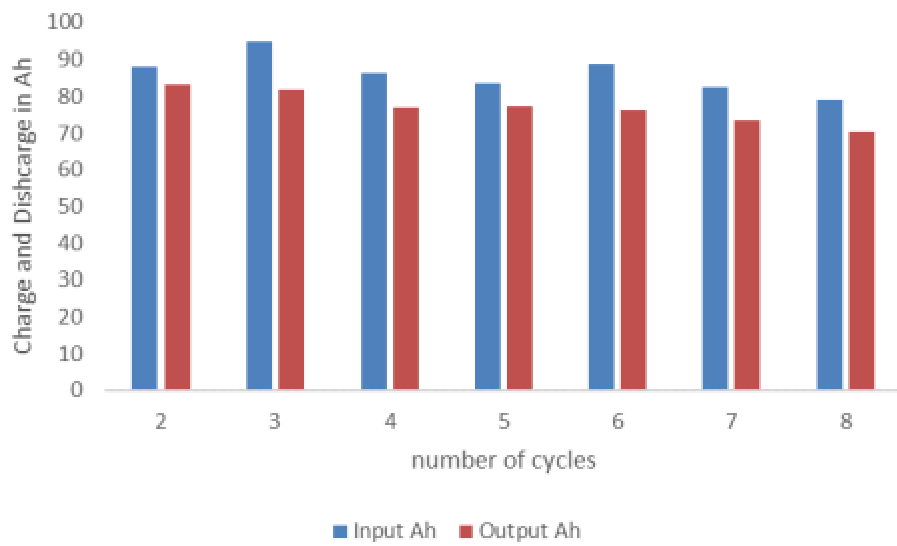

Figure 29 Capacity Degradation for Lead Carbon battery at 80% DOD cycles (source: CES)

4. Factors affecting energy output from SPV & Battery

Solar Charge controllers

In order to maximize the energy from solar array the battery input has to be controlled for maximum charge acceptance and other electrical losses to be minimized. Specific functions of charge controllers & their voltage/current settings are most important for maximizing power plant and battery output.

SPV Capacity sizing

It is seen that solar array capacity is decided- considering the daily energy consumption by the electrical loads. Correct way is to decide the battery capacity- based on daily energy consumption by electrical loads & size the solar capacity on the energy needed to recharge the battery every day.

Cleaning of Solar PV Panels

While conducting tests at the laboratory and at the site, it was noticed that dust on solar panels had an impact on battery output. At our college roof top test installation- at similar irradiance and temperature, the solar panels with 45 days of accumulated dust provided 6% less output than that from the clean panels. At the actual ground level sites, the reduction in the solar generation was observed to be over 12% for same period of accumulated dust. Hence for ensuring that the batteries do not stay at partial state of charge especially during the cloudy days, the cleaning of panel at regular interval need to be done. Frequency of cleaning would depend on site to site. In some of the sites close to paddy field, an over 5% drop in output was observed within a week's time. Hence during the harvest season in such sites- cleaning should be carried out at least once per week. Figure 30 (picture on left) demonstrates cleaning of panel at a rural microgrid-though in not a very ideal way- while the right hand picture is that of the solar panels installed on the roof of the college laboratory.

Figure 30 Cleaning of solar PV panel at a rural micro-grid and at solar rooftop PV plant (source: CES)

Sizing of DC Cables to Charge Controller

Size of the DC cable connecting solar panels to the charger controller also need to be optimized for the reduction in the loses which should be kept under 3 % in ideal cases as per guidelines of several tenders.

Table 2 Solar DC Cable Ratings as per IS 694 and IS 1554 part 1

Cross section area (mm^2)	Max Copper Resistance @ 20 degree centigrade (Ohms/km)	DC Current rating as per 2 cables adjacent on surface (Amperes)	Max Volt drop / (Ampere. meter) (m Volt per A.m) at 20 degree at rated current

6	3.3	51	3.29
10	1.91	71	1.91
16	1.21	95	1.21
25	0.78	120	0.78
35	0.554	153	0.56
50	0.386	202	0.39

Required Functions of Charge Controller & optimal settings

One of the most critical component in a solar power plant with batteries is the charge controller-and its vital functions apart from stopping reverse flow are (i) Regulating the charging voltage to save battery from overcharge/gassing (ii) Voltage regulation to prevent undercharge & capacity loss of battery (iii) Protect battery from deep discharge (iv) Ensure maximum charging efficiency & (v) Provide periodic rejuvenation treatment to prevent capacity deterioration & obtaining full service life from battery. Careful selection of CCU with these specifications and using these functions will result in full output & life of the SPV plant & battery.

Unfortunately, most of the known brands in the market do not have these functions as - observed during our project analysis. Buyer/User should specify these requirements for the solar charge controller.

Over-charge – It's Effect & Protection by charge controller:

The charging curves shown in Figure 31 and Figure 32-depict the increase in voltage with time & state of charge- for flooded (Tubular & pasted plate) & VRLA (AGM and Gel Tubular) batteries respectively.

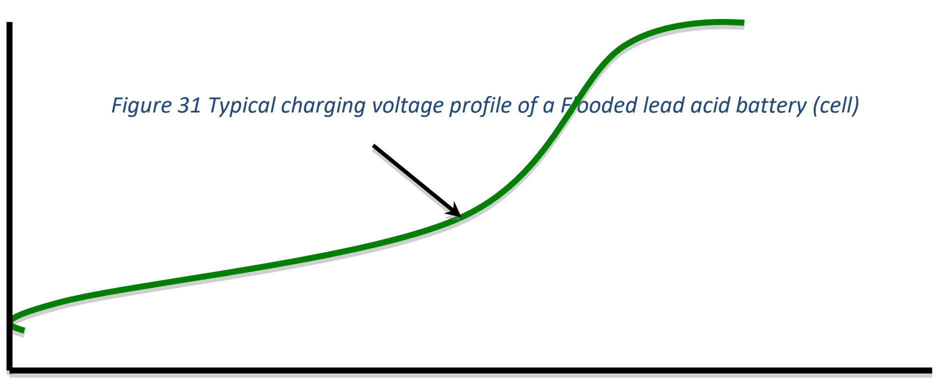

Figure 31 Typical charging voltage profile of a Flooded lead acid battery (cell)

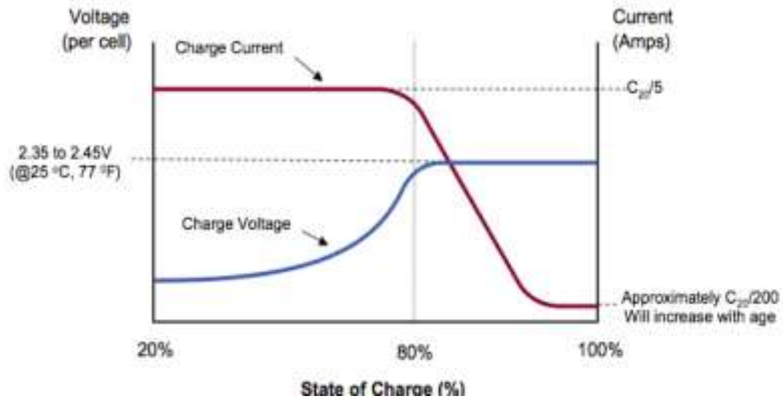

Figure 32 Typical charging voltage profile of a VRLA Battery (cell)

Both the above indicate a slow rise in voltage as the battery gets charged up to 80% of its capacity after which there is a rapid increase in voltage if charging is continued at the same rate.

It means that the charge acceptance by the battery is extremely good till it reaches 80% state of charge and much lower thereafter- which causes voltage to rise sharply. The knee of this curve is known as gassing point where electrolysis and large scale gas evolution starts. This is the regulation point for solar charge controller to limit voltage & current so that excess supply does not (a) cause gassing (b) generate heat.

The bar charts in Figure 59 is an illustration of daily over charge to some extent due to the higher setting of maximum charge voltage-above the ideal regulation voltage. The extra energy input- is not accepted by the battery in the form of charge which can be seen from the difference between the charge input & output. This causes gassing & temperature rise - and early failure of battery- depending on extent of over charge. Proper regulation voltage setting as illustrated in Figure 49 causes no overcharge.

Controller failure to avoid Overcharge leads to Corrosion & plate shedding: Charge controller should protect battery from overcharging. An -increase in temperature- caus-ses plate deformation, corrosion & shedding of active material as shown in the earlier picture. The battery loses its capacity and develops internal short circuits caused by shedded active material which can bridge the positive and negative plates.

Controller to avoid Excessive Gassing : The terms- gassing and over charge ha-s - been explained earlier in this manual. With excessive gassing in flooded batteries- there is high degree of water loss. In VRLA batteries, excessive gassing causes permanent water loss leading to capacity reduction and early failure. It also generates high gas pressure inside batteries causing them to bulge, as shown below.

Figure 33 Bulging of Battery with Over Charging

Deciding Regulation Voltage of solar charge controller: Ideal regulation voltage in a solar charge controller is that, which neither allows over charge nor does it keep the battery under charged. Manufacturers indicate gassing voltage at 2.25 Volts per cell & 2.35 volts/cell respectively-for VRLA & Flooded batteries. These voltage settings are good for a full recharge when batteries are charged 24 hours in a day as in Inverters and UPS systems. In solar application, if batteries are even discharged by 30% to 40% regularly- it is safe to set the regulation voltage at 2.35 Volts/Cell and 2.45 volts/cell respectively. F-For VRLA & Flooded batteries respectively, since the solar charging time is only 7 to 8 hours/day. Battery picks up charge quickly without any overcharge in limited available time.

Most standard charge controllers regulate at 2.25 Vpc. During prolonged tests on charge controllers available in the market, it was found that most of them regulate the solar charging voltage at 2.25 Vpc. As a result, batteries are never fully charged and major part of the solar power in the 2nd half of the day is mostly wasted since controller starts regulating or restricting the charge. Hence the following table can be used to determine the charging cut-off voltage for off-grid solar power plants where at least 30% to 40% of the battery capacity is used every day. It is not for solar power plants which are hardly used.

Table 3 Charging Cut-off voltage setting for VRLA and Flooded Batteries in Off-grid solar PV plants

Battery Bank Voltage (V)	Charging Cut-off Voltage (V)	
	VRLA	Flooded

12	14.1	14.7
24	28.2	29.4
48	56.4	58.8
96	112.8	117.6
120	141	147
240	282	294
360	423	441

Controller voltage setting causing undercharge & its effect: When solar PV recharge provides lesser energy than that was discharged from the battery (recharge AH = discharge AH + 10%), it is known as under-charging and results in progressively lower output from the battery. It mostly happens if solar controller charge voltage setting is lower than proper regulation voltage. It may also happen if the solar array has inadequate capacity to meet the daily discharge cycles of the battery. Continuous undercharging causes permanent capacity loss of battery due to hard sulfation in plates.

Figure 34 illustrates how undercharging takes place. The charging during cycle 1 to cycle 22 has been carried out with proper regulation voltage. During cycling, a small capacity reduction has taken place as usual, after which, an equalizing charge brings back full capacity to the battery. Thereafter, discharge-recharge cycle is carried out by setting the controller voltage at 2.25 volts/cell as against 2.4 volts/cell earlier and the battery charge acceptance is seen to fall drastically – a case of undercharging. Most of the charge controllers, both MPPT and PWM, available in the market have a voltage of 2.25vpc.

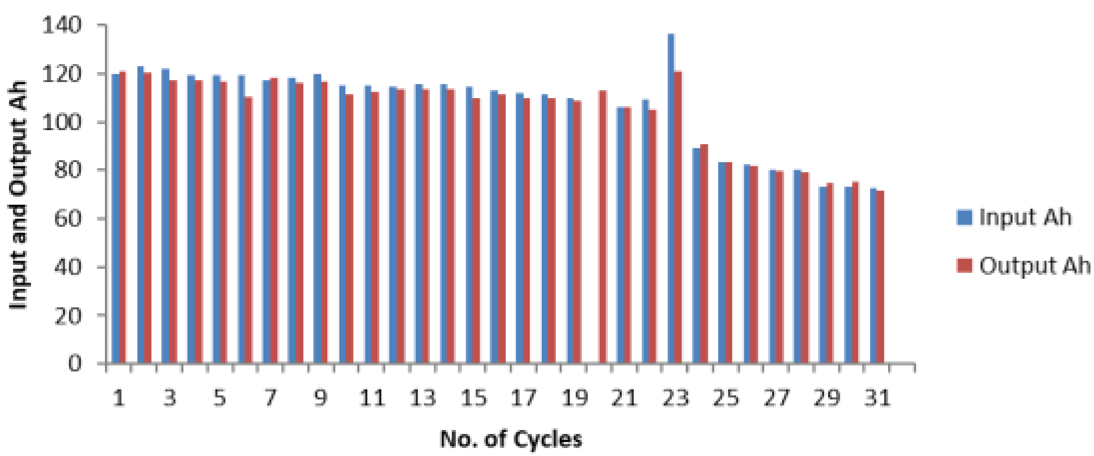

Figure 34 Faster degradation of capacity due to undercharging from cycle 24 to 31 (source: CES)

While deciding the charging regulation voltage in the solar charge controller, with caution it should be noticed that it is not same for all types of lead acid batteries.

Controller/ Inverter protection to avoid Deep discharge of battery – Its effect: Deep discharge phenomenon and its reason has been already explained earlier. As explained above, this occurs due to wrong discharge cut off voltage settings in the inverter or the controller. Slow discharge can deeply discharge a battery and just any cut off voltage setting will not do as can be seen from Figure 35. Normally, inverters have discharge cut off protection, but if it's improper, controller has to do the job.

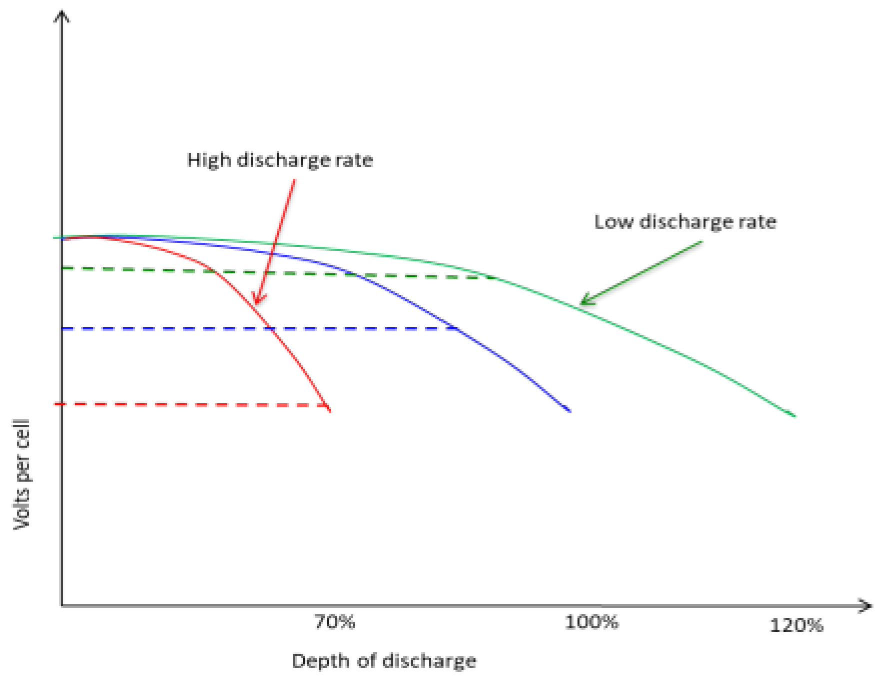

Figure 35 Different cut-off voltage to be set at different rate of discharge

Large number of failures due to deep discharge: There are innumerable cases where off grid solar users have observed that battery does not pick up charge even after prolonged solar charging. These are almost always, due to deep discharge as explained above. To avoid this problem, this manual has provided instructions and data (please see the voltage versus time curves at various rates of discharge as given later) for setting cut off voltage as per the loading of the plant during the night time. The process for recovering from a deep discharge failure is also explained in O&M portion later.

PWM Charging for regulation:

The regulation voltage can be maintained by pulse width modulation of charging as shown in Figure 36. Duration or pulse-width of current is reduced when the battery voltage is above & increased when it is below the set regulation voltage, in order to keep the average voltage within regulation limits. For efficient use of power during last 20% charging, PWM is to be used, even for MPPT controllers.

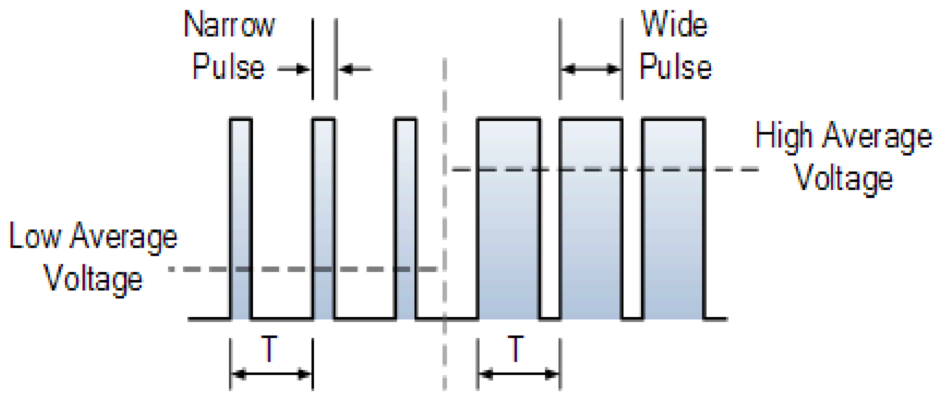

Figure 36 Pulse width modulation scheme for charge regulation of batteries

Controller to ensure Max Battery Charging Efficiency: Figure 31 and Figure 32 clearly demonstrates high current acceptance of batteries in discharged state which reduces progressively as the gassing voltage or 80% state of charge is approached. This is confirmed by BIS 6497 (solar batteries) which pegs the Ah efficiency higher than 95% for a battery at less than 50% state of charge.

Hence, most efficient use of solar battery charging is possible in the first few hours of the day till battery picks up 70-80% of required charge. Thereafter, even if the solar radiation is high, the battery cannot accept the high charging currents & most of the solar power is wasted. It is a good idea to use solar power only for battery charging, till the regulation voltage is reached, after which, the excess solar output can be used for daytime use equipment like water pumps, wheat grinder, grid export etc.

Depending on the site location, time of the year, the night time electrical loads & solar & battery capacity, we can provide a chart indicating (a) the time required for battery recharge (b) the extent of excess power available in the later part of the day, on an hourly basis.

Maximum Charging efficiency available in MPPT charge controllers:

To understand the output from different charge controllers, commonly available solar charge controllers of well known brands were tested for daily output under the same cycling conditions -The MPPT controllers were found to provide between 20% extra charging energy (Watt Hours) up to 80% state of charge of the battery. Figure 38 illustrates the time variation of power input by a MPPT & a PWM charge controller under same solar radiation & battery condition.

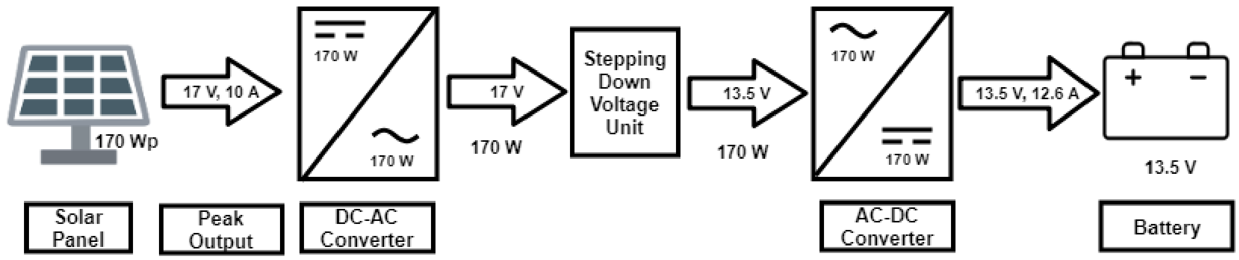

Figure 37 Block Diagram representing components of MPPT in a solar PV plant (source: CES)

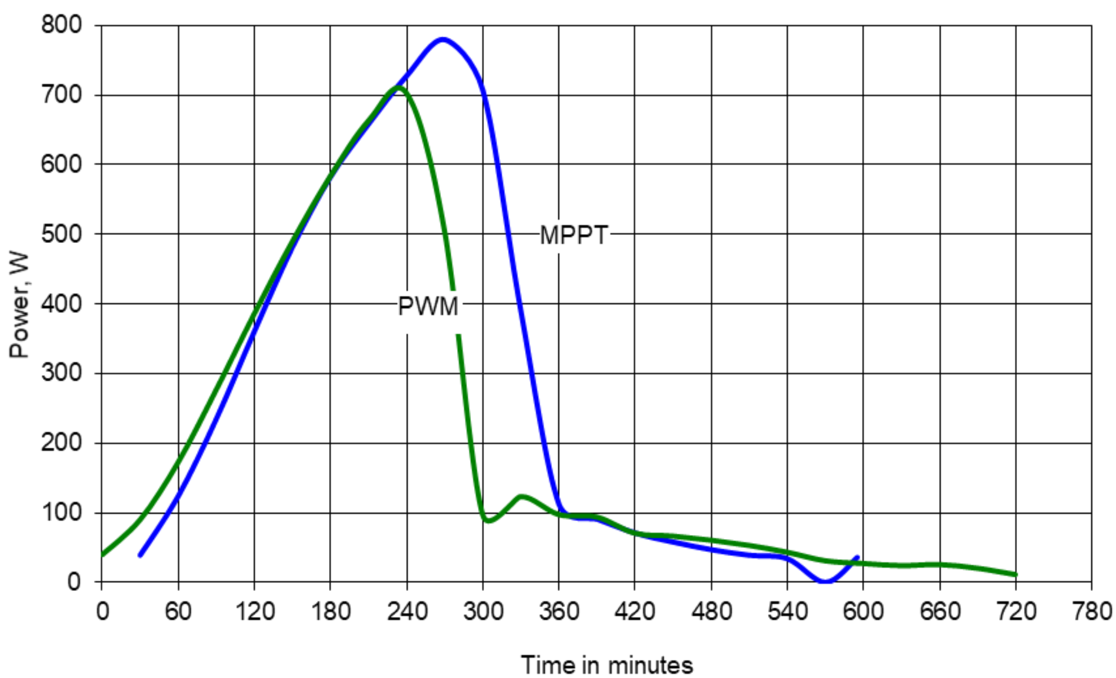

Figure 38 Comparison of power input to battery from PWM and MPPT Charge Controller (source: Experiment conducted by CES at PCCOE lab)

Table 4 Comparison of average energy generation (battery input) When charging through MPPT and PWM controllers

Sr no	**Date**	**Battery 1 (MPPT Charge Controller) Wh Input**	**Battery 2 (PWM Charge Controller) Wh Input**
1	12/04/2018	2927.120	2503.735
2	14/04/2018	2944.706	2361.462
3	18/04/2018	2998.351	2553.870
4	20/04/2018	2929.470	2412.976
	Average Wh Input	**2949.9**	**2458.0**

The MPPT controller however, cuts off charge after reaching regulation point of 2.25 V per cell while the PWM controller continued charging even at 2.25 V per cell. If the MPPT charge controller had a PWM mode operating after the regulation voltage- then its output would have been even more.

Periodic charge by controller to prevent capacity deterioration & early failure of battery:

This vital function of the controller is done by carrying out periodic equalizing charge on the battery- The periodicity & duration depends on the extent of discharge and the battery undergoes in every cycle. As seen in the cycling duty bar charts above-capacity of any battery goes down progressively on cycling in solar power plants. It is seen that batteries that are discharged more in each cycle, the capacity reduction is faster. Some types of batteries were found to function better in solar plant cycling duty & lose capacity at a much slower rate than others.

In any case, the batteries need to get a periodic equalizing charge (phenomenon explained earlier in the manual) in order to regain the full capacity. However, it was found that many of the commercially available charge controllers did not have an equalization mode. Charge controllers which have an equalizing mode, are also not found very useful- since- they either switched off the equalizing charge after 1 or 2 hours or are more sophisticated ones have a pre settable equalizing mode for starting the process but none to ensure that the process stops only after the operation is completed properly.

It is strongly recommended to use a charge controller which can provide equalization for long hours. It can be seen from the cycling bar charts that equalizing charge process takes additional 8 to 10 hours after the battery is fully charged by normal charge setting in the controller. This will mean almost 2 days of continuously charging - the battery without any discharge. However it is possible- without discontinuing the night time power supply- This is explained in detail in the part equalizing -charge in the O&M chapter.

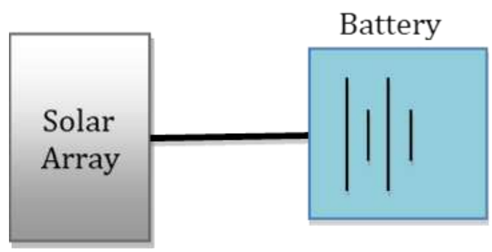

Figure 39 Initial Condition of the battery

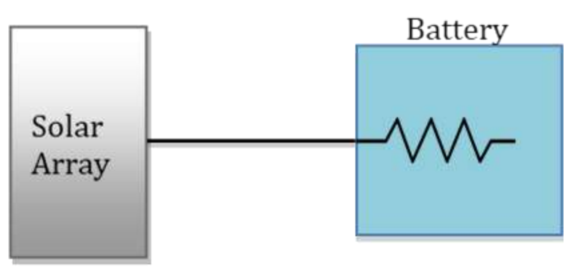

Figure 40 Increase in resistance with time due to sulfation & no equalizing charge

Hard Sulfation in the absence of periodic equalizing & its effect: The battery slowly deteriorates in its capacity since lead sulfate accumulates in place of the active material in the battery plates. The picture of a sulfated plate of battery shown earlier in the manual illustrates how- the internal resistance of the battery increases. Increase in internal resistance reduces the power supply from the solar PV resulting in lower output from solar and further reduction in battery capacity & increase in hard sulfation. It is a vicious cycle and most of the solar power plants lose almost 50% to 60% of their output in 3 to 4 years. By 5th year, the battery would have failed- quite unnecessarily. Such old & sulfated batteries also can be revived- if they are not too old and some successful operations done in the field are also explained.

5. System Designing & Sizing

In this manual, we have provided required life, performance and charge acceptance information about each type of battery earlier. The judgment of selecting the right type of battery under different location, space, serviceability & price conditions is left to the buyer or user. One should however- always pre check the quality of products as per the guidelines given in this manual- like- actual capacity, cycle life, discharge performance, recharge efficiency, retention of charge, size and weight etcetera.

Selecting the Right capacity battery for given electrical loads

Stationary batteries rated at C10 will provide full capacity when discharged in 10 hours but different Ah or Wh output at other rates of discharge. Battery capacity for required duration can be calculated- using Table 1. However, calculating battery capacity from voltage Vs time discharge curves provide more accurate results since they relate to the end of discharge voltage also. The discharge curves in Figure 41 and Figure 40 were obtained during preparation of this manual by capacity tests on 12 volts monoblock flooded tubular batteries & Gel tubular batteries respectively. These curves show the drop in voltage over time for 12 volt batteries converted to 2 V cell level for various discharge rates. The curves in Figure 40 have been used for explaining capacity calculation later.

For example (a) 0.05C means a discharge in amperes which is 0.05 X Capacity of battery. Hence, if the battery capacity is 100 AH, the discharge curve in this case is for 0.05 X 100 = 5 Amperes (b) Similarly, 0.1C discharge rate for this 100Ah battery = 0.1 X 100 = 10 Amperes & (c) 0.15C = 0.15 X 100 = 15 Amperes and so forth.

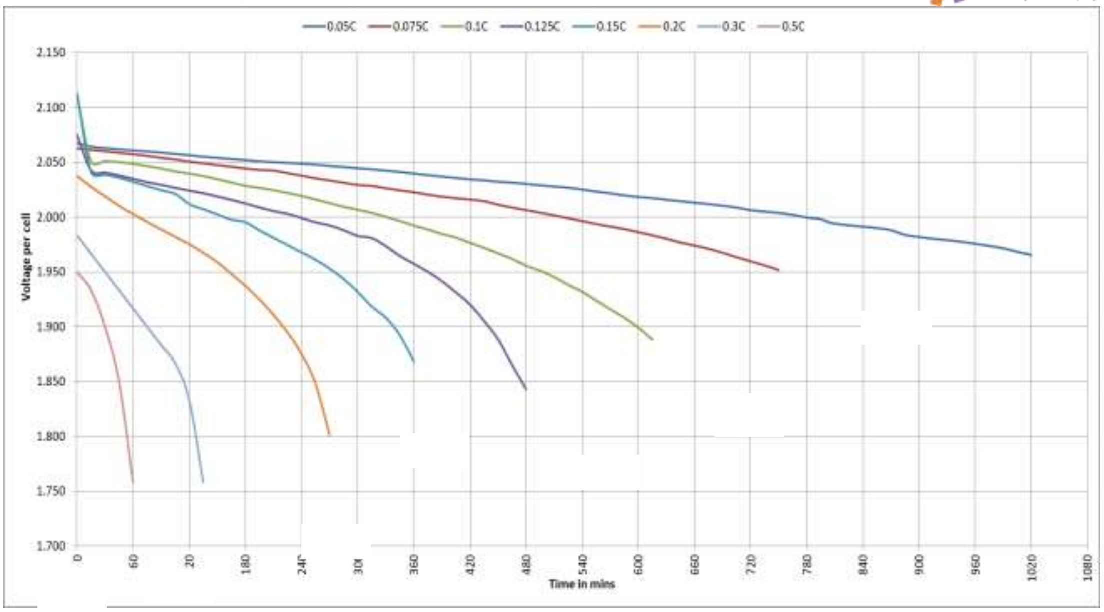

Figure 41 Discharge characteristics of Flooded Lead Acid Battery from capacity tests

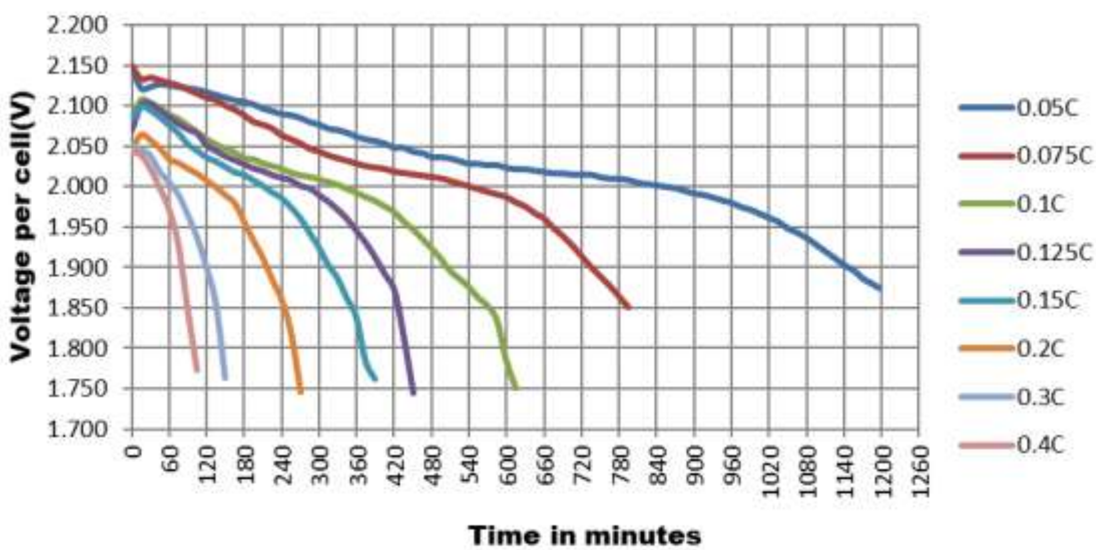

Figure 42 Discharge characteristics of Gel tubular Battery from capacity tests

(c) If the discharge current, its duration and the lowest permissible or cut off voltage on discharge is known, the required capacity of a battery or cell can be calculated. The user can ask for similar discharge curves for specific batteries or cells from the battery manufacturers.

Example 3:

The power required from a 48 Volts battery is 700 watts for a duration of 5 hours & 30 minutes. The discharge cut off voltage of inverter is 45.6 Volts. What is battery capacity required for this load?

Battery is sized by using following steps:

Step1: Determine the maximum current output from battery = 700W ÷ 45.6V = 15.3 Amperes

(Note: Maximum current is drawn when voltage is lowest during discharge)

Step 2: Determine the discharge cut off voltage. It is 45.6 Volts ÷ 24 cells = 1.9 volts/cell

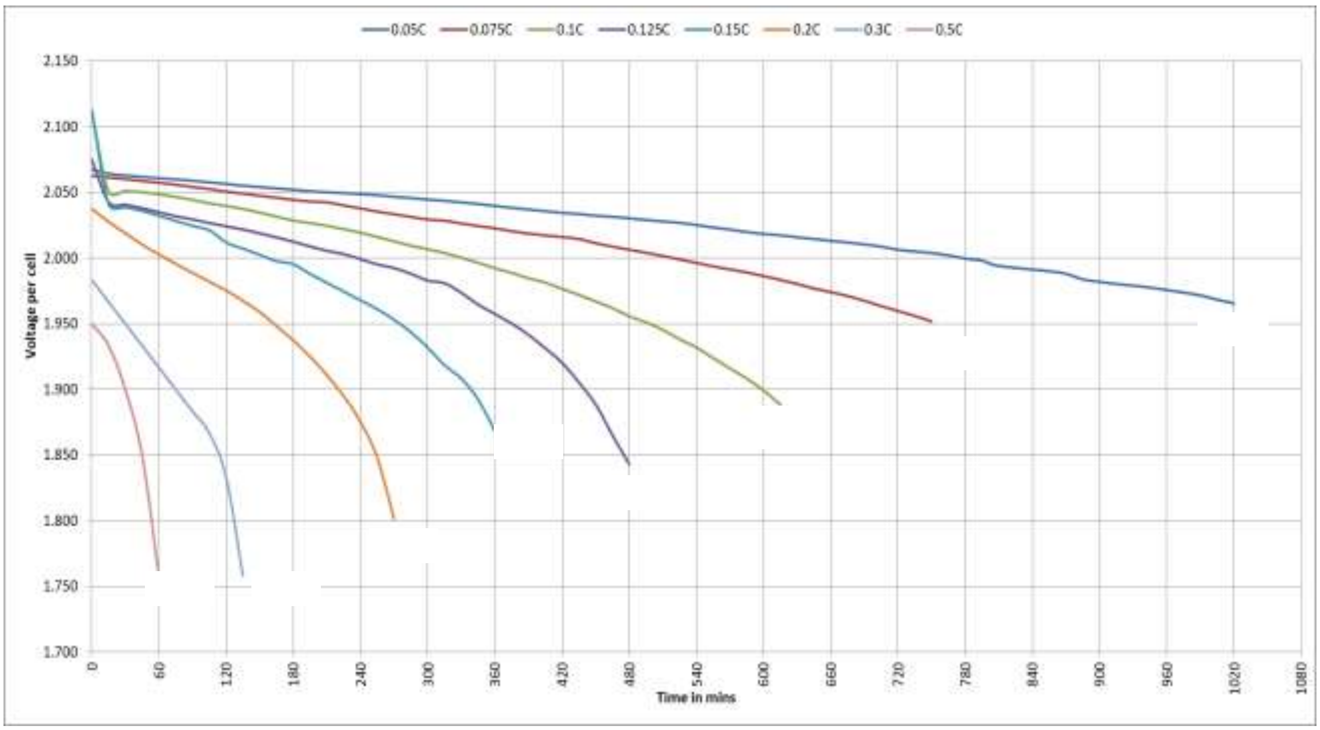

Figure 43 Battery sizing using discharge characteristics of 12 V Flooded lead Acid Battery

<u>Step 3</u>: Using the Voltage Vs Time discharge curve in figure 30 above, a vertical line is drawn from the point of 5 hours 30 minutes (330 minutes) in the X axis. Then a horizontal line from 1.9 volts/cell in the Y axis needs to be drawn. The discharge curve which is nearest to the meeting point of the vertical & horizontal line should be selected as discharge rate requirement. Here, it is the 0.15C rate of discharge curve, C being the capacity of battery & 0.15C the discharge rate in amps.

Step 4: The required rate of discharge is 15.3A as calculated in step 1 and also 0.15C of battery as found from the time vs. voltage discharge curve. So 0.15C = 15.3 Amps. Hence, C (Capacity of battery at C10) = 15.3/ 0.15 = 102 AH @ C10. Considering the nearest available capacity, the battery required is 48V100AH @ C10, or, capacity in terms of energy storage, is 4.8 kWh.

Step 5: A flooded battery or VRLA cannot be discharged more than 80% & 50% of their capacity respectively. Here, the discharge is 15.3A X 5.5 Hrs. = 84 AH. Therefore, the minimum capacity of flooded battery = 84AH ÷ 0.8 = 105AH or near about available capacity. The VRLA battery minimum capacity would be 84AH ÷ 0.5 = 168AH or near about available capacity

Example 4: The power required from a 240 Volts battery is 15 kW for a duration of 2 hours & 30 minutes. The discharge cut off voltage of inverter is 222 Volts. What is the battery capacity required for this electrical load?

Step1: Determine the maximum current from battery = 15000W/ 222V = 67.5 Amperes.

Step 2: The lowest /cut off voltage on discharge is 222 Volts/ 120 cells = 1.85 Vpc

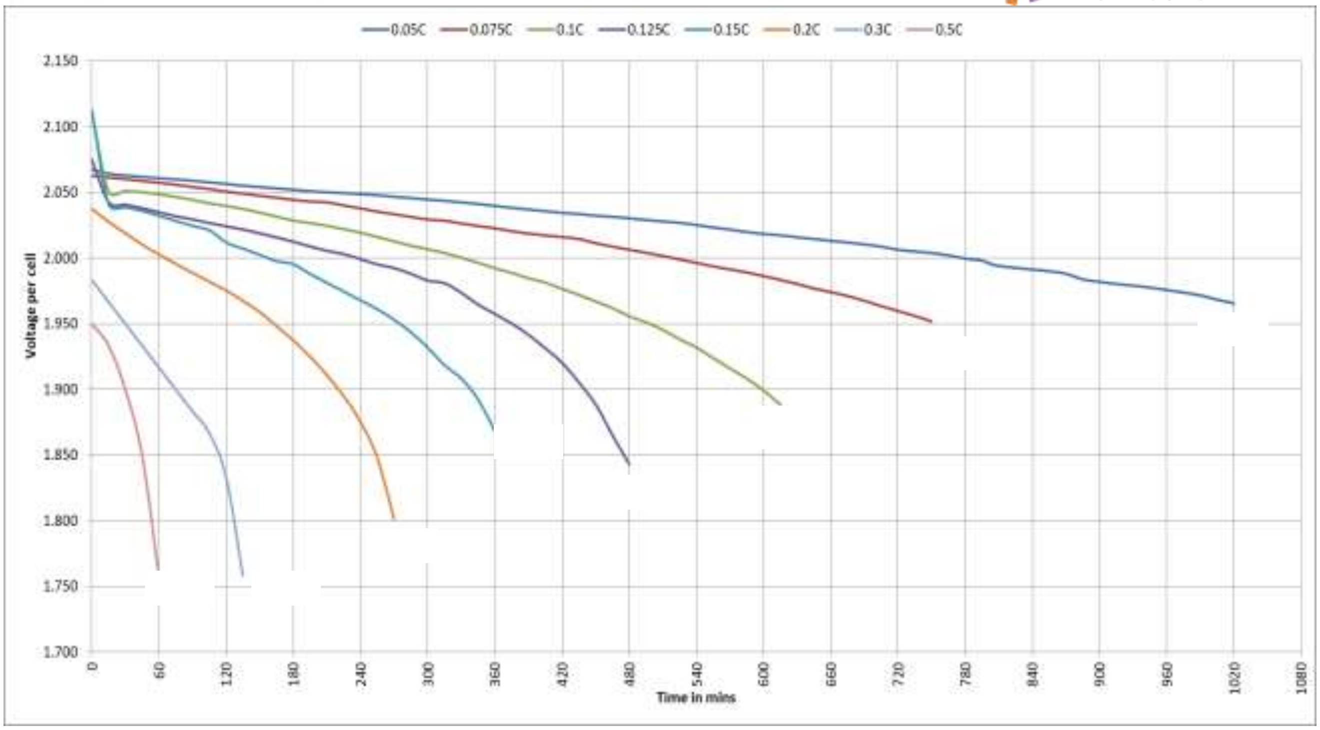

Figure 44 Battery sizing using discharge characteristics of 12 V Flooded lead Acid Battery for Example 2

Step 3: Using the Voltage Vs Time discharge curve in Figure 44, a vertical line from the point of 2 hours 30 minutes (150 minutes) in the X axis needs to drawn. Similarly, a horizontal line from 1.85 volts/cell in the Y axis needs to be drawn. As the point of intersection is determined, the nearest curve on the right should be chosen. Here, it is 0.2C discharge curve.

Step 4: The required rate of discharge is 0.2C of battery. So 0.2C = 67.5 Amps. Hence, C (Capacity of battery at C10) = 67.5/ 0.2 = 337 AH @ C10. Considering the nearest available capacity, the battery required is 240V 350AH.

Step 5**:** Assuming it is a flooded battery, check if the discharge is within 80% D.O.D limits. Here discharge = 67.5A X 2.5 Hrs. = 169AH. So, considering 80% D.O.D, minimum battery capacity should be 169AH ÷ 0.8 = 211AH. Designed battery capacity is well above the safe limits & OK.

Example 5: Calculating battery capacity for staggered power supply: Find out capacity for a 48V battery in solar power plant where Inverter discharge cut off voltage is at 45.6 Volts and loads are:

* 2KW Wheat grinder runs from 8AM to 12PM (4 Hrs)

* 1.5 KW water pump runs from 12PM to 6PM (6 Hrs)

* 50 X 20W CFL lights operate from 6PM to 12AM (6 Hrs)

* All power supply are from the battery based inverter

* The Max & min daily average temp. here are 35°C & 15°C respectively during summer and winter.

Step 1: Calculate the discharge rates (current) in each case:

For 2KW Wheat grinder, the discharge rate = 2000W ÷ 45.6V = 43.8A

For 1.5 KW water pump, the discharge rate = 1500W ÷ 45.6V = 32.9A

50 X 20W CFL lights, the discharge rate = 1000W ÷ 45.6V = 21.9A

Step 2: Prepare load chart with duration & cut off voltages as shown in Table 5.

Table 5 Typical Load Chart for calculation of battery capacity

Duration in Hours	Load in Amperes	Cut-off Volt/Cell	Capacity reqd. AH	AH Cap available	AH Cap to be added	AH Cap utilized	Residual Cap AH
4	43.8	1.9					
6	32.9	1.9					
6	21.9	1.9					
Total							

Step 3: Calculate battery capacity required for first load cycle from discharge curve in Figure 45

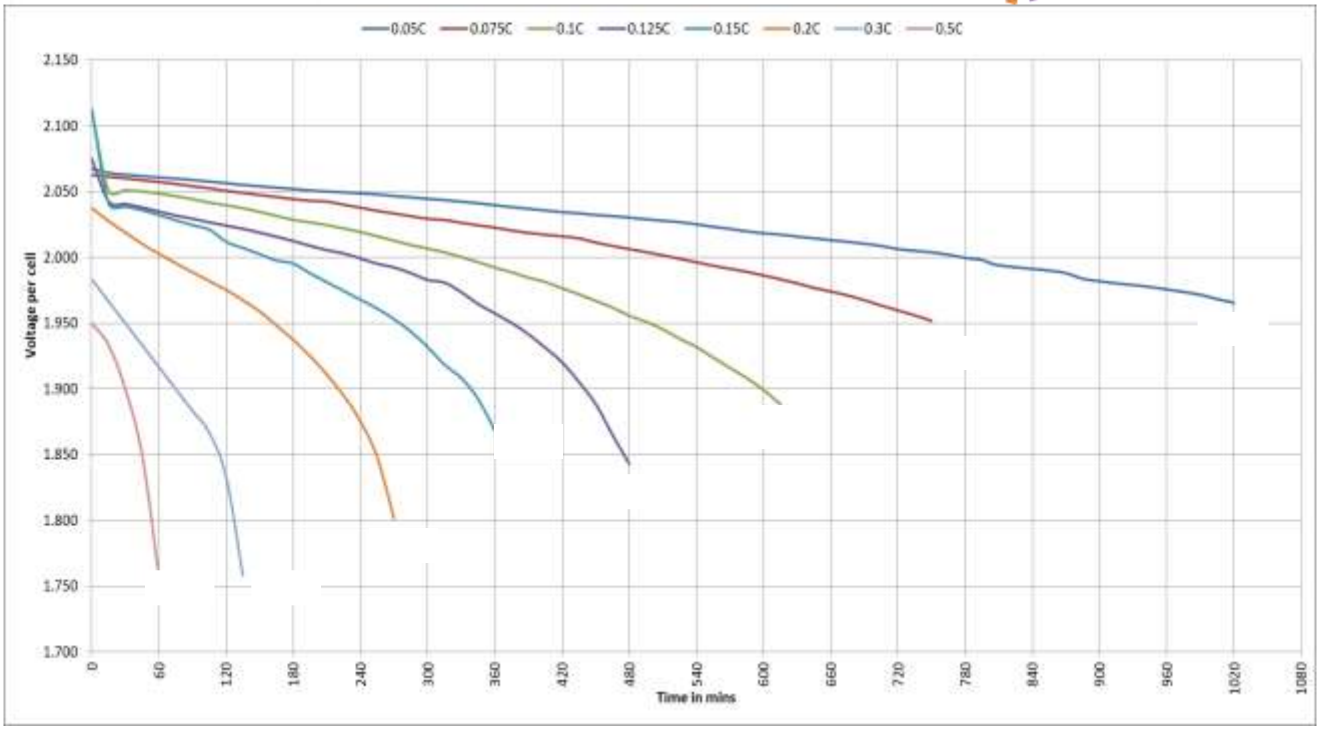

Figure 45 Battery sizing using discharge characteristics of 12 V Flooded lead Acid Battery for Example 3

For 4 hours discharge (240 min) to end voltage of 1.9 VPC, nearest discharge curve is 0.2C. Since actual discharge required = 43.8 Amps = 0.2C, the battery capacity required for the first load cycle C = 43.8 ÷ 0.2 = 219 AH @ C10. The first load cycle is filled in the load chart as shown in .

Table 6 Load Chart for calculation of battery capacity

Duration in Hours	Load in Amperes	Cut off Volt/Cell	Capacity reqd. AH	AH Cap available	AH Cap to be added	AH Cap utilized	Residual Cap AH
4	43.8	1.9	219	0	219 (219 – 0)	175.2 (4X43.8)	43.8 (219- 175.2)
6	32.9	1.9					
6	21.9	1.9					

(Note: The residual capacity becomes the available capacity for next load cycle)

Step 4: Calculate battery capacity required for 2nd load cycle from discharge curve & fill in load chart as in Table 5(b). At 6 hours discharge, the nearest curve is 0.15C. So, battery capacity required for this load cycle C = 32.9 /0.15 = 219Ah @C10

Table 7 Load Chart for calculation of battery capacity

Duration in Hours	Load in Amperes	Cut off Volt/Cell	Capacity reqd. AH	AH Cap available	AH Cap to be added	AH Cap utilized	Residual Cap AH
4	43.8	1.9	219	0	219 (219 – 0)	175.2 (4X43.8)	43.8 (219 - 175.2)
6	32.9	1.9	219	43.8	175.2 (219 – 43.8)	197.4 (6X32.9)	21.6 (219 – 197.4)
6	21.9	1.9					

Step 5: Calculate battery capacity required for 3rd load cycle from discharge curve & fill in the load chart as in Table 8. At 6 hours discharge, the nearest curve is 0.15 C. So, battery capacity required for this load cycle C = 21.9 ÷ 0.15 = 146Ah @C10

Table 8 Load Chart for calculation of battery capacity

Duration in Hours	Load in Amperes	Cut off Volt/Cell	Capacity reqd. AH	AH Cap available	AH Cap to be added	AH Cap utilized	Residual Cap AH
4	43.8	1.9	219	0	219 (219 – 0)	175.2 (4X43.8)	43.8 (219-175.2)
6	32.9	1.9	219	43.8	175.2 (219 – 43.8)	197.4 (6X32.9)	21.6 (219 – 197.4)
6	21.9	1.9	146	21.6	124.4	131.4	14.6

Step 6: Therefore Battery capacity required for meeting all the 3 staggered loads is:

Table 9 Load Chart for calculation of battery capacity

Duration in Hours	Load in Amperes	Cut off Volt/Cell	Capacity reqd. AH	AH Cap available	AH Cap to be added	AH Cap utilized	Residual Cap AH
4	43.8	1.9	219	0	219	175.2	43.8
6	32.9	1.9	219	43.8	175.2	197.4	21.6
6	21.9	1.9	146	21.6	124.4	131.4	14.6

Battery Capacity required	**518.6**	504	

Step 7: We arrive at a battery capacity of 518.6 Ah @ C10 with a residual capacity of 14.6 Ah remaining after all the 3 steps of discharge. We have explained, it's detrimental to discharge a flooded tubular battery beyond 80% of its rated capacity or- there should be 20% residual capacity left in the battery.

The 14.6 Ah residual capacity is much lower than 20% of capacity of 518.6Ah after discharge of 504 Ah. Hence, a safe capacity sizing would be 504 Ah ÷ 0.8 = 630 Ah @C10

For 2 or 3 days energy storage, multiply battery capacity by 2 or 3 respectively and final capacity will be 1260Ah or 1890Ah. Some even ask for 5 days storage-but- bigger the battery capacity, higher the self discharge losses as explained earlier. The 10% loss/month rises to 30%/month or, 1% per day as battery ages. So, for a 5 day storage, the loss is 5% per day. Better to select around 2 day's storage.

Temperature Compensation (Step 8): The standard temperature for full/rated capacity of battery is 27° Celsius. For every 1°C drop in temperature, the available battery capacity is reduced by 0.5%.

In this case, lowest average temperature being 15°C, the battery capacity will be reduced by (27°C - 15°C) X 0.5% = 6% & battery will provide 94% of its rated capacity output in winter.

In order that the battery provides full output in winter also, the capacity required is 607.7Ah ÷ 0.94 = 646.5 Ah at C10 rate and at 27°C standard temperature.

Capacity degradation/ageing factor (Step 9): Capacity of all equipment get derated as it ages. For batteries, the capacity degrades slowly- every year- till it reaches 80% of its rated capacity at the end of its service life. For critical installation, it is essential that the battery provides required energy (required power & duration of backup) till the end of its service life.

Hence, if this power plant is critical for life saving or defense etcetera, the designed capacity of the battery-considering capacity derating factor is 646.5 Ah / 0.8 = 808 Ah

Divide Battery Capacity into 2 Parallel strings (Step 10): Instead of one set of 48V 800Ah battery, plan for 2 sets of 48V 400Ah batteries to be connected in parallel as shown in Figure 46. This will allow one extra day of equalizing charge- once in a month- without disturbing the night time power supply. For more information on equalizing-kindly refer to Equalizing Charge Process part of the manual.

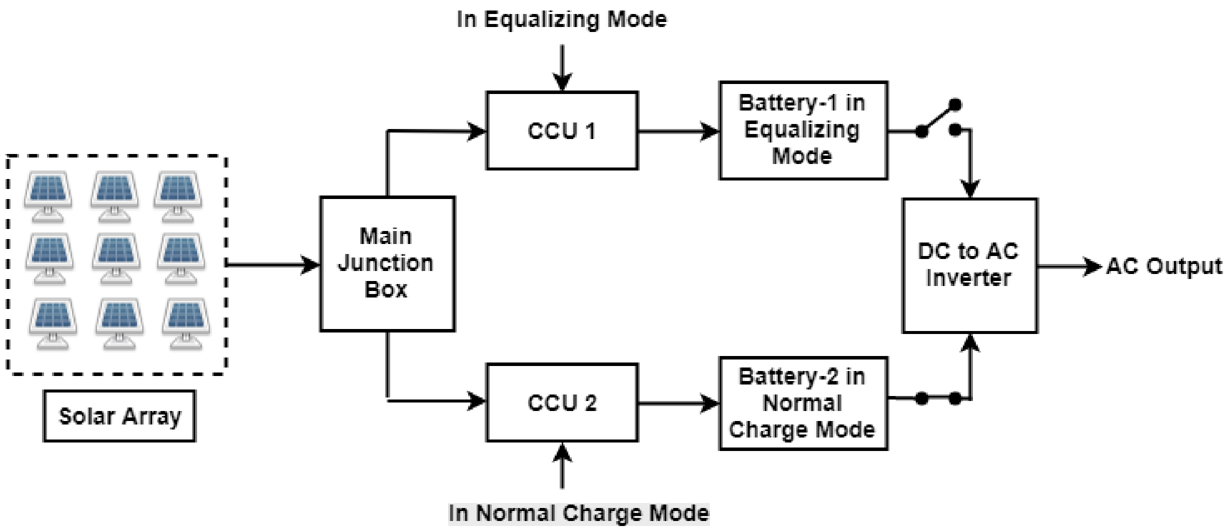

Figure 46 Paralleling of battery bank to ensure continuous power supply to grid during equalization process

Discharge Curve for VRLA Batteries

Discharge Voltage Vs Time Curve for Gel Tubular VRLA Batteries:

The following discharge curves were obtained during preparation of this manual by capacity tests on 12 volts monoblock Gel tubular batteries. These curves shows the drop in voltage normalized to 2 volt cells at various discharge rates. - It can be used in similar fashion as shown for the flooded tubular batteries- to ascertain required battery capacity.

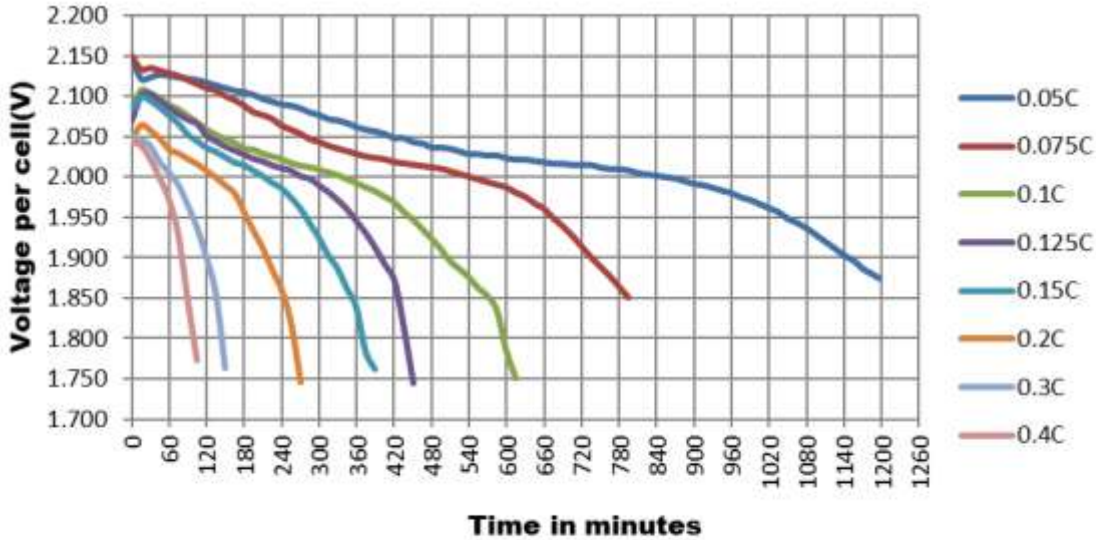

Figure 47 Voltage discharge curve of gel tubular VRLA (source: CES)

Discharge Voltage Vs Time Curve for AGM VRLA Batteries: The 12 volts AGM VRLA batteries tested by our team us didn't - showed satisfactory results since the deterioration of the capacity was quite rapid on cycling. Hence we do - not recommend- 12V VRLA AGM batteries for cycling applications. The 2 volt cells may be considered however- in specific cases.

Note of Caution: Unlike the Flooded Tubular and VRLA Gel Tubular batteries where an 80% depth of discharge is prescribed, the AGM VRLA batteries should not be discharged beyond 50% D.O.D.

Discharge Voltage Vs Time Curve for AGM VRLA Lead Carbon Batteries:

Our tests on similar batteries available in the market did not yield any encouraging results (severe capacity drop on repeated cycling duty) and hence this product is not being dealt with in the manual at this stage.

Figure 1 2.4 kWp solar PV plant at the lab (source: CES)

Figure 2 Discharging of a lead acid battery carried out at constant current at CES lab at PCCOE (source: CES)

Problems arising from incorrect battery capacity

Incorrect capacity will mean either under capacity or over capacity of the battery in relation with the total electrical energy to be supplied from it.

Problems from under capacity:

a) Battery will not provide power for required duration after a few days of operation- if the battery capacity is selected for energy storage for 1 day only. If the battery capacity has 2 to 3 days storage capacity, this energy shortage problem may arise when there are 1 or 2 sunless or very cloudy days in between. Hence, battery capacity recommended is for around 2 days storage and the solar PV capacity should be adequate for 1 day's battery recharge + 10% over capacity for recharging the battery from 2 consecutive days of discharge during rainy days.

b) If -battery is deep discharged- it will not pick up recharge in the subsequent solar days. While many flooded lead acid batteries have failed due to this, it is much more prevalent in VRLA AGM batteries. A major case in point- are the premature failure of VRLA batteries in solar lanterns. Just by avoiding deep discharge, the life of these solar lantern batteries can be extended many fold. The earlier part explains the phenomenon of deep discharge adequately.

Battery life can be reduced due to selection of lower than required capacity. Table 10 for 2V flooded tubular cells shows the life cycles of battery at various depth of discharge as shared by various lead acid manufacturers for solar application.

Table 10 Effect of DOD on cycle life (Source: Industry primaries and BIS Doc ET 11 (6497)

Depth of Discharge	Approximate number of life cycles at 27°C as presented by lead acid battery manufacturers
20%	5000
50%	2500
80%	1200
More than 80%	Drastic reduction in life (as per BIS Doc ET 11 (6497)

From the above table, it can be seen that an under capacity battery which discharges 80% of its full capacity every day- can have a life- not more than 1200 days (approx) or about 3.5 years. This life can be extended to 7 years by correct sizing so as not to discharge more than 50% of its capacity every day. Discharging beyond 80% of its capacity can have very harmful effects on the battery life.

d) Ensure battery life by selecting correct capacity:

Example: What will be the capacity of a 24 volt battery for a 5 hour daily discharge at the rate of 1000 watts, where the cut off voltage of the inverter is 22.8 Volts DC? The battery should provide a 10 years' service life.

- 10 years service life would mean 10 X 365 = 3650 life cycles

- 1000 Watts discharge for a 24V battery = 1000W ÷ 22.8V = 43.8A
- So, total discharge from battery is 43.8A X 5 Hours = 219AH/ Cycle
- 3650 cycles means half way between 5000 cycles (20% DOD) and 2500 cycles (50% DOD). Battery is not to be discharged beyond 35% D.O.D.
- Hence battery capacity required = 219AH ÷ 0.35 = 625AH @C10, in Which case, battery will be discharged 35% every cycle & will provide 10 year life.

Problems arising from over capacity

a) **Self discharge loss in battery:** Bigger the battery capacity, higher is the self discharge loss in watt hours. For example, a 10 KWh capacity flooded tubular battery energy storage will lose (10% ÷ 30 days) = 0.33% per day or, 10KWh X 0.33% = 33Wh per day. If a 20 kWh battery is used, the self discharge will be 20 X 0.33% = 66 Wh/day

As the battery ages, the self discharge loss increases and can be as high has 3 to 4 times at the end of its life. Hence, the 10 kWh battery will lose 33 Wh X 4 = 132 Wh and the 20 kWh battery will lose 66 Wh X 4 = 264 Wh/day. Too much oversizing is not recommended.

b) **Difficulty in recharge**: Battery needs a minimum charging current for - recharging. Normally, it should not be less than 3% of its capacity value in amperes. For example, a 100Ah battery needs at least 3 Amps to recharge & a 500Ah battery will need minimum 15A. These are absolute minimum figures and normally a recharge in 8 hours of solar time requires an average of 6% to 10% of its capacity in amps.

c) **Stratification of electrolyte**: Oversized batteries, as experienced, are rarely full charged with such low currents. Without full charge at any time, there will be no gassing or mixing of electrolyte and heavy electrolyte will settle at the bottom while light electrolyte floats at the top. Battery will lose its capacity.

6. Installation and Commissioning of the Batteries

This chapter will help the user in understanding procedure of installation and commissioning of batteries at solar PV plant site- This - will also cover the procedure of dispatching, reviving and storing the batteries before they are installed at the site.

Procedures for Dispatch, Receipt and Storage of Batteries

1. Batteries should leave manufacturer's factory in freshly charged condition. In case there is a substantial time gap between production and dispatch, the batteries should be subjected to one round of freshening charge. This does not apply for batteries-which are dispatched in dry and uncharged or dry charged condition.

   (Note: **Dry and uncharged** batteries have no charge and need to be filled with electrolyte and then undergo a full process of initial charging before they are used. **Dry charged** batteries are charged batteries- which get activated as soon as they are filled with electrolyte. A short first charge is then required to get them fully charged. Both these procedures are provided in the battery manufacturer's user manual.

2. All battery manufacturers provides a packing material in the battery carton for guarding against the damage to battery tops and terminals. However, a hard board placed over each layer of battery before next layer above- distributes upper layer battery weight evenly.

3. The Procedure for receiving a supply of batteries at site warehouse are as under:

   - Check for any signs of damage to the battery cartons or packing cases, shifting or falling of material before they are unloaded from the truck.
   - After unloading-open each carton or packing box for the following checks after which re seal the cartons or fix the packing box cover.

- Check and record any physical damage to the battery or its terminals.
- For flooded batteries, check the battery electrolyte level & specific gravity of each cell. If the specific gravity of the cells is lower than recommended range & also not uniform- then all the batteries must be imparted a freshening charge before they are stored or installed. Cells with low electrolyte level then need to be topped up with electrolyte of same specific gravity as in the cell.
- For dry & uncharged as well as dry charged batteries, check whether proper quantity of electrolyte and DM (de-mineralized) water is - supplied along with batteries.
- For VRLA AGM or Gel electrolyte batteries- check for presence of any electrolyte droplets or spillage on battery top at vent holes or terminals and also at the sides of the battery at the junction of lid and battery container. Such spillage is not acceptable.
- Check for any corrosion at battery terminals.
- Check open circuit voltage of charged batteries (VRLA & flooded) to ensure that battery is received fully charged condition.
- If the OCV is found to be much less than full charge OCV, batteries will need freshening charge before they are stacked/stored.
- Check quantity of accessories like fasteners, washers, cables, warranty cards and petroleum jelly delivered with the battery with the packing list & challan.

4. Batteries in a proper condition after checking are to be stacked in the warehouse- but not in too many layers so as not to put excessive weight on the bottom most layer. Again, using a hard board/ply board between layers of batteries is a good idea. A slightly raised platform- using wooden pallets is better rather than stacking on ground.

5. Do not stack the batteries along the wall of the warehouse. Keep at least 200 mm space between the battery stack and wall. This prevents electricity earth leakage through damp walls.

6. For large capacity batteries/cells above 500Ah or 700Ah, it is preferable to unload them at the site itself rather than trans-shipping from the warehouse. This reduces probable transit damage.

7. – The large capacity batteries - stored in warehouse- should be kept on wooden pallets with ground clearance- for ease of lifting them during dispatch. If cranes and hooks are used for loading or unloading, the hooks should be safely insulated from the battery terminals to avoid accident.

8. Batteries thus stored are to be supplied to the field/site on a "first in first out" or FIFO basis, such that older batteries are issued earlier than freshly received batteries. Date-wise stacks can be marked with placards for identification.

9. The battery storage should preferably be in a cool and dry place. Avoid direct sunlight on the batteries, which can cause heating. Batteries lose energy quickly at higher temperatures or if there is excessive moisture in the atmosphere.

10. If the batteries are stored for more than 3 months, check the open circuit voltages of all such batteries. Only if voltage of batteries is found to be lower than full charge OCV- say- lower by 0.05 volts per cell, the batteries will need **freshening** charge. The 12 volts VRLA (Gel & AGM) batteries have an OCV of around 12.9 to 13 volts. Hence, look for stored batteries having 12.6 volts or less open circuit voltage.

11. For large capacity VRLA/GEL batteries with multiple 2-volt cells, the full charge voltage would be around 2.15 – 2.17 volts per cell. Look for cells with 2.1 volts or lower OCV.

12. **Freshening charge** is imparted at a constant voltage of 2.35/2.4 volts per cell with a current limit of 3% of the battery capacity in amperes. For example, it will be 3 Amps or 15 Amps limit for 100Ah and 500Ah batteries respectively. For 12-volt batteries, this charge is to be continued till the battery voltage on charge- becomes constant at 14.4 volts/battery and current tapers down to 0.1/0.2 amperes for 3 consecutive hourly readings. For 2-volt cells, the voltage remains constant at 2.4 volts per cell and current is 0.1/0.3 amps for 3 consecutive hourly readings. After charging is stopped, the OCV of all cells should be near full charge value after few hours' rest.

13. The battery storage area should have openings to allow cross ventilation. This allows for dispersion of any gases from batteries and also keeps –it cool.

14. No fires,- smoking and - sparks are allowed in the battery storage area. Wearing metallic wristbands etc. while handling charged batteries- can cause heavy sparking.

15. It is preferable to provide for a tap or running water source near the location of warehouse or service station to enable immediate washing of any accidental spillage of electrolyte on the body of any workman in the battery area. Electrolyte spillage on human body irritates the skin and hence washing with ample water is recommended. Spillage in eyes will need immediate medical attention.

Procedures for Installation and Commissioning of Batteries

Flooded batteries of a solar power plant are installed in a separate battery room. VRLA batteries can be installed in a battery room or in the control room itself where the solar charge controller and inverters and various metering devices are located.

Installation

1. Battery room should be located as close as possible to the solar array/ power plant and cables cross section & cable length should be such that the D.C voltage drop from solar array to the solar charge controller/battery is not more than 3%.

2. Battery room shall be well ventilated- preferably with cross ventilation through windows. Exhaust fans can be used if there are no windows in battery room. Air ventilation disposes off any evolved hydrogen gas and also aids in cooling.

   (Note: (a) A minimum of 2 air changes/hour is recommended for vented batteries Which VRLA batteries do not require but- it is preferable to have arrangements for extreme case of overcharging due controller malfunction (b) It is preferable not to have a very low ceiling in the battery room, since hydrogen gas being lighter than air, tends to accumulate near the ceiling.

3. In hot locations, GI or asbestos sheets- if used for roofing- can raise the room temperature. Keeping the battery room cool extends the battery life.

4. **The layout drawing** for installation of the battery & connecting cables- should be prepared and suitable markings made on the battery room floor after necessary measurements. Ideally, the batteries should be installed along the walls (with a small gap in between) & middle portion of the room kept vacant- for ease of servicing.

5. **Series or Parallel Connection of Batteries**: Too many parallel circuits of batteries do not allow equal distribution of current in each of the parallel circuits. This - can cause voltage difference among circuits- resulting in circulating current. Up to 2 or 3 parallel circuits of batteries are fine. In case multiple parallel circuits have to be used due to low capacity of each battery, the last connection drawing on extreme right of Figure 48 is recommended.

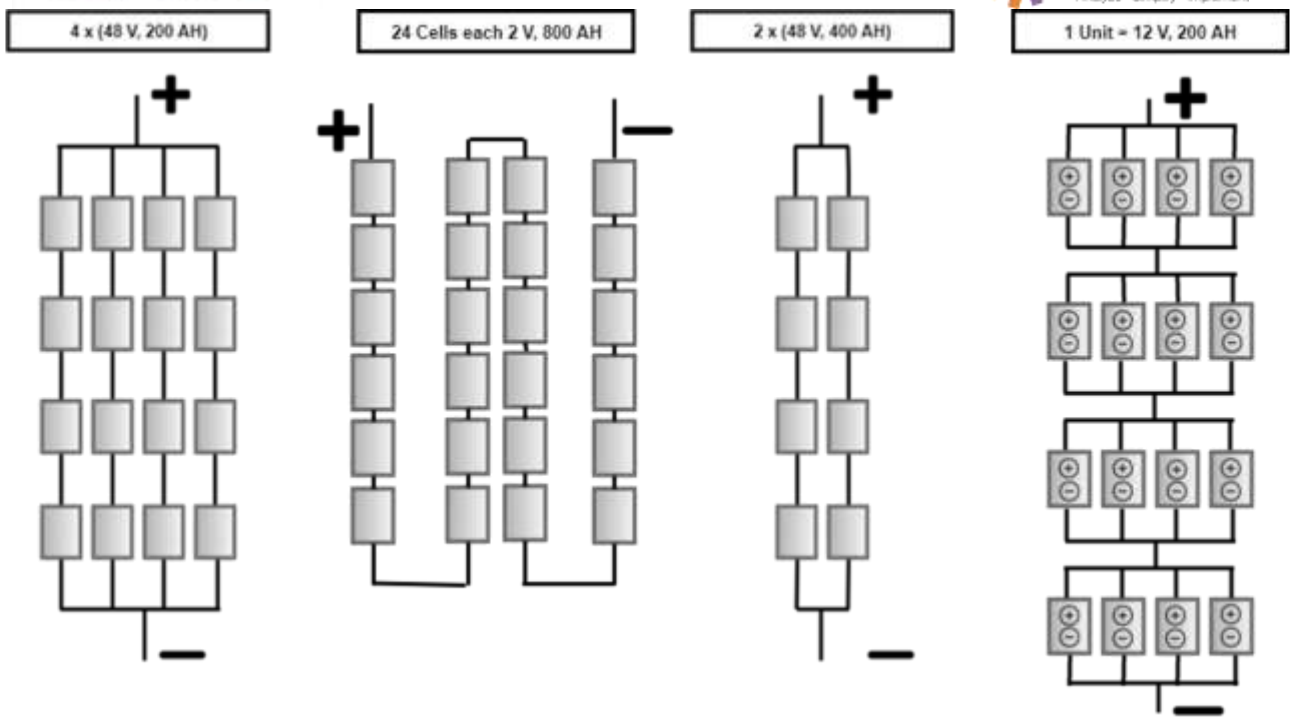

Figure 48 Parallel Connection of Lead Acid Cells & 12V batteries

6. The minimum gap between the walls of the room and the battery should be 150 mm for protection from earth leakage in the event of dampness of the walls as shown in Figure 49. There should be gaps between batteries also.

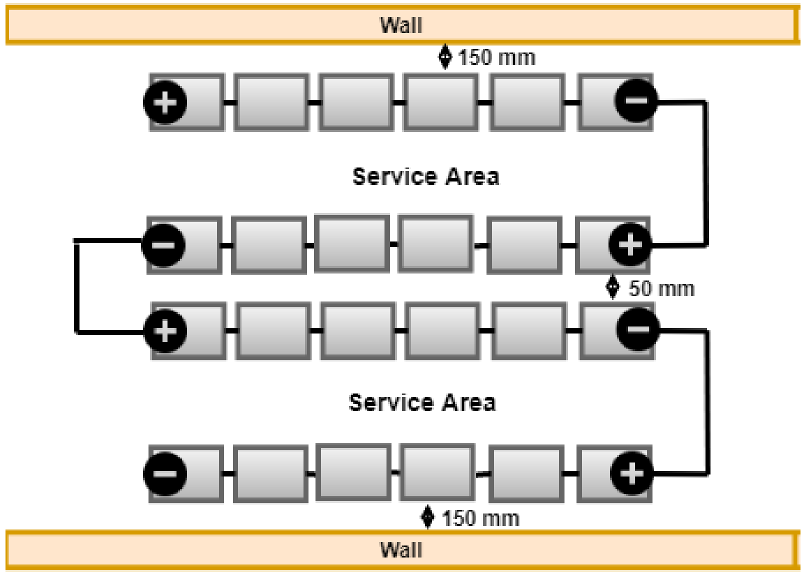

Figure 49 Layout of lead acid cells in a battery room (source: CES)

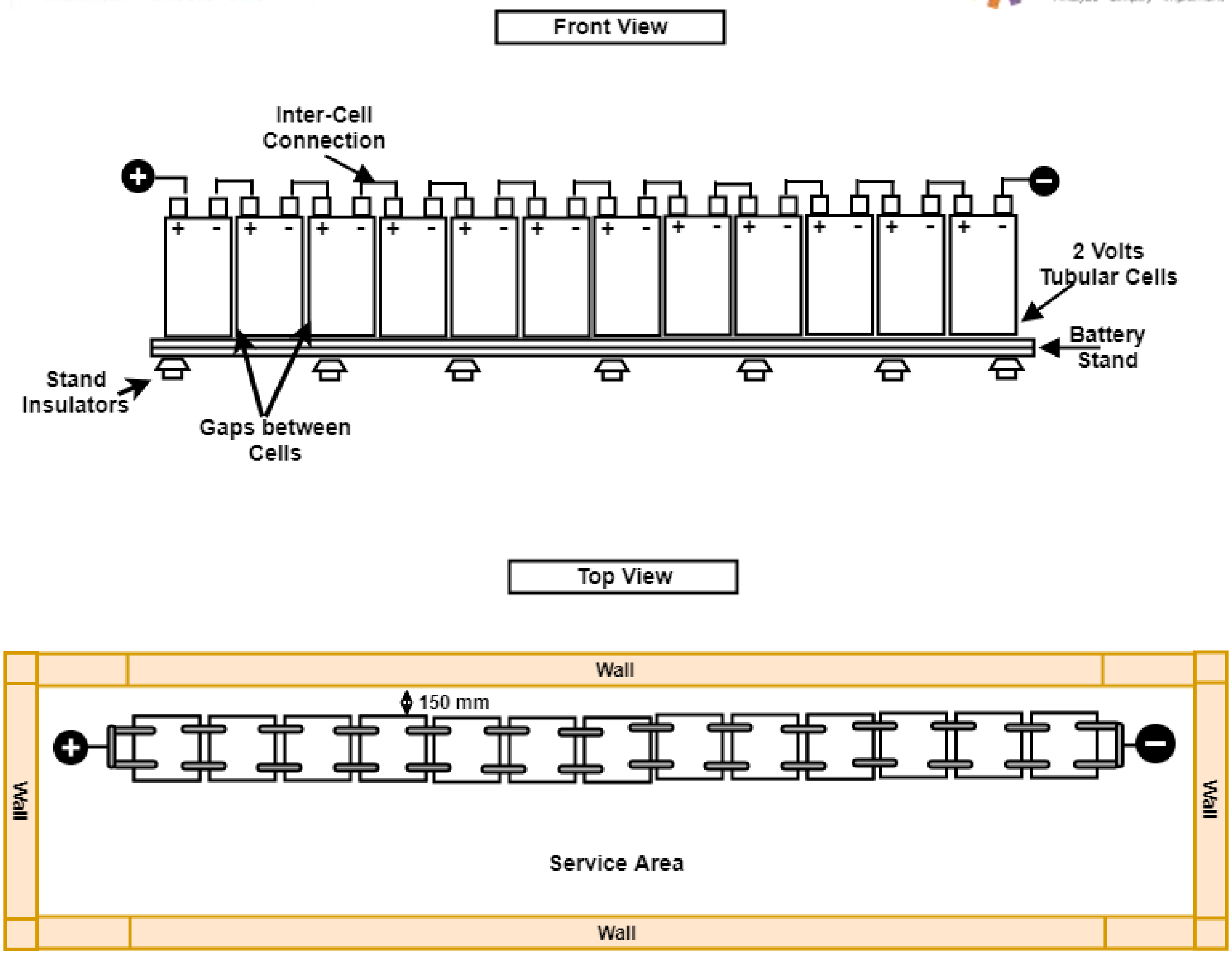

Figure 50 Front View and Top View of layout of 2V lead acid cells in a battery room (source: CES)

7. Any battery, with total voltage above 50 volts should be provided with battery or stand insulators as seen in Figure 50 in order to avoid electrical earth leakage- This - happens due to excessive moisture in atmosphere or spillage of electrolyte from the battery. Specially designed battery insulators only should be used as shown hereunder.

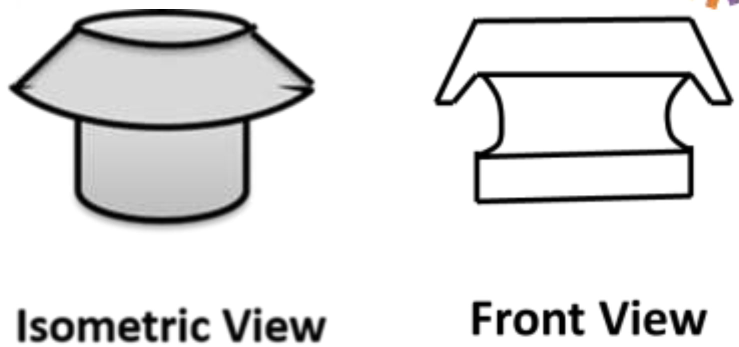

Figure 51 Battery stand insulator (source: CES)

8. Before starting installation- one should ensure required quantity of batteries- accessories like connectors, cables, fasteners, insulators, and petroleum jelly are available and are in good condition along with necessary tools and tackles. Check voltage of batteries & cells to ensure full charged condition.

9. Install all the batteries as per the marked battery layout. Use only insulated tools & tackles and avoid wearing wet clothes, wet shoes, metallic wristbands or other metallic paraphernalia while working on charged batteries. Avoid flames, smoking or any sparks in battery room. Battery/cell Inter-connections are to be made after installation is complete. Do not yet connect battery to inverter or controller without precaution as explained later.

10. All interconnecting cables should have crimped cable lugs or eyelets for fixing with the battery terminals. The cable lugs and fasteners (nuts & bolts) should be lead coated. Each bolt to be fixed with a plain and a spring washer.

11. Before connecting the inter battery/ inter cell connectors/cables, smear the battery terminals, cable lugs and the lead coated fasteners with a thin layer of petroleum jelly and fix the inter-cell/ inter-battery connections with fasteners.

    Fasteners are to be tightly fixed- to avoid electrical sparks by loose contact-. Over tightening can damage the battery terminals- which are made of lead. Loose contacts have sometimes resulted in explosion of batteries.

12. For batteries with voltage of 110 volts or more, there should be one switch-fuse unit as shown in Figure 52 between the battery and solar charge controller and another one between the battery and inverter. This is for isolating the battery if needed.

Figure 52 Battery switch fuse unit (source: Indian TradeBird)

Commissioning of battery

13. Keep both the isolator switch fuse units in open condition as shown in fig.38. Now connect the complete battery bank to the isolator switch and switch to solar charge controller on one end and battery bank to isolator switch and switch to the DC-AC inverter on the other end. Thereafter switches can be closed. Directly connecting high voltage battery to inverter without

an isolator switch can cause a huge spark- resulting in accidents. While disconnecting the battery or any cell- reverse the process- i.e. - isolate battery first- and then disconnects cells.

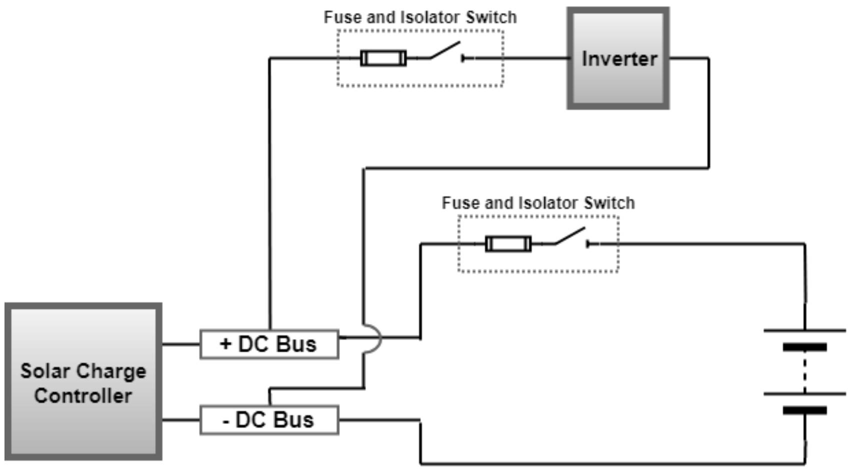

Figure 53 Battery connection to inverter and charge controller with fuse and isolator switch protection

14. Before closing the battery connection switches at the solar charge controller and the inverter end, obtain the open circuit voltage readings of all cells or batteries for future reference of battery state of charge before commissioning.

15. After switching on both the switch fuse units- switch on the inverter- while all the electrical loads or appliances are in switched off condition. Check current at both inverter output and also at the inverter input which the battery output is also. The current noted at inverter input will indicate its idle load and if any current is observed at the inverter output, it will indicate that there is an earth leakage in wiring.

16. The current and voltage input to the solar charge controller from SPV should be noted and also the output voltage from solar charge controller to battery to ensure maximum power input at all times. Check the regulation voltage of the charge controller. Lower than design voltage will result in battery remaining undercharged & higher voltage will result in overcharge & premature failure.

17. The battery should now be put on a capacity test to check – its full capacity -. This record, when compared to future capacity tests- will show the annual degradation trend for forecasting the expected service life. A capacity test discharge also improves battery output & charge acceptance.

18. The test discharge can be conducted by discharging the battery through the inverter preferably at the C10 or 0.1C rate of discharge. For an 800Ah battery, it would mean discharging it @ 80 Amperes to an end voltage of 1.85 Volts per cell (Or as specified by manufacturer) X Number of cells in battery. Discharge at higher rate will not serve the purpose of improving battery output

19. Finally, the battery is to be recharged, using the solar power plant & charge controller. All the charging parameters like voltage, current, temperature & solar radiation are to be recorded at 30-minute intervals.

    - Check Whether the charging power is at maximum level till regulation voltage limits are reached, as per the solar radiation (minus the losses)

    - Check the controller operation at regulation voltage and current control

    - Compute the total watt-hour energy input to the battery for the whole day during sunlight hours, by using the 30-minute interval voltage and current data recorded. It should be around 80% of the theoretical solar energy output for the average solar radiation during the day.

    - The battery should be in fully recharged condition before handing over. If solar array capacity is not enough for recharging battery to full state of charge in one day, charging is to be continued till WH discharge (during capacity test) + 10% is fed into the battery. Record the time.

- After full recharge, wait for 3-4 hours & then measure the open circuit voltage of all cells or batteries- which should be same as recorded under point 7.

20. The solar power plant battery can now be formally handed over for use.

7. Operations & Maintenance

A regular watch on the performance and a few simple periodic maintenance as explained- will provide almost full energy from the battery and the plant every day along with full service life.

List of Dos and Don'ts for O&M of Off-grid Solar PV Plant

Before getting into the specifics of operation and maintenance of battery and PV system there are certain general instructions in form of DO's and DON'Ts that should be followed:

Table 11 List of Dos and Don'ts for O&M of off-grid solar PV plant

DO's
● Keep the -solar -panels -clean (avoid dust de-rating losses) ● Keep the battery tops -clean (avoid earth leakage losses) ● Ensure tightness of inter cell or cable connectors ● Ensure maximum charging current till gassing voltage is reached ● Use battery stand insulators for system voltages above 48V ● Keep battery room well ventilated ● Install battery in a cool and dry place ● Carry out periodic equalizing charge ● Always recharge a battery after discharge ● In case, the battery has been deep discharged beyond 100% capacity or discharged and not recharged for a long time, revival charge is to be carried out as soon as possible- under expert guidance ● Use insulated tools when working on battery ● Whenever battery or cells are being disconnected or reconnected, first disconnect the complete battery from the inverter or electrical load before proceeding to take out or

reconnect inter-cell connectors. Failure to do so may result in heavy arcing/sparks.

- Top up flooded batteries with DM water at required intervals

DON'Ts

- Don't allow acid and dust to accumulate on battery or stand
- Don't discharge battery beyond 80% capacity (life is reduced)
- Never discharge a battery- by-passing the charge controller or under voltage cut off system. It will be deep discharged
- Don't discharge battery beyond 100% capacity at C10 (it will be virtually impossible to recharge it with solar power). Ask for expert service.
- Never keep a battery in discharged condition for many days
- Never over charge a battery (symptoms are high voltage & high temperature on charge/ bulging containers of VRLA (AGM/GEL) batteries/ -severe water loss & increase in topping up frequency in flooded batteries/ smell of acid mist in air
- Don't allow battery temperature to increase above recommended value
- Don't allow high charging current above gassing voltage
- Don't allow direct sunlight or excessive heat in battery room
- Never allow flame/sparks/smoking in battery room
- Do not wear wet clothes or wet shoes while working on battery
- Never top up flooded batteries with acid, use only DM water (unless battery had toppled and electrolyte had spilled/drained out of the battery)

Periodic Maintenance and Operations of Batteries

Following are the list of activities and procedure which needs to be carried out periodically in order to attain safe operation & best performance out of batteries and the solar power plant:

1. Battery tops, body and battery stands should be kept clean. During charging, electrolyte spray tends to form over battery tops & if allowed to stay for long- they cause surface leakage current, earth leakage and in extreme cases, electrical shocks and even fire. Periodically clean the batteries with water and dry them. Fig 38 shows a surface leakage of 8.9 volts between the terminal and the top/body of the battery and this leakage voltage is Nil when the battery top is cleaned with water. Cleaning with dry cloth will not remove the acid traces since sulfuric acid is hygroscopic in nature.

Now, this leakage voltage will increase during the charge-more so- when multiple batteries are in series and will create sparking on the body and if allowed for long, the battery will catch fire. In absence of special insulators, if the electrolyte film can find a way to the ground, there will be earth leakage, causing discharge from the battery.

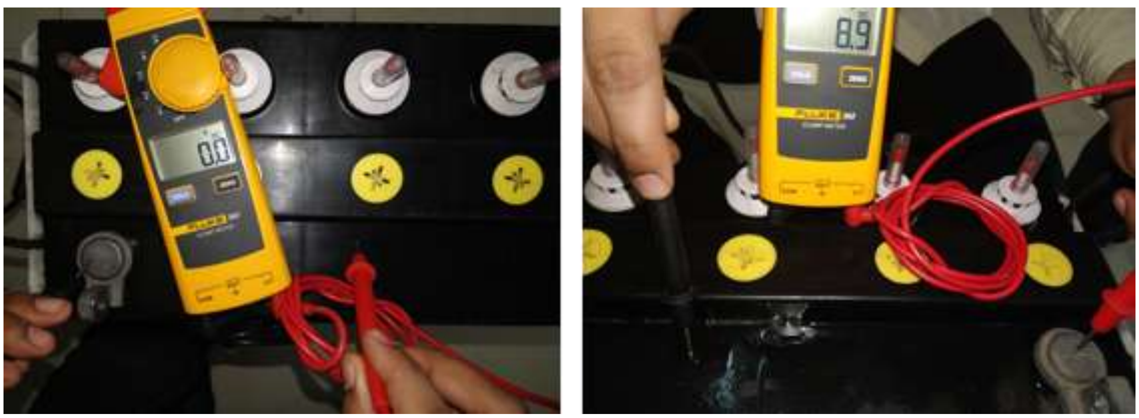

Figure 54 Measuring of leakage voltage on clean and unclean battery soiled with electrolyte

As seen in Figure 54 12 V battery on right shows a surface leakage voltage of 8.9 V between battery top and terminal. The same battery on left shows zero leakage voltage after electrolyte film is washed away.

2. Batteries should never be deep discharged. It is impossible to recharge a deep discharged battery in a solar power plant. The deep discharged battery can be recovered by extended charging with an AC-DC battery charger, under expert guidance. Extreme deep discharge leads to failure of battery.

3. To avoid deep discharge of battery, set a proper discharge cut off voltage in the inverter or solar charge controller. The voltage setting will depend on the rate of discharge and the depth of discharge that you allow. In case, accurate cut-off voltage cannot be set-a timer setting can be

used- considering the rate and depth of discharge. Following discharge curve and procedure can be used for setting the correct discharge cut off voltage to avoid deep discharge:

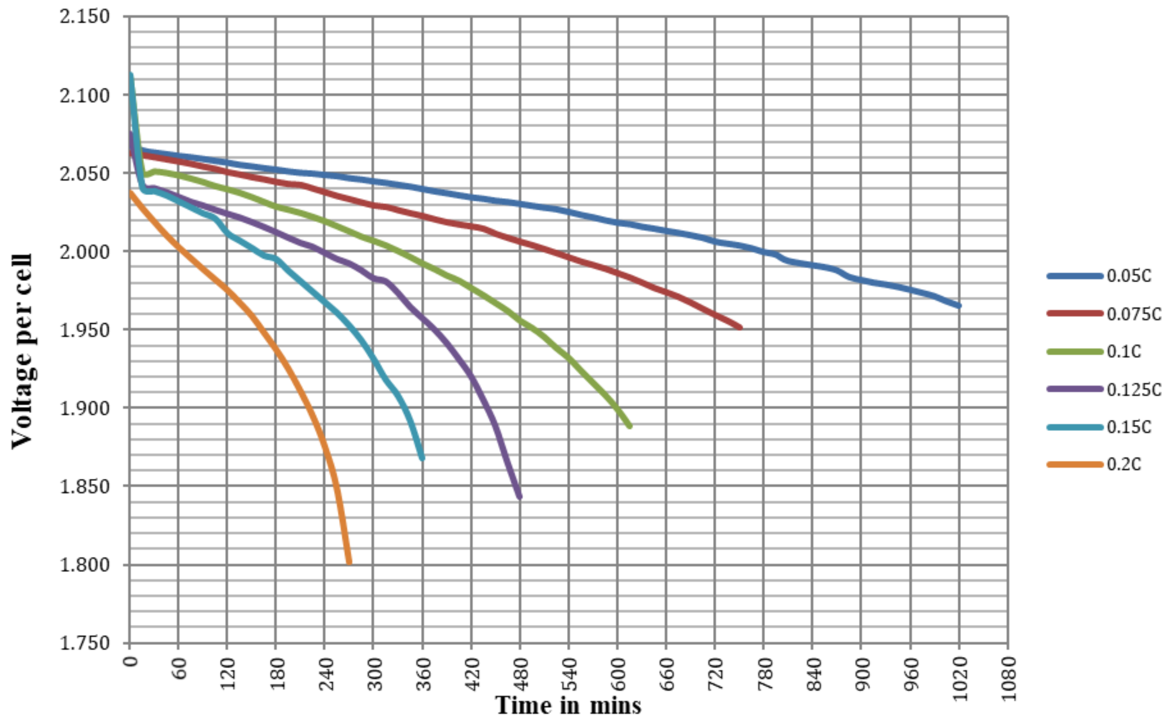

Figure 55 Discharge voltage vs time curve for flooded tubular battery (source: CES)

Example: A 48V400AH @C10 is being used for a daily power supply @ 30 amperes. At what point, should we stop the discharge?

a) Let’s assume that the battery should not be allowed to discharge beyond 80% D.O.D

b) Determining the rate of discharge: A 30A discharge for 400AH battery is 30 ÷ 400 = 0.075C.

c) Discharge Duration at 80% D.O.D: max discharge allowed = 400AH X 80% = 320AH. At a rate of 30Amps, it takes 320Ah/ 30A = 10.5 Hours (690 Minutes) of discharge.

d) Locate 690 Min on X axis & draw vertical line to cut 0.075C discharge curve

e) The vertical line cuts 0.075C at 1.96 Volts/cell COV.

f) Therefore discharge cut off voltage should be 1.96 VPC or 47V for battery

4. After the under voltage cut off has tripped the system, the re-connect should take place only after the battery is recharged next day and reached a voltage of 2.25 volts per cell on charge.
5. Avoid wearing wet clothes or wet shoes and metallic wristbands or other metallic paraphernalia while working on charged batteries. Avoid flames, smoking or possibility of any sparks in the battery room.
6. Keep the battery room well ventilated at all times. This allows dispersion of any accumulated hydrogen gas and also keeps the battery cool, for longer life.
7. A little over charging is not bad for solar power batteries- since solar power is available for a short time during a day. However, if excessive gas evolution or high temperature of batteries/ cells is noted- it is wise to discontinue charging for some time till the battery cools down. The controller regulation voltage is possibly set too high and needs to be reduced. Excessive overcharge causes bulging of VRLA batteries as shown in Figure 56, high water loss in flooded batteries and drastic reduction of life in both cases.

Figure 56 Image of a bulged lead acid battery

8. The duration of backup power from the battery is to be noted every day. Whenever the backup time is reduced by 15% to 20% over a period of time- considering that the backup power & its duration is same every night, it is time for periodic maintenance.

As witnessed in Figure 58 capacity reduction of more than 20% noted on 26th cycle and equalizing charge instituted on 27th cycle returns full capacity to the battery from 28th. 51st cycle again calls for equalizing charge. The frequency of equalizing charge of once in 24/25 days will reduce to once in 50 days or more if DOD of battery is reduced from 80% to 50%

21. Check for drop in voltage between output of solar junction box and input of solar charge controller, which should be within 3%. In case of higher voltage drop, check the quality of connection between solar panel, JB and controller.

22. Check the tightness of all interconnections between batteries, cables, charge controllers, inverters, DC distribution boards, switch fuse units etc.

23. Check for signs of corrosion or sulfation at any of the battery or cell terminals. Any corrosion should be removed by cleaning with water soaked cloth (preferably hot water which easily dissolves sulfates) followed by reapplication of a thin layer of petroleum jelly on the battery terminals, cable lugs and the lead coated fasteners. However, corrosion/sulfation of terminal of VRLA batteries are very uncommon and if such phenomenon is seen- it may be due to seepage of electrolyte from terminal sealing or from the gas escape vents which is not acceptable.

24. While servicing high voltage batteries- keep both switch fuse units (at inverter end and at solar charge controller end) in switch off condition. This is even more vital while removing or re connecting any inter-cell or battery connection. In absence of this precaution, there may be heavy arcing at the point of contact- which may lead to explosion in the battery/ Cell.

25. Record the voltage readings of all cells/batteries. If the measurements are made periodically, at the same time of the day/night, comparison of the voltage readings will indicate the trend of the state of health/ state of charge.

26. When the battery backup duration is reduced by 15% to 20% (till cut off voltage of inverter or controller), it is time for imparting equalizing charge to the battery.

Importance of Equalizing Charge in cycling batteries

Equalizing charge is the most important maintenance activity for any solar power plant- to be carried out by a solar charge controller without which- the battery & the power plant will lose 60-70% of its capacity in 2-3 years -. Most of the solar power plants surveyed by - our team, have failed due to this.

Any type of battery in solar power plants- picks up a little lesser charge in every cycle of discharge & recharge. It is the regulation voltage setting which limits the current after reaching gassing voltage to avoid overcharge & limited current cannot fully recharge the battery in 7½ - 8 -hrs. of solar charging.

It is seen from controlled experiments over 60 days period of cycling in laboratory and captive solar power plants, the battery output reduces approximately by 10% & 20% within a month when cycled at 40% & 80% depth of discharge respectively. The above mentioned experiments confirm this.

In Figure 57, the data shows capacity drop of a 12 V flooded tubular battery from 100% (80 DOD capacity) to 80% capacity.

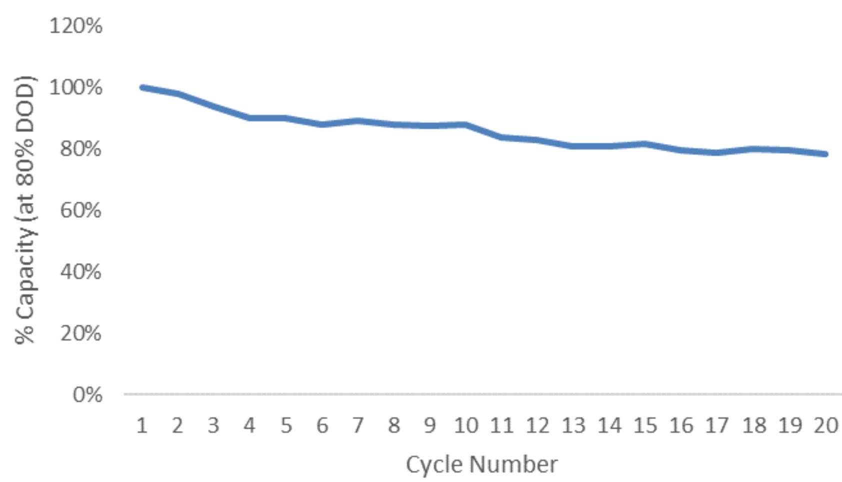

Figure 57 Ah Output in % of a flooded tubular battery at 80% DOD (source: CES)

Equalizing charge was imparted after the battery ha-s done 27 cycles as per the solar charging conditions by charging the battery for 8 Hours. Equalization charge was carried out it by 40% extra charge input to battery at a very low current (3% of the battery capacity in Amps) & high voltage (to allow current to enter the battery by overcoming high internal resistance). This means about 10 to 12 hours of equalizing charge after a normal, full day's solar charge, or in other words, 2 days charging without any discharge.

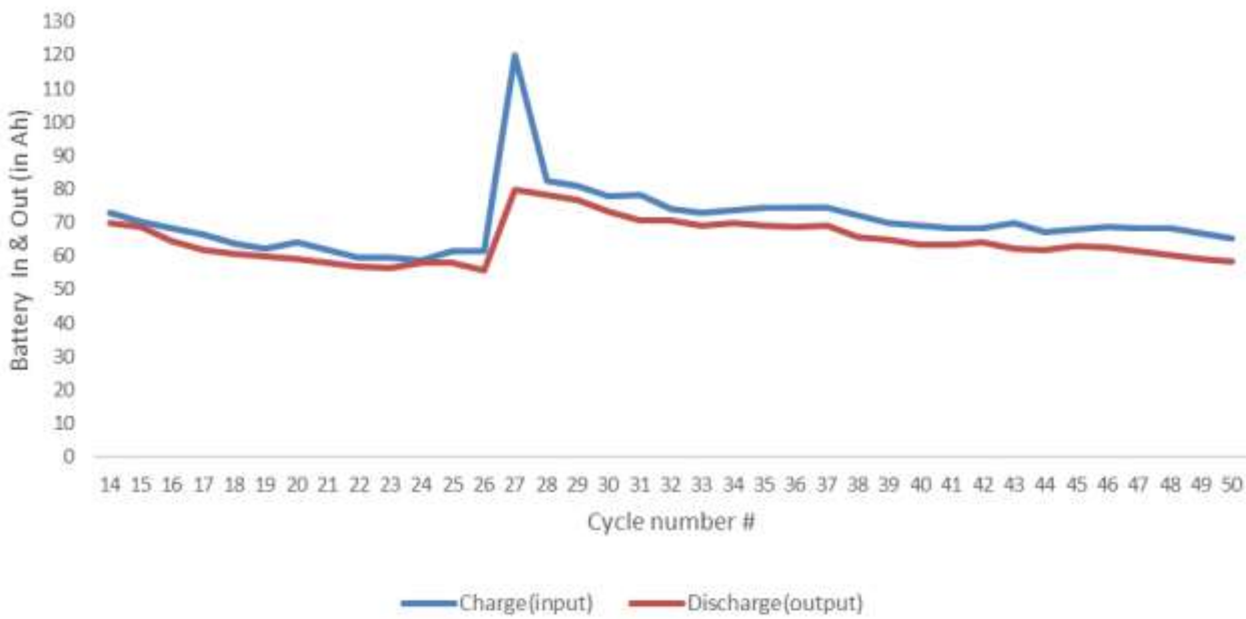

Figure 58 Tubular battery during cycling in laboratory. Simulating solar charging by 12% constant current followed by 2.4 V/C constant voltage for total 8 hours & discharge to 80% DOD (source: CES)

On 28th cycle, the battery regained 100% capacity & provided the same 80% output as on the first - day/ 1st cycle as shown in Figure 58. The performance of the battery was - well till 25% of capacity was reduced during next 25 days and then- next equalizing charge was done. Hence it can be noted for highly utilized battery at 80% DOD-. Equalizing should be done for one day cycle after almost every 20-25 days.

There is also another way of charging as seen in Figure 59. -The output of the battery is seen to be almost same for discharge up to 20% SOC for each of the 11 cycles. This was possible since peak of charge voltage was not limited to 2.4 volts/cell but it allowed to increase to 2.7 volts or maximum charge voltage. The current was reduced to 6% of battery capacity in amps to avoid high temperatures & excessive gassing. However, it can be seen that the battery AH efficiency is reduced to 83-84% as against 90% Ah efficiency (including equalizing process) as observed in Figure 58. This causes around 16-17% % energy loss leading to increase of battery temperature & reduction in battery life & hence not recommended.

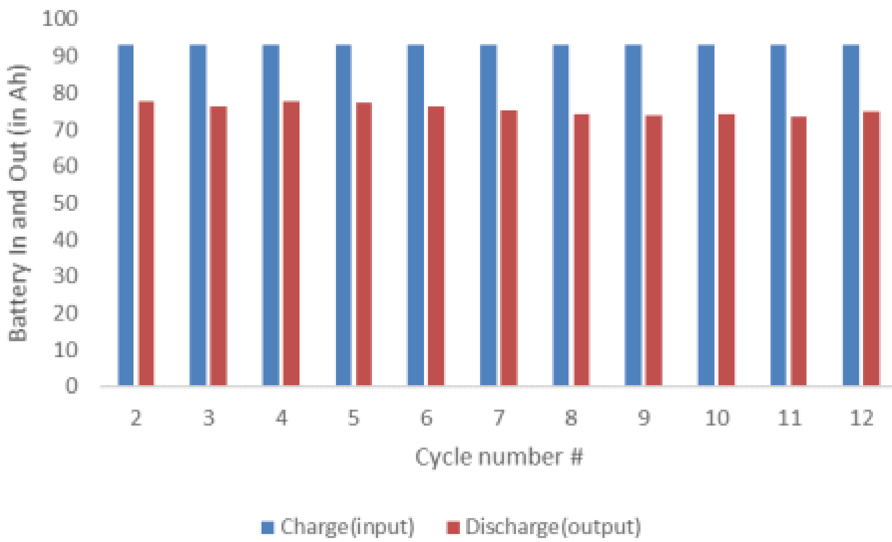

Figure 59 Tubular battery charging with 12% constant current initially till regulation voltage of 2.4Vpc then @ 6% constant current to 2.7 VPC for a total of 8 Hrs. & discharge to 80% DOD (source: CES)

Therefore -equalizing -charge at the right time, right voltage & current setting and correct duration is the most important function of a solar charge controller & preventive maintenance requirement in a solar power plant. Further, a site with higher battery utilization would require equalization more frequently than a site with low utilization of battery.

Site Visits and Findings

For understanding the extent of plant & battery deterioration due to absence of periodic equalization, recovery process on failed/ highly deteriorated systems were carried out at 4 off-grid microgrids sites.. The idea was to recognize the sites which were more than 1 year old and batteries were both over and underutilized with different technologies like flooded tubular and AGM VRLA which are the two most popular technologies used at the sites. Once these sites were recognized, CES representatives installed remote monitoring system at these sites and recorded daily generation, load and battery input, output and voltage data before and after performance optimization exercise.

After data was collected for few days, CES and CLEAN representative again visited the sites and carried out capacity checks on battery with completely draining the battery at rate close to C10. After the capacity and condition of battery was identified, equalization charge was carried for two to seven days as required by the sites.

It was seen that in a few years, **the battery gets heavily sulfated, loses about 50% to 60% of its capacity and so does the solar power plant and it takes between 2-3 days to 5-6 days of extended equalizing charge to revive the battery from hard sulfation to fully active condition**.

Site 1 – 3 years old underutilized flooded tubular battery: A 3 years old 6 kW solar PV microgrid with AC coupled battery and solar.

Figure 60 Flooded tubular battery bank at site 1 (source: CES)

Daily battery output at the site was observed in the range of 8-10 kWh per day and installed 48 V battery bank compromise of 24 X 2V800Ah flooded tubular cells connected in series. Since the battery capacity is 38.4 KWH- the output of 7-8 kWh per day- as seen in Figure 62- which makes it an underutilized site. Although, the battery was discharging at only @20A for only 8 kWh discharge/day, discharge end voltage should be minimum 49 V but voltage was going down to 47 V every night & the few refrigerators in village could not operate. An extended equalization charge was carried out for two days by input of extra 27 kWh at very low current and high voltage in monitored condition.

Figure 61 Solar panels at Site 1 (source: CES)

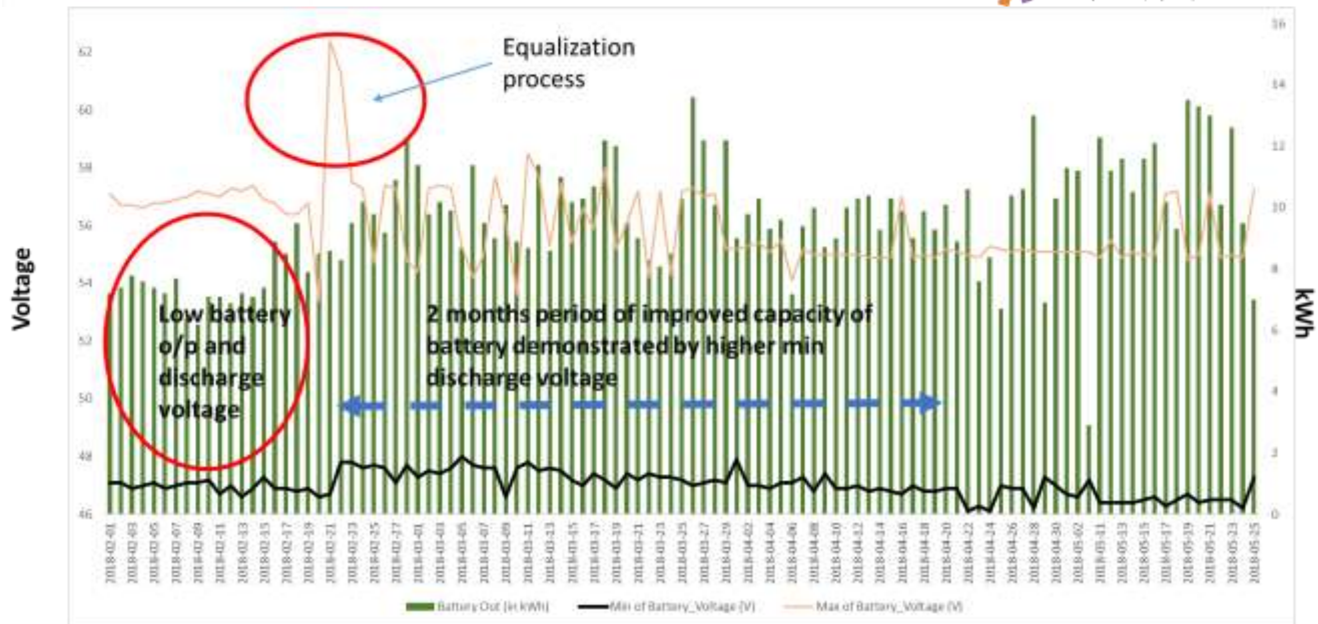

Figure 62 Battery Maximum, Minimum Voltage and Output for a microgrid with low battery utilization (source: CES)

The battery parameters as seen from Figure 62- were monitored for almost three months after the service charge- through remote monitoring. It can be seen that the battery bank after the equalization started delivering 3-4 extra kWh/ night with a higher end of discharge voltage & this improvement lasted for 2 months. Hence, this battery should be equalized every 2 months-to retain its full capacity

Site 2 – 18 months old well utilized VRLA battery: A 18 month's old 35 kWP solar PV plant with DC coupled solar PV and battery. The battery comprising of 3 X 48V600AH VRLA (48V1800Ah/ 86.4KWh) output had deteriorated to 17-18 kWh output per night as against a demand of 50KWH at night & 100 kWh for 24 Hours. Before 7 pm the battery would drain out and operator would start diesel genset. Daily solar output (35 kWp) had reduced to 70 kWh/ day as against the original output of 140kWh/ day.

Figure 63 AGM battery bank at site 2 (source: CES)

In this case too, the 18 months old battery was found to have developed high internal resistance due to hard sulfation since controllers could not impart the required equalizing charge. By re setting some of the control parameters- followed by extended service charge for 5 days- the battery bank again started accepting full charge from the SPV system as shown in Figure 63. **The solar plant again provided 130 kWh/day & battery started supplying 54 kWh at night without problem. Due to lack of monitoring systems, the state of the battery could not be monitored after the extended service charge- but the user/plant operator stopped using D.G for next 30 days as battery output covered the evening load**.

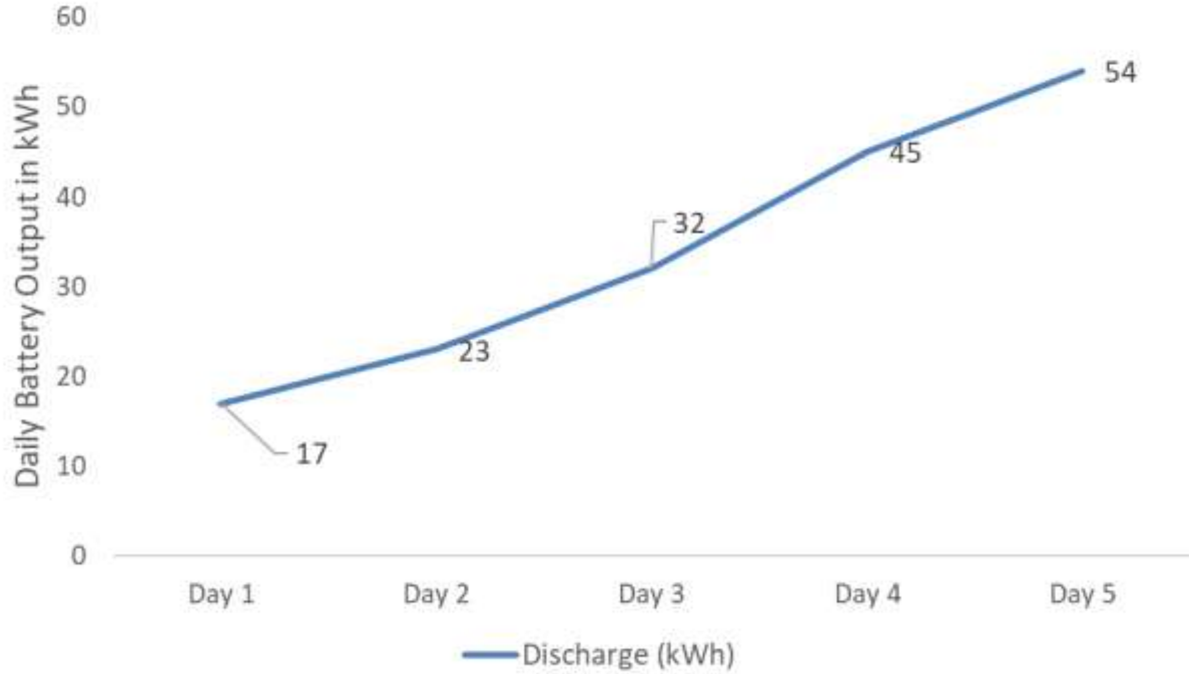

Figure 64 Daily discharging output of 1800 Ah VRLA battery during a five day equalization process

The replenishment of battery took over five days of charging as the auto equalization carried out by inverter was not set correctly. Most of the -solar -power -plants fail due to the above reason which is compounded by hard sulfation in battery plates which start acting like resistance and reduce the incoming solar power- more - each day. Figure 39 and Figure 40 illustrate the same.

Site 3- Cluster of sites with underutilized batteries: Performance of battery bank at a cluster of ten solar PV plants was observed through remote monitoring and it was observed that ability of the battery banks to deliver output at all the sites had limited to a small fraction of their rated capacity. Details of all the ten plants and their performance can be observed in Table 12.

Table 12 Performance of Lead Acid Batteries at ten solar PV plants in a cluster in Central India (Source: CES)

	Solar PV (kWp)	Type of Battery	Battery Rate Capacity (kWh)	Age of Battery (in years)	Avg Battery In (kWh)	Avg Battery Out (kWh)	Calculated Battery Capacity (%)
Site 1	100	Flooded Tubular	384	7	135	52	32%
Site 2	50	Flooded Tubular	108	8	13	6	10%
Site 3	20	Flooded Tubular	216	7	35	2	1.5%
Site 4	5	Flooded Tubular	57.6	6	8	4	27%

Site 5	5	Flooded Tubular	38.4	6	7	4	30%
Site 6	20	Gel Tubular	144	4.5	25	15	25%
Site 7	10	Flooded Tubular	72	6	11	1	16%
Site 8	10	Flooded Tubular	72	6	9	4	20%
Site 9	10	Flooded Tubular	72	6	13	2	4%
Site 10	10	Flooded Tubular	72	6	10	2	5%

Even at the end of the life, the battery is expected to provide 80% of the capacity which is not the case at these plants. All the plants here are showing current capacity of less than 32% which is very low and such a reduction in capacity over age of 4-8 years can be attributed to considerable sulphation and lack of required O&M.

Such condition can be averted with periodic maintenance which is mentioned in the manual. At this point also, many of these sites can be recovered as shown in Figure 60. However the process of rejuvenation might take a little longer as these batteries apparently are heavily sulphated as they are not maintained for years.

Site 4 – 3 years old minigrid with 72 kWh well utilized flooded tubular battery: Daily battery output at the site was observed in the range of 25-35 kWh per day and installed 240 V battery bank compromise of 120 X 2V 300Ah flooded tubular cells connected in series. Figure 65 shows the battery bank at the site in Bihar.

Figure 65 Battery output data in kWh for site 4 before and after equalization (Source: CES)

Since the battery capacity is 72 KWh, the output of 25-35 kWh per day-as seen in Figure 65- makes it a well utilized site with output in range of 30-50% of rated capacity. Everyday diesel genset - was running at the site for the duration over an hour in time period of 6 pm to 9 pm when load use to reach close to 8-10 kW. The purpose of running DG at the site was to extend the battery output throughout the night. Hence, the operators were looking for additional 5-10 kWh from battery to stop the use of diesel genset in this case. Later, the CES and Clean representatives - attempted equalization to improve output from the battery bank. An extended equalization charge was carried out for four days by input of extra 90 kWh at very low current and high voltage in monitored condition.

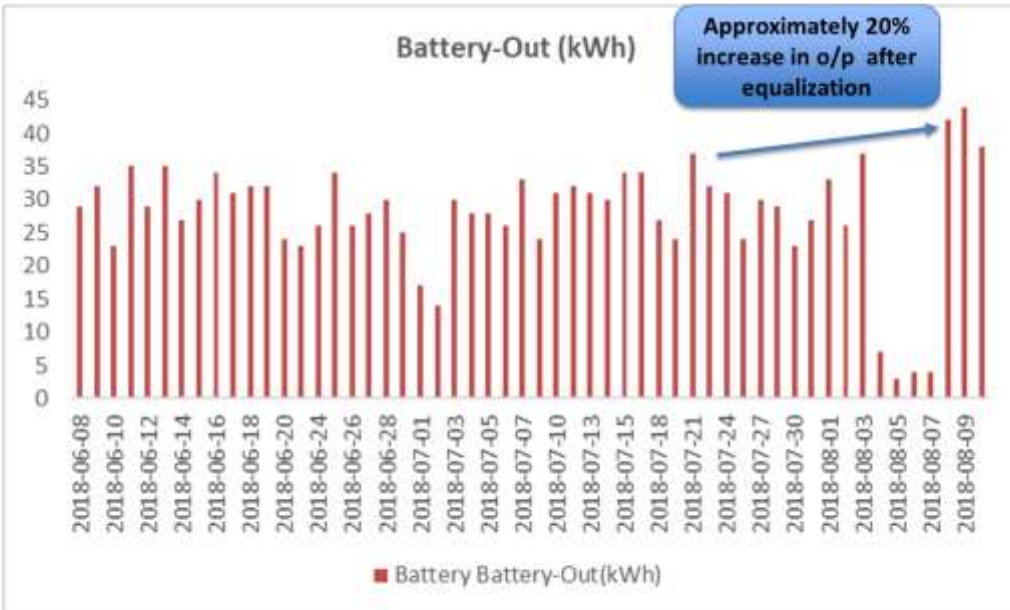

Figure 66 Battery output data in kWh for site 4 before and after equalization (Source: CES)

As observed – in Figure 66, battery output capacity was increased to over 45 kWh which was on prior days witnessed below 40 kWh. **There was at least a visible difference of 15-20 % in the battery output after equalization. - As reported by the onsite operators, the diesel generator was not used after the equalization process was carried out. Since the battery usage in over 50% of the rated capacity, the equalization should be carried out in every 30-40 days for healthy operation of the battery in this case.**

Equalizing Charge Process

Following process may be followed for imparting equalizing charge to a solar lead acid battery:

a) First charge the battery to maximum level with the solar charge controller in boost charge mode and continue till maximum voltage of 2.35 volts/cell or 56.5 volts is reached for a 48 Volt battery and current tapers off to a low value. While 2.35volts/cell setting is preferable for quickly charging the battery, many charge controllers in the market (1 kW to 5 kW range) have a single setting of 2.25 volts/cell & here, 54 volts will be the maximum voltage on charge.

b) Put the controller on equalizing charge mode. It is preferable to impart equalizing charge to a flooded battery with maximum voltage of 2.7/2.6 volts per cell, or 64.8V/62.4 Volts for a 48V battery. For VRLA batteries, a voltage of 2.4 volts/cell or 57.6 for 48V battery will be ideal. Some controllers have separate settings for flooded & VRLA batteries while others have only one setting at 2.5 Volts/cell. Continue charging at a low constant current till battery voltage reaches & remains constant at the maximum voltage set in the controller for 2 to 3 hours.

c) - The charge controllers which are available in the market- was seen that the equalizing mode automatically switches back to boost mode after one or two hours. This is very inadequate time for equalizing charge that has to be ON for at least 8-10 hours-depending on battery condition. In such case, switch back to equalizing mode and keep equalizing ON till condition (b) is met.

d) During equalizing charge, the charging current should be limited to 3% of the battery capacity in amperes but not much lower than that. For example, the equalizing current for a 100Ah battery should be 3 Amperes and that for a 600Ah battery should be 18 Amperes and so forth. The solar charge controller should have a current limiting function during equalizing mode.

e) Check temperature rise during the entire process & discontinue charging if it increases by more than 4°C - 5°C during the equalizing charge. Continue charging after temperature drops.

f) After equalizing, give it a rest for a few hours & then check the battery specific gravity & open circuit voltage in case of flooded & VRLA battery respectively. They would have reached the full charge levels. Hereafter, battery backup will increase to the original level.

Annual Maintenance

1. Carry out checks & consequent servicing-as during periodic maintenance- but more thoroughly.
2. In case, periodic equalizing charge has not been done, the battery would have lost capacity due to hard sulfation. In such cases, impart extended charge (after boost charging) at higher voltage and low current limited to 3% of battery capacity in Amperes. Continue charging till each it reaches 2.5 volts/cell (15V for 12V battery/ 60V for 48V battery) or the maximum equalizing charge voltage setting in the controller and it remains constant for at least 2 hours.

   The time required for extended equalizing charge is substantially more than periodic equalizing charge and the duration –depends on - how long the battery did not get equalized. For example, a 48V 4000 Ah VRLA battery-whose capacity had come down to 25% after 2 years & 6 months of use-could be revived to 90% of its capacity after continuous extended charge for 7 days. This process should be done under expert guidance- as there is a possibility of failure by overcharge.

3. After above charge process- allow the battery to rest for 2 to 3 hours and check the open circuit voltage of all cells/ batteries. Voltage should be uniform at around 2.15/2.17 volts/cell for VRLA and full specific gravity for flooded tubular- which shows that all cells are now fully charged.
4. Once in a year, after equalizing or extended equalizing charge- there must be a full test discharge of batteries. This will improve their performance & indicate the prevailing capacity. The test discharge shall be carried out @C10 rate up to an end voltage as given by battery manufacturer. Yearly capacity test results can be extrapolated to estimate expected battery life.
5. When such a C10 capacity test after full & equalizing charge yields less than 80% of the rated capacity of the battery, the battery has reached the end of its service life.
6. After test discharge, fully recharge the battery by applying boost charge @ 2.35 volts per cell or 56.5 volts for a 48V VRLA battery & 2.4/2.45 V/cell for flooded battery. It may be 2.25 Volts/cell or 54V for 48V battery for charge controllers with setting of 2.25 volts/cell.
7. Clean all cells and batteries-using cloth with water and allow them to dry. Clean all battery terminals with same wetted cloth and apply petroleum jelly.
8. Finally, check the following
    - Tightness of all connections
    - Condition of fasteners
    - Condition of inter-cell and inter battery connectors
    - Check for signs of high temperature
    - Check discharge cut off voltage
    - Check boost charging current and peak voltage
    - Check equalizing charge current and peak voltage

Troubleshooting

Sl. No.	Symptoms	Checks	Diagnosis	Solution
1	Excessive water loss from battery	Compare with earlier topping up frequency or check normal frequency from manufacturer	Charge controller voltage setting is high & battery is being over charged	Reduce regulation voltage of charge controller to correct level
2	High Battery temperature	Sharp Temperature increase noted during charging	Charge controller voltage setting is high & battery is being over charged	Reduce the regulation voltage to correct level at charge controller
3	Electrolyte specific gravity is above recommended level	Check if the electrolyte level has gone too low If that's not the case	Water Topping up not done voltage setting is high & battery is being over charged	Top up with water Reduce the regulation voltage to correct level at charge controller
4	Smell of electrolyte fumes in air	Check all 3 above	Same as above	Same as above
5	VRLA batteries containers (AGM or Gel) have bulged	Check for sharp temperature rise during charging of	Charge controller voltage setting is high & battery is being	Reduce the regulation voltage to correct level at

		battery	over charged	charge controller
6	AH output from battery is low	In flooded battery check if specific gravity is low In VRLA (AGM & Gel) battery check for low open circuit voltage	Charge controller voltage setting is lower than recommended & battery is being undercharged	Increase the regulation voltage charge controller to correct level
7	AH output from battery is low Battery voltage drops in a short time on discharge	Check If battery voltage rises quickly on charge Check if the solar panel output to battery is low even when solar radiation is high and the battery is in discharged condition	Most probably, hard sulfation developed in the battery plates	Extended high voltage recharge at lowest recommended current for a few days till condition improves. During this treatment, battery should not be discharged at all.
8	Daily AH output from battery reduces progressively	Compare daily input AH with earlier values if they are reducing	If the answer to first check is Yes and that to last three checks are Yes as well, then	Periodic equalization charge. Periodicity depends on the occurrence of this

	Daily AH output of solar to battery reduces progressively Daily AH input to battery reduces progressively even though battery is in discharged condition	Check if solar panels are being cleaned Check if all electrical connections are OK Check the daily solar radiation	the battery plates are slowly developing hard sulfation	symptom
9	Charging current is very low even when solar radiation is high	Check if battery is fully charged Check if controller voltage setting is OK	If the answer to the 1st checks is "No" and that to 2nd check is "Yes" then the battery has developed hard sulfation in plates	Extended high voltage recharge at lowest recommended current for a few days till condition improves. During this treatment, battery should not be discharged at all.
10	Battery gives lower discharge output in Amp Hours even after accepting full charge in terms of the Amp. Hours input	Confirm battery got full charge: check Sp. Gr / voltage on top of charge. For VRLA battery check open circuit voltage after 1 hour	If the answer to 1st, 2nd and 3rd check is Yes, check battery output current after opening isolator. If battery output Amp is very high, there are short circuit or earth leakage in the circuit	Locate and remove short circuit or earth leakage from the electrical circuit

		of charge completion Check if voltage reduces rapidly if discharged immediately after charging	If battery the output Amp in open circuit is Nil, then one or more batteries may have developed short circuit inside.	Locate the short circuited cells or batteries and replace them. Otherwise, the healthy cells/batteries will also fail
11	Battery gives lower discharge output in Amp Hours even after accepting full charge	Keep battery unused for 2 to 3 days and check if Sp. Gr or OCV goes down If the answer is Yes, check if batteries or the stands are clean and dry or they have acid and dirt on them.	If the answer to 1st and 2nd check are Yes, then the battery has severe earth leakage	Clean the battery and battery stand by water and wipe dry. Surface/earth leakage should disappear
12	Battery gives lower discharge output in Amp Hours even after accepting full charge	Keep battery unused for 2 to 3 days and check if Sp. Gr or OCV goes down If the answer is Yes,	If the answer to 1st and 2nd check are Yes, then the battery self discharge loss is high, due to high ambient temperature	Avoid direct sunlight or very hot air ingress in to the battery room

		check for high battery room temperature		
13	Battery gives lower discharge output in Amp Hours even after accepting full charge	Confirm battery got full charge: Sp. Gr increases on charge. For VRLA battery check open circuit voltage after 1 hour of charge completion. OCV value should be around full charge voltage as indicated by manufacturer	If the answer to 1st and 2nd check are No, then the battery has probably reached the end of service life. To double check, fully charge battery by boost charge followed by equalising charge and carry out capacity test. If capacity is less than 70% of rated capacity, battery has definitely reached the end of service life	Replace the complete battery bank
14	Battery catches fire / is damaged by fire	For flooded battery, check accumulation of acid and dirt on the batteries and	Acid and dirt have provided path for leakage current which in extreme case can result into	Replace battery and always keep battery & its stand dry & clean

		stands	battery fire	
15	Battery catches fire / is damaged by fire	Check for electrolyte on battery surface. In VRLA battery, acid seepage happens if terminal or container & lid sealing is bad Check the if charging voltage is set at high level. In case of high ambient temperature, voltage should be low	If yes, battery container sealing or terminal sealing has failed. If the charge voltage setting is high and the ambient temperature was also high as well, there may have been a thermal runaway.	Replace battery Replace battery and reduce the setting of charging voltage
16	Electric shock is felt when the battery or its stand is touched	Check accumulation of acid and dirt on the batteries and stands	If Yes, then it is a severe case of earth leakage current	Clean the battery and battery stand by water and wipe dry. For VRLA, refer pt. 15 Also, insist on special battery insulators for batteries which are more than 50 volts
17	Explosion in one or more battery/cells	Check for signs of heavy sparking at any of the battery terminals	If there is a sign of sparking/ melting of terminal or terminals, the explosion has occurred due to this	Replace exploded batteries or cells Ensure there is no loose intercell, inter

		Check if battery room ventilation is OK	In case of lack of ventilation, the result will be severe	battery or battery end terminal connections Strictly observe no smoking, flame/ spark in the battery room
18	Battery open circuit voltage is too low	Check if one or two cell has much lower voltage than others that have almost equal & good voltage Most of the cells have unequal voltages, some low and others higher	If answer to 1st check is Yes, then these cells may have short circuit inside Battery has been in partially charged condition for long	Replace the short circuited cells if the battery is not too old Impart equalising charge to battery
19	The battery does not supply any current on discharge & terminal voltage is NIL	Confirm that each cell or battery are in fully charged condition Check if any battery or cell is showing NIL voltage at its terminal	If answer to 1st & 2nd check is Yes, then the cell or battery which shows NIL voltage has become open ckt. /disconnection inside	Replace open circuited battery/cell

		Check the inter cell connections for any disconnection	If the answer to 1st and 3rd check is Yes, then there is a loose cable connection	Tighten the cable connections between the batteries/cells
20	In VRLA battery, bulging noticed in one or two battery/cells	Check if other cells/ batteries have also bulged some extent	If the answer is No, then the bulge is due to malfunction of battery relief valve	Contact manufacturer for repair/replacement of that cell/battery
21	Battery terminal is found to be damaged	Check if the terminal damage is external or internal to the cell	May be due to over torque while installing May be due to manufacturing defect	Contact manufacturer for repair or replacing the battery or cell
22	Battery capacity less than 70% or 80% even after full charge & extended charge	Double check by a 2nd capacity test	If Yes then the battery has reached end of its service life	Replace battery

List of Abbreviations

W	Watt
kW	Kilowatt
PV	Photovoltaic
O&M	Operations and maintenance
SPV	Solar photovoltaic
C Rate	Charging Rate / Discharging Rate
Ah	Ampere hour
DC	Direct current
AC	Alternating current
PWM	Pulse width modulation
VRLA	Valve regulated lead acid
Wh	Watt hour
OEM	Original equipment manufacturer
SoC	State of Charge
DoD	Depth of Discharge
OCV	Open circuit voltage
BIS	Bureau of Indian Standards
AGM	Absorbed glass mat
UPS	Uninterrupted power supply
LM	Low maintenance
Vpc	Voltage per cell
MPPT	Maximum power point tracking

For more details, please contact:

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