# Project Completion Report

# On

# Design and Development of Batteries For Solar Photovoltaic Applications

(MNRE Sanction No.1/2(01)/2006-SEC dated 22.02.2008)

**Collaborative project**
**Between**

**CSIR- Central Electrochemical Research Institute, Karaikudi**

**MNRE-Solar Energy Centre, New Delhi.**

**JUNE 2012**

**CONTENTS**

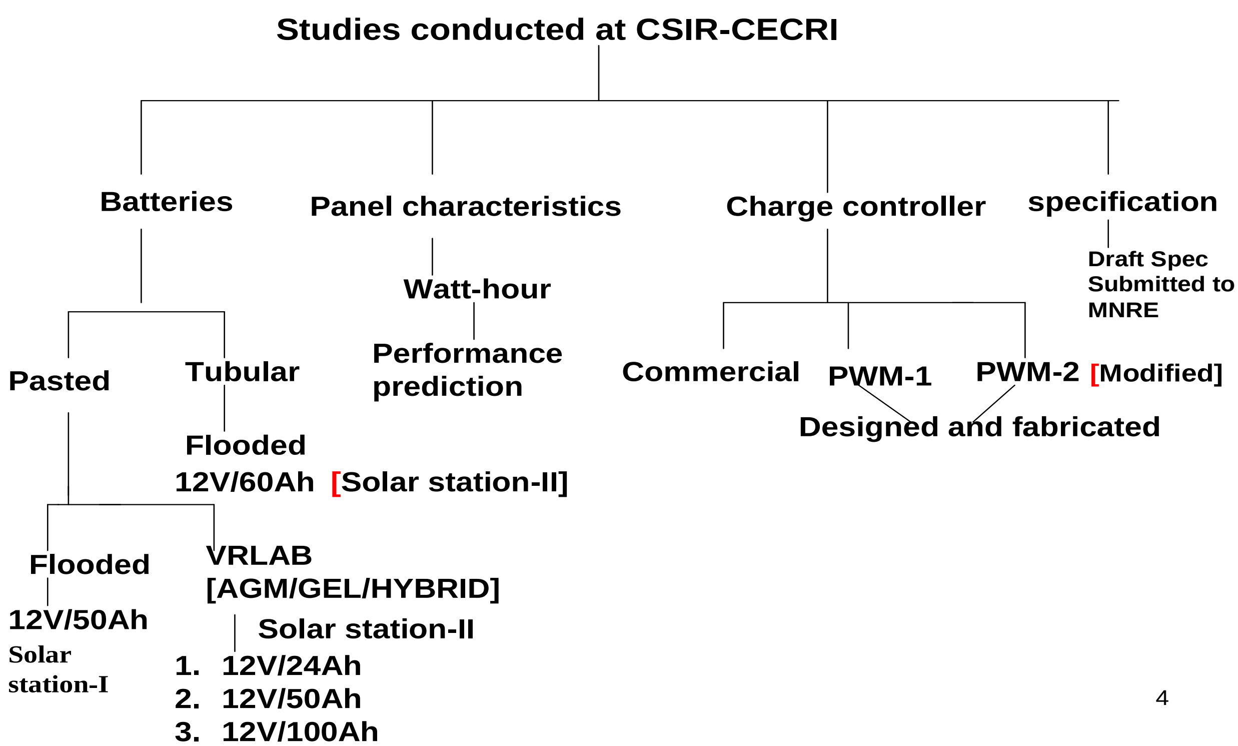
# EXCUTIVE SUMMARY

India is running one of the largest SPV programme among the developing countries. Storage batteries are being the most critical component of any SPV system in view of cyclic availability of the sun in 24h domain and the intermittent nature of available radiation. Since there is no systematic study on various aspects of selection and performance of lead-acid and other storage batteries for PV applications in the literature CSIR-Central Electrochemical Research Institute and MNRE- Solar Energy Centre submitted an Research and Development Technology project namely “Design and Development of Batteries for SPV Applications” to Ministry of New and Renewable Energy[MNRE].The broad objective of the project is to optimize the battery performance in various PV applications by way of developing suitable lead-acid batteries and their charging mechanism.

The specific objectives are:

1. Failure analysis of the used batteries in the existing solar PV applications
2. Design and Development of suitable lead-acid batteries for SPV applications
3. Development of test protocols for batteries SPV application
4. Exploring battery chemistries other than lead-acid battery
5. Studying of existing circuit designs for charge controllers and optimizing their performance
6. Dissemination of information thus generated through workshop and conferences.

The duration of the project is four years from April 2008 onwards. The cost of the project is Rs. 236.90 lakhs and CSIR-CECRI share is Rs.133/- lakhs. CSIR-CECRI has undertaken the following works and completed:



The following are the conclusions:

1. Performance of Valve Regulated Lead-acid battery [VRLAB] and flooded tubular lead-acid battery are better than the low maintenance flat plate lead-acid battery on account of low operational window, minimal water loss and good state of health.
2. Sulphation is the major failure mode in lead-acid battery operated under partial state of charge [PoSC] operation. The crystallization mode of lead-sulphate changes from three dimensional to two modes as the specific gravity moves down from 1.280 to 1.220.
3. The performance of PIC based Pulse Width Modulation charge controllers are better than the conventional series type charge controller.

The coordinators for the project are:

1. Dr.P.C.Pant --- MNRE- Solar Energy Centre
2. Er.S.Ambalavanan --- CSIR--- Central Electrochemical Research Institute

## 1.0 Storage batteries for SPV application:

India is running one of the largest SPV programme among the developing countries. Storage batteries are being the most critical component of any SPV system in view of cyclic availability of the sun in 24h domain and the intermittent nature of available radiation. Since there is no systematic study on various aspects of selection and performance of lead-acid and other storage batteries for PV applications in the literature CSIR-Central Electrochemical Research Institute and MNRE- Solar Energy Centre submitted an Research and Development Technology project namely “Design and Development of Batteries for SPV Applications” to Ministry of New and Renewable Energy[MNRE].The broad objective of the project is to optimize the battery performance in various PV applications by way of developing suitable lead-acid batteries and their charging mechanism.

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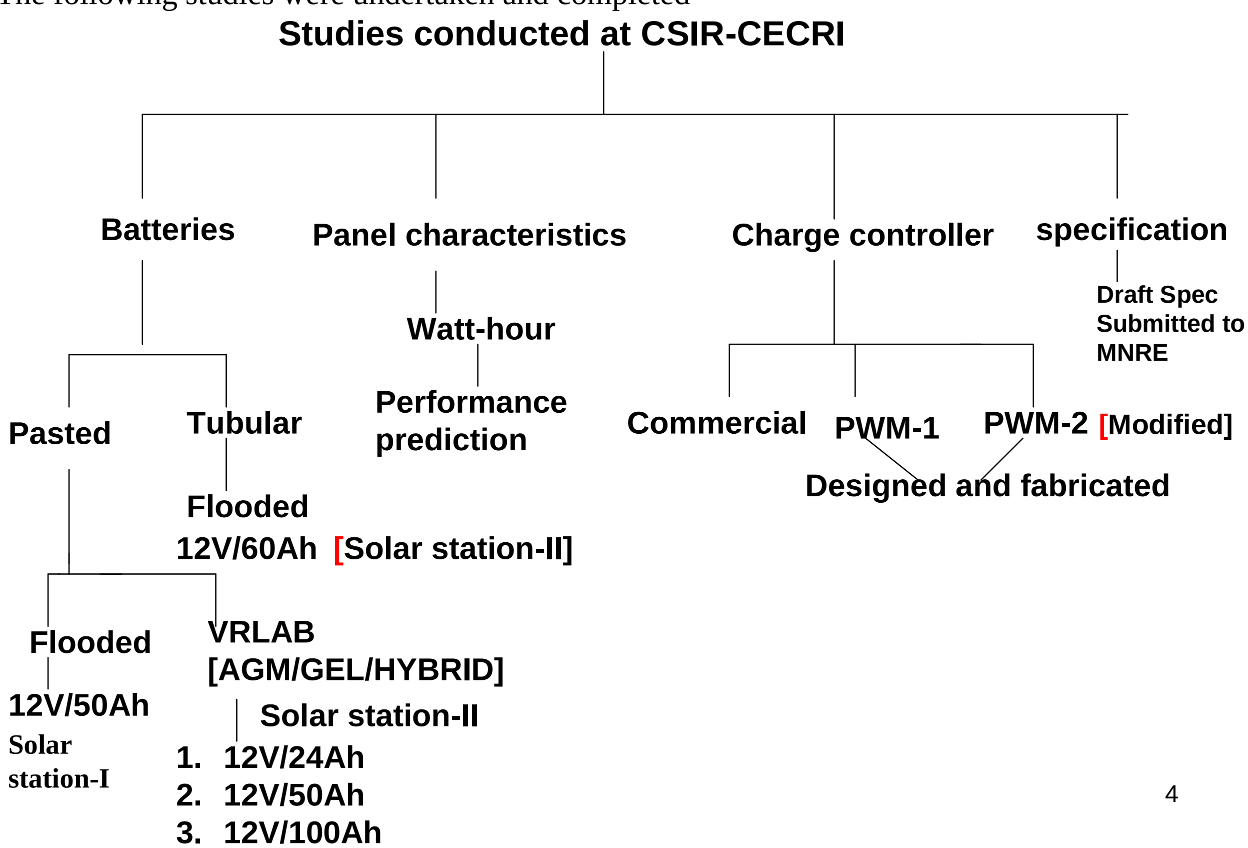
12. Dissemination of information thus generated through workshop and conferences.

The following studies were undertaken and completed



## 1.1 Lead-acid battery for SPV application

### 1.1 Solar station - I

Lead-acid battery is often the weakest link in photovoltaic [PV] installations. At CSIR-CECRI a study was conducted on the various versions of lead-acid batteries namely gelled-electrolyte Valve Regulated Lead-Acid Battery [VRLAB], Absorbent-Glass-Mat [AGM] VRLAB and hybrid VRLAB and flooded- electrolyte versions of lead-acid batteries. These batteries were fabricated with the help of a battery industry and their performances were tested in stand-alone solar-lighting application during the period 2006- 2008. The details of the study were reported in ref [1]. The results of the studies are given below:

Schematic dig.[1] for data logging system employed to monitor battery performance for solar-lighting application in solar station-I.

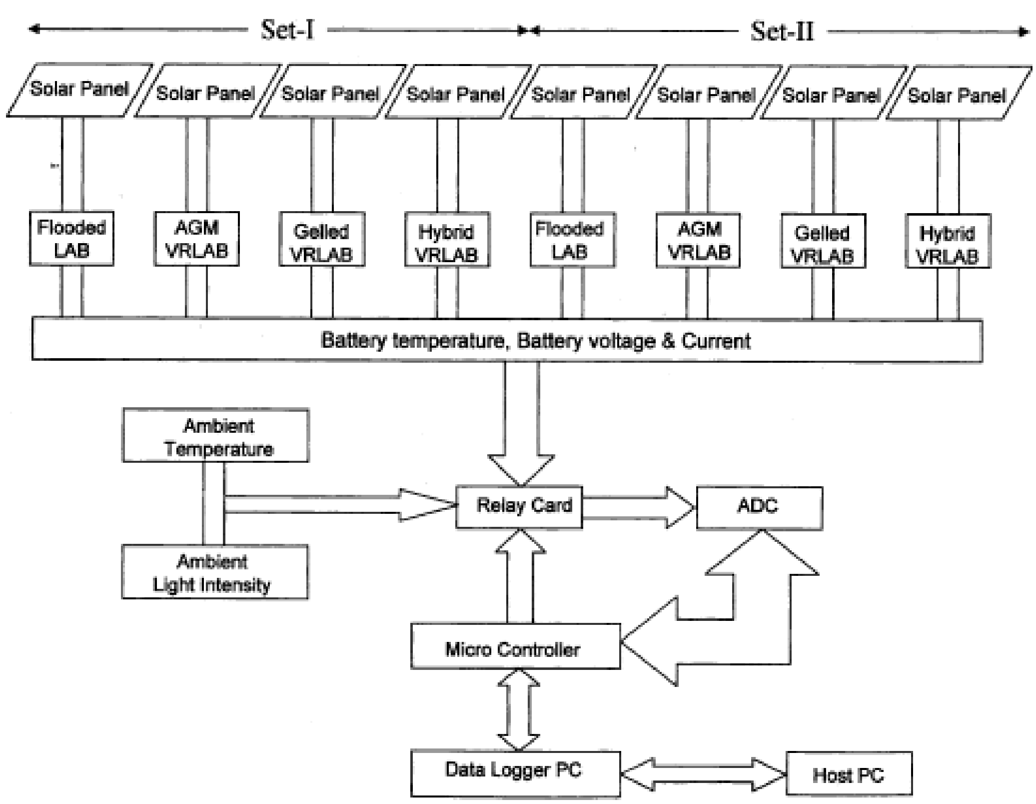



**Fig.1. Schematic dig. of solar station -I**

### 1.1.1 Results

For solar lighting application conducted on hybrid VRLAB, AGM-VRLAB , gelled electrolyte VRLAB and flooded electrolyte lead-acid batteries suggests that VRLA batteries exhibit both low operational window, minimal water loss and good state of health compared with flooded lead-acid batteries. This is shown in fig.2.

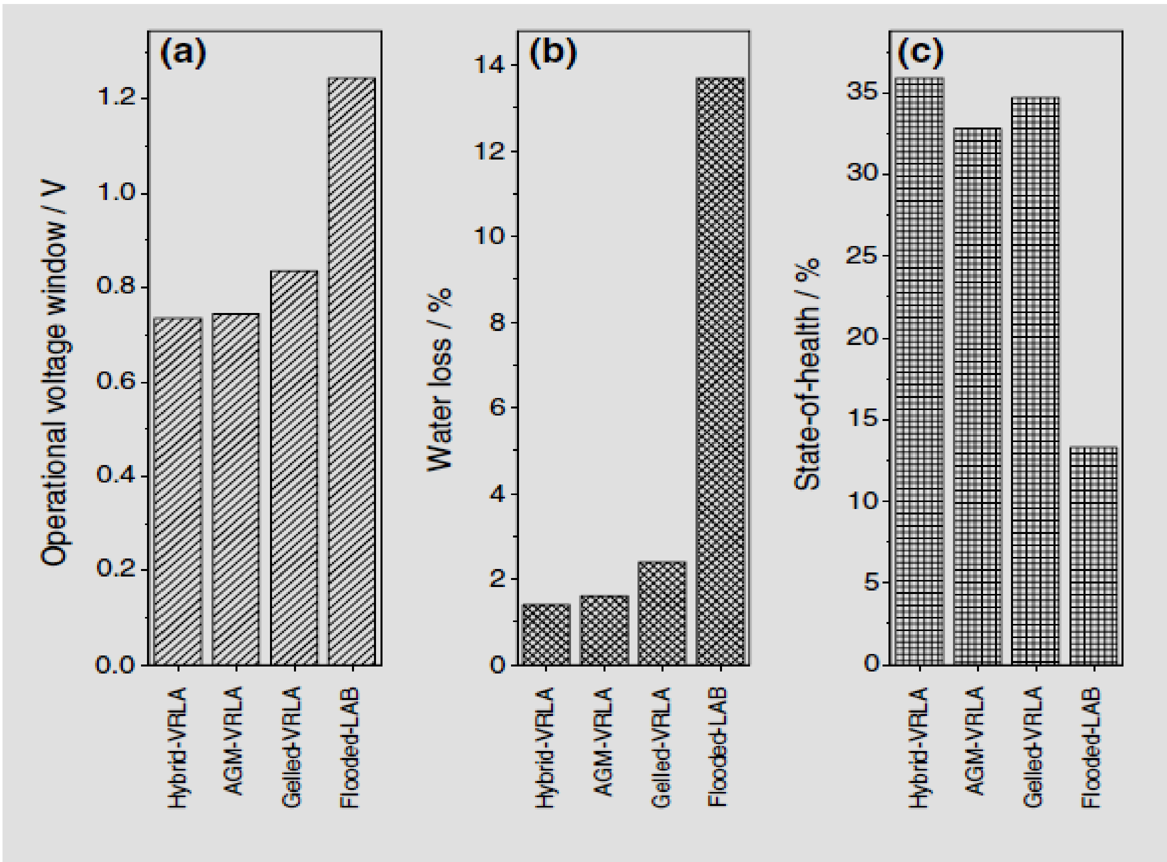



**Fig.2. Histogram showing a. operational window b. water loss c. state- of- health for hybrid VRLA, AGM VRLA. Gelled VRLA and flooded lead-acid batteries**

The charging characteristics of the said batteries on a clear and cloudy days were shown in fig.3.It is clear that the charge input to the battery through SPV panel depends on solar insolation which is low during cloudy days as shown in fig.4. . This affects the discharge characteristics of the storage system as the end of discharge voltage reaches quickly as shown in fig.5.

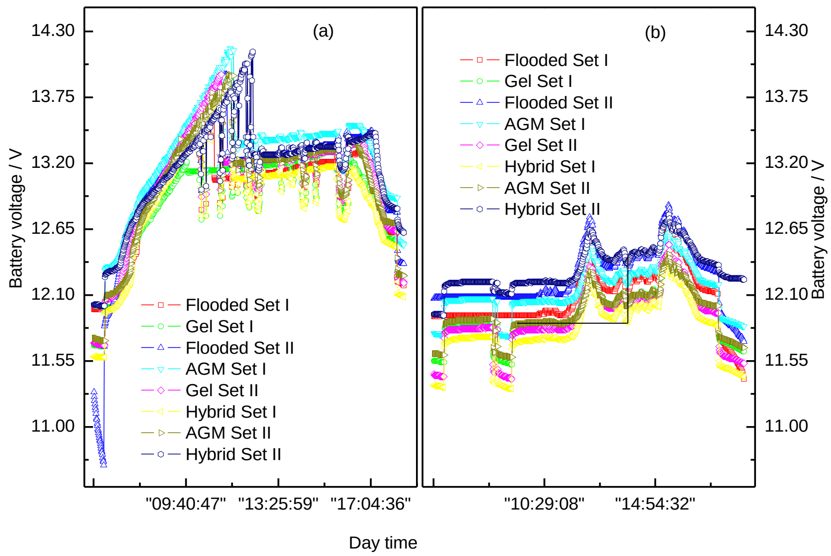



**Fig.3 Typical charge data on (a) a clear day and (b) a cloudy day for various types of lead-acid batteries employed during the solar-lighting application.**

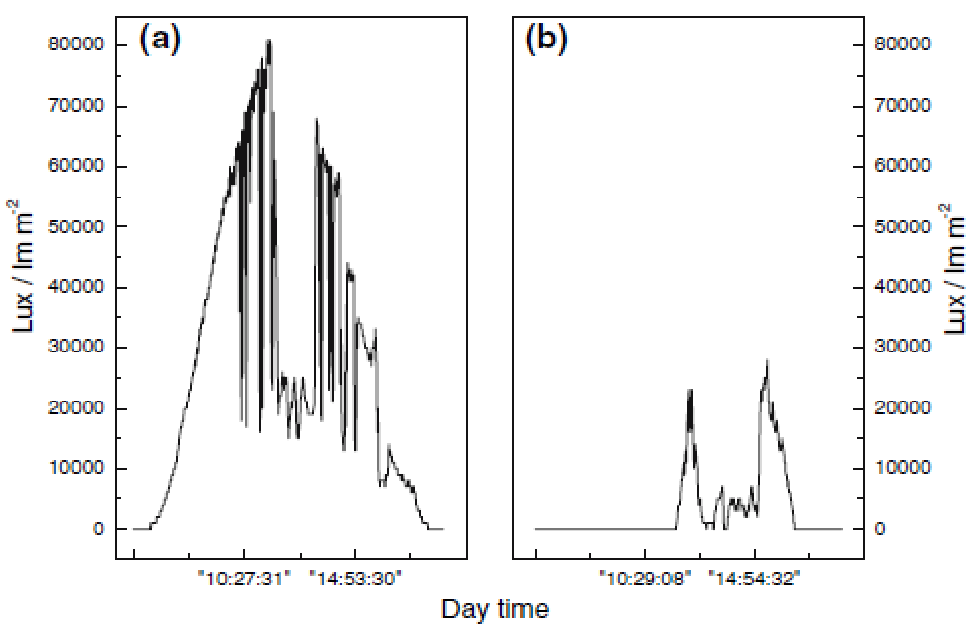



**Fig.4 Typical lux data on (a) a clear day and (b) a cloudy day for various type of lead-acid batteries employed during the present solar-lighting application study**

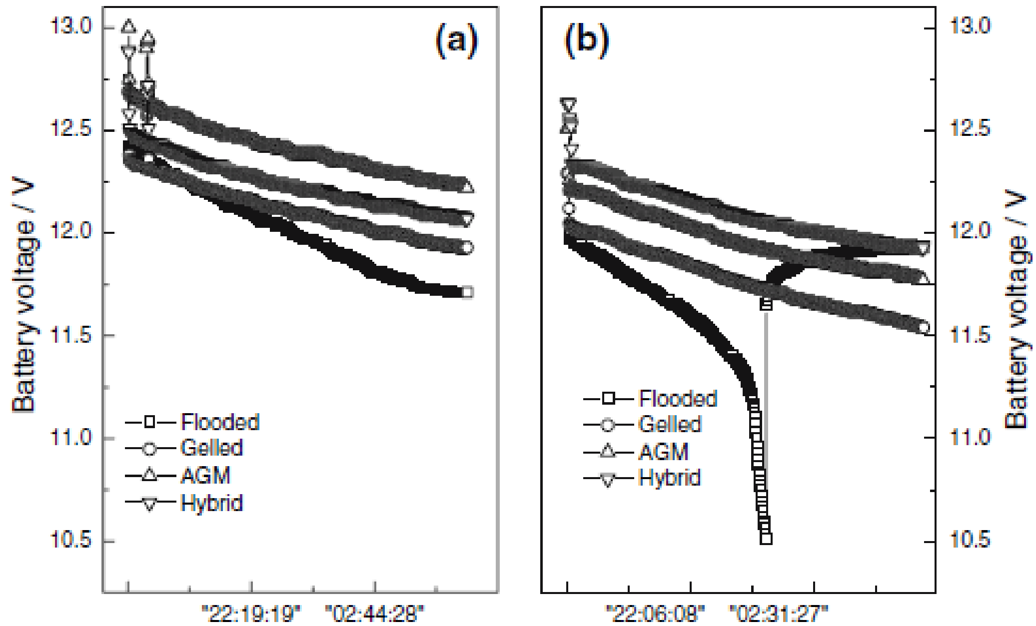



**Fig.5 Typical discharge data on (a) a clear day and (b) a cloudy day for various type of Lead-acid batteries employed during the present solar-lighting application study**

### 1.1.2Conclusions

The field study for PV stand-alone solar-lighting application conducted on hybrid VRLA, AGM VRLA, gelled-electrolyte VRLA and flooded-electrolyte lead acid batteries suggest that VRLA batteries exhibit both lower internal resistances with high thermal stability, which are desirous of a battery for any PV stand-alone application

## 1.2. Solar station II

Based on the results obtained from the preliminary studies, a new solar battery testing station [station II] with 36 nos. of PV lighting systems were installed and testing of batteries started in 2006. The photographs of the testing station II is given in fig 6 and data logging in fig.7

**SOLAR STATION II**

**Fig.6. Photograph of solar station II**

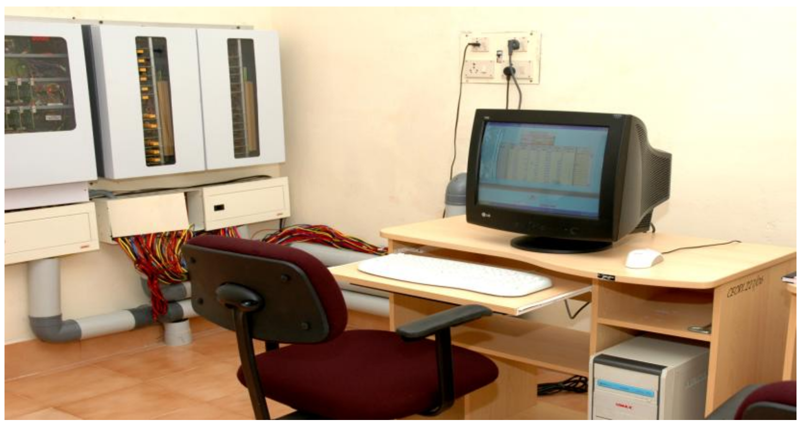


**Fig.7. Photograph of data logging in solar station II**

In solar station II studies were under taken for battery sizing in solar stand alone street light application. As per MNRE guidelines, the total sunless days for the battery to be performed are five sunless days. In this study we used VRLAbatteries of AGM, GEL and Hybrid. The capacities of these batteries were 12V/ 25Ah, 50Ah, 100Ah. These batteries were assembled in battery industry. The said batteries were fitted to the to street-lighting solar photovoltaic (SPV) panels having two sub-panels each of which comprised 36 silicon cells. The impedance of each sub-panel was 2.35 X with Vmp (voltage at maximum power) = 17 V, Isc (short-circuit current) = 2.5 A, and Pmax (maximum power) = 40 W ± 10%. The energy in each of the battery was used to light an 11 W CF lamp during night (18:00–6:00 h). These batteries were charged during the daytime.. Provision was made to collect battery temperature (both ambient and cabinet), current, voltage, energy input and intensity of solar radiation using data logger. All the studies were conducted on three sets of batteries. The discharge capacity through 11W CFL from dusk to dawn is 15Ah.The daily depth of discharge for the batteries with capacity of

12V/25, 50, 100Ah were 60%, 30%, 15% respectively. Fig.8 depicts the capacity vs depth of discharge.

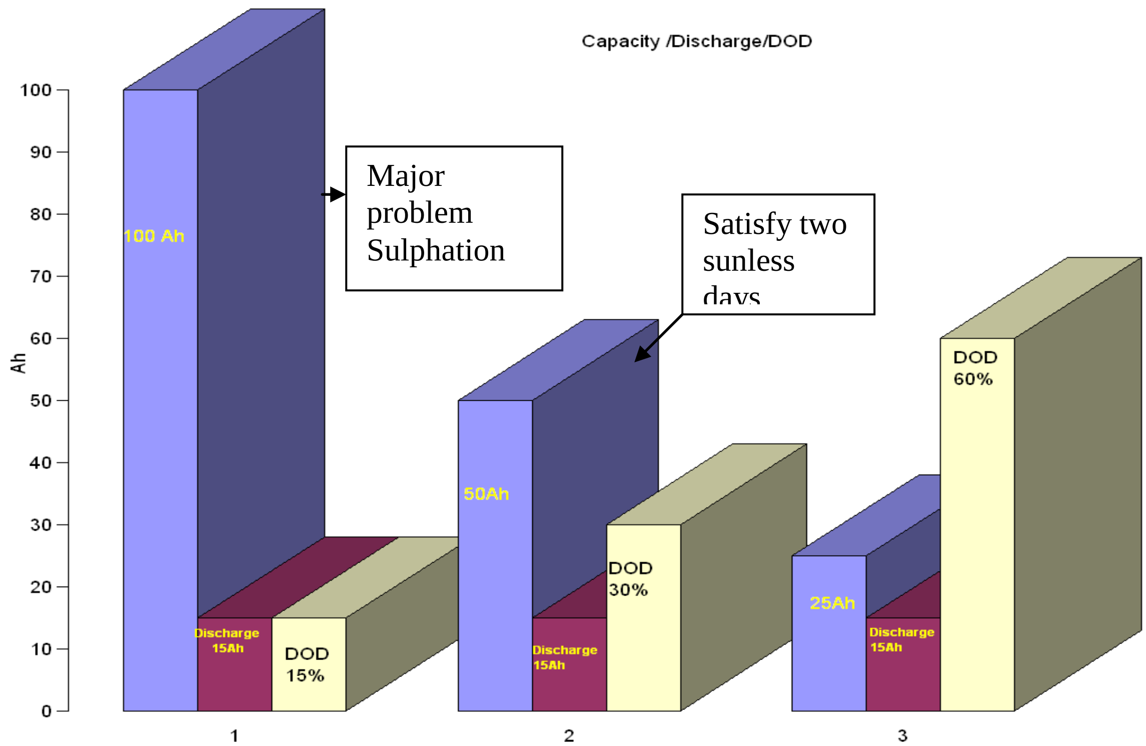



**Fig.8 Depicts histogram Capacity vs. DOD**

## 1.2.1 Conclusion:

It is seen that 12V/24Ah VRLA battery will not satisfy three sunless days. However it attains the rated capacity during sunny days.The 12V/50Ah VRLA battery will work for two sunless days and 12V/100 Ah will work for five sunless days.

## 1.3. Nomograms

Based on the above studies nomogram was drawn as shown in fig.9, which shows the relation ship between capacities, state of charge and for five sunless days.

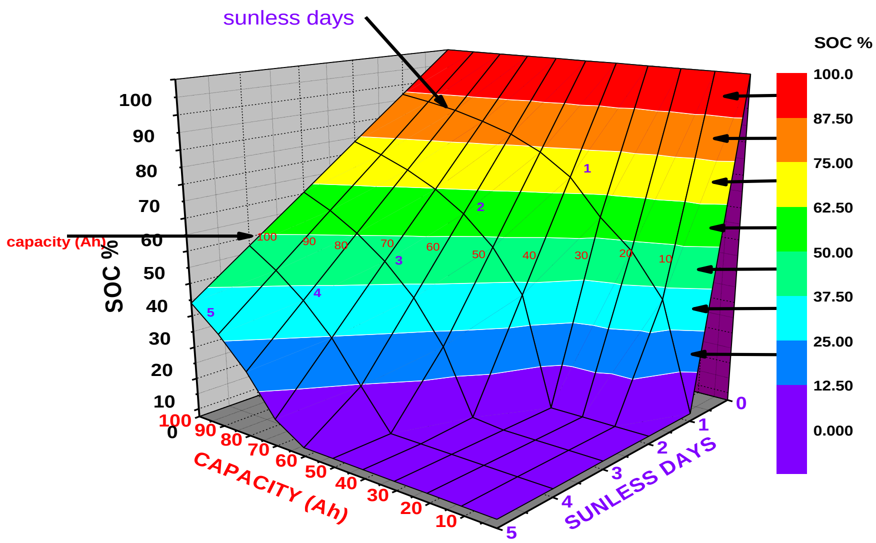



**Fig.9 Relationship between capacity, sunless days and state of charge [SOC]**

It is clear that the use of higher capacity battery will meet the demand for energy during sunless days. However higher capacity battery will take long time to attain the rated capacity during sunny days, thereby the chances for irreversible lead sulphate formation are more. This is shown in the fig.10.

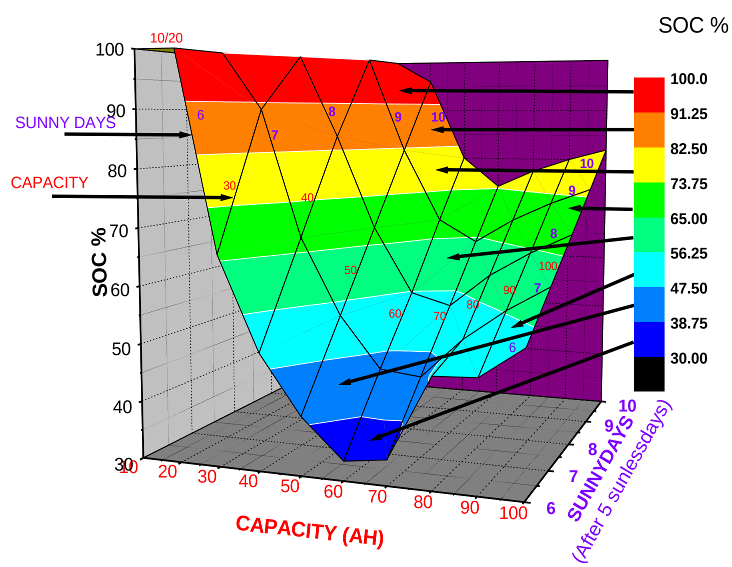



**Fig.10. Relationship between capacity, state of charge [SOC] and after five sunny days**

Based on the nomogram for 11W CFL solar stand alone lighting application the daily discharge output from the battery is 150-180Wh. The table 1. gives Wh generated by 80W panel under different insolation.

**Table: 1 Panel power output at different insolation**

| Insolation W/sq. m | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
|---|---|---|---|---|---|---|---|---|---|
| 100 | 8.5 | 17 | 25.5 | 34 | 42.5 | 51 | 59.5 | 68 | 76.5 |
| 200 | 17 | 34 | 51 | 68 | 85 | 102 | 119 | 136 | 153 |
| 300 | 25.5 | 51 | 76.5 | 102 | 127.5 | 153 | 178.5 | 204 | 229.5 |
| 400 | 34 | 68 | 102 | 136 | 170 | 204 | 238 | 272 | 306 |
| 500 | 42.5 | 85 | 127.5 | 170 | 212.5 | 255 | 297.5 | 340 | 382.5 |
| 600 | 51 | 102 | 153 | 204 | 255 | 306 | 357 | 408 | 459 |
| 700 | 59.5 | 119 | 178.5 | 238 | 297.5 | 357 | 416.5 | 476 | 535.5 |
| 800 | 68 | 136 | 204 | 272 | 340 | 408 | 476 | 544 | 612 |
| 900 | 76.5 | 153 | 229.5 | 306 | 382.5 | 459 | 535.5 | 612 | 688.5 |

For the same load and wattage of the panel, charge acceptance for the low capacity battery is higher than the higher capacity battery on account of high depth of discharge. The table-2 gives how the performances of the batteries vary with different capacity.

**Table-2. For the same load, how the performance vary with different capacity batteries**

**Battery capacity different**
**Assume two solar panels of 40Wpconnected in parallel to each battery for a load of 11W CFL,12hrs.with discharge current 1.3A each, discharge output = 15.6Ah**

| 12V/25Ah lead - acid battery | 12V/75Ah lead- acid battery |
|---|---|
| Daily depth of discharge15.6/25 = 62.4% | Daily depth of discharge 15.6/75 = 36% |
| State of charge = 37.6% | State of charge = 64% |
| 1.Charge efficiency is high | 1. Charge efficiency is low |
| 2.Lighting during cloudy days not possible | 2. Lighting during cloudy days possible due to oversize battery |
| 3.Battery reaches full soc during sunshine | 3. Battery never reaches full SOC during next sunshine–under goes sulphation |
| 4.No sulphation | |

In the case of same capacity of the battery, when wattage of the panel is increased, it affects the storage system with grid corrosion and shedding which is shown in the table-3.

**Table-3.Module sizing for the same load and battery capacity**

| **40Wp panel** | **80Wp panel** | **120Wp panel** |
|---|---|---|
| **One panel** | **Two panels are connected in parallel** | **Three panels are connected in parallel** |
| **$I_{scc}$ 2.5A** | **$I_{scc}$ 5.0A** | **$I_{scc}$ 7.5A** |
| **Disch.output thro.CFL<br>12h* 1.25A =15Ah** | **Disch.output thro.CFL<br>12h* 1.25A =15Ah** | **Disch.output thro.CFL<br>12h* 1.25A =15Ah** |
| **avg.current 1.25A for 6hrs =7.5Ah [charge]** | **avg.current 2.5A for 6hrs= 15Ah[charge]** | **avg.current 3.75A for 6hrs= 22.5Ah[charge]** |
| **Problems:<br>Battery undercharging<br>Negative plate sulphation<br>Bulging of container** | **Problems:<br>Daily input and output equal.<br>Battery undercharging after sunless days.** | **Problems:<br>Battery overcharging<br>Water loss<br>Grid corrosion,<br>shedding of active mass** |

## 1.4 Tubular lead-acid batteries

In the one day workshop held at Chennai on 1.10.2010, the participants from the battery industries requested CECRI to collect data for tubular lead-acid battery for solar street light application. CECRI fabricated 12V/60Ah flooded tubular lead-acid battery for the said application with the help of battery industry at Bangalore. These batteries were fitted to the existing solar stand alone street light application and data were collected. Its performance in the field is being studied. Fig.11 shows the performance characteristics of flooded tubular lead-acid battery

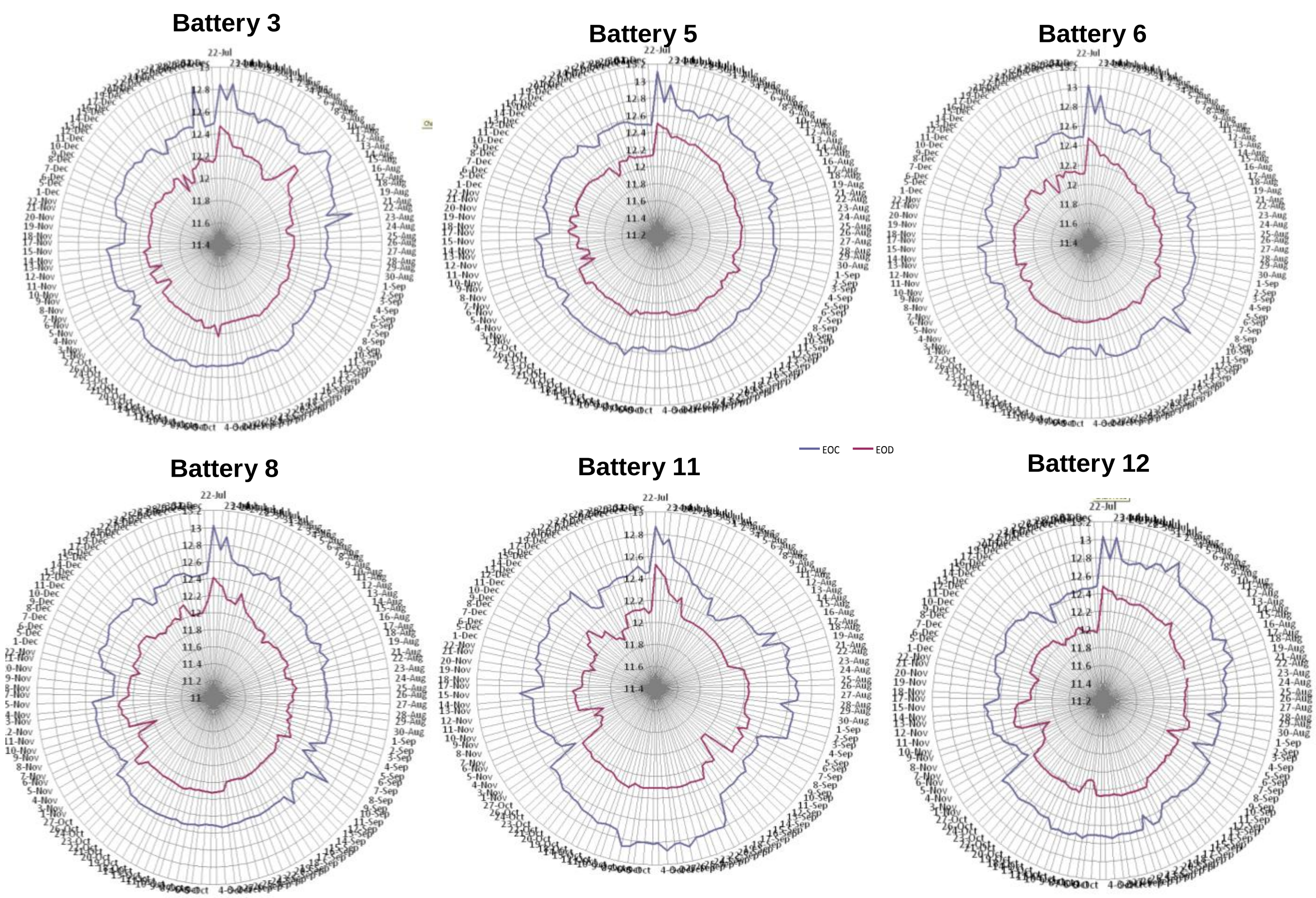



**Fig.11. End of charge [EOD] and End of discharge of flooded tubular lead-acid battery**

The data collected for the flooded tubular lead-acid battery for the said application was compared with VRLA batteries. Their figs.12 were given below. It was seen that the end of charge and end of discharge voltages were higher for the VRLA battery. It indicates the charge acceptance for the VRLA battery was higher.

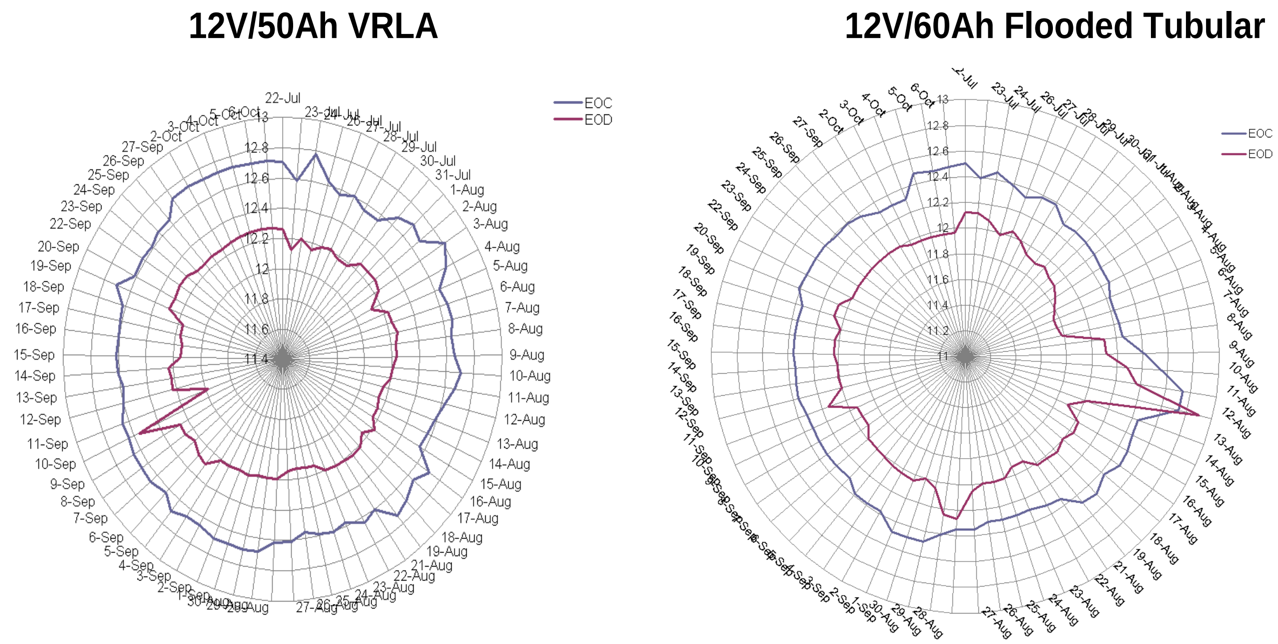



**Fig.12 comparison between VRLA and Tubular lead-acid battery**

## 1.6 Other storage systems

CSIR-CECRI also studied the use of Lithium-iron- phosphate batteries for the solar photovoltaic stand alone lighting application. An agency at Chennai supplied 12V/7Ah of the said battery. It was fitted to the solar stand alone lighting system and its performance data were collected. Fig.13. shows the charge cure of the lithium-iron- phosphate batter fitted to the solar stand alone lighting system. Fig.14 shows plot between charging current vs time. Further studies are needed with the use of these batteries for SPV application

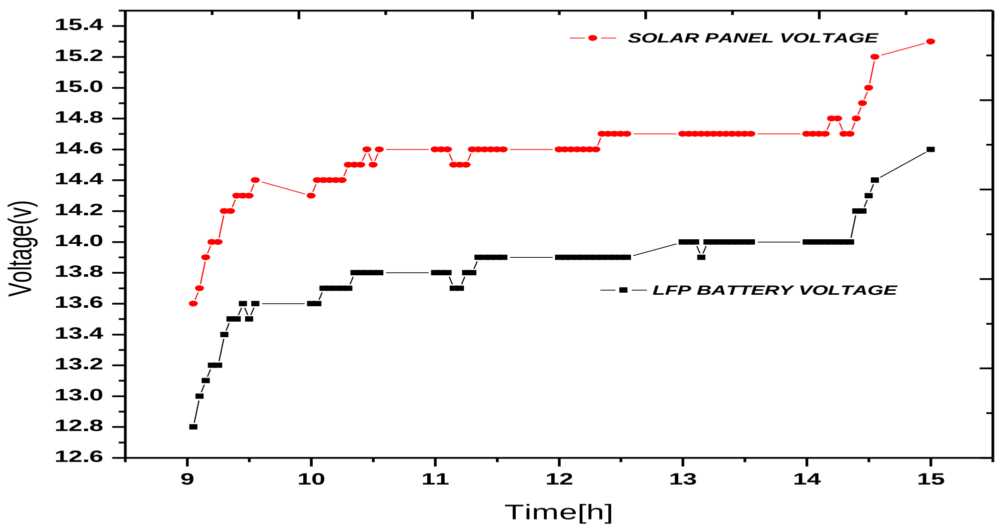



**Fig.13 charging Voltage-time graph for charging of LFP battery**

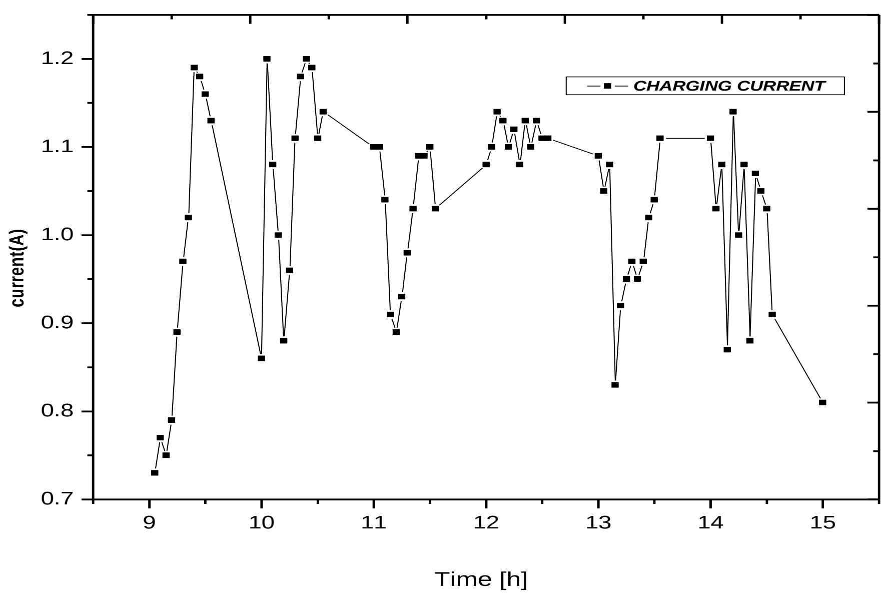


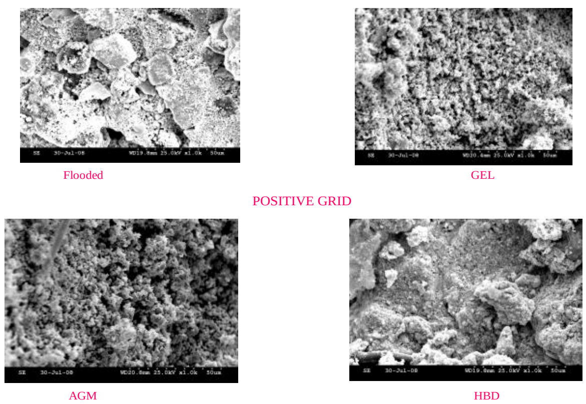

**Fig.14 charging current -time graph for charging of LFP battery**

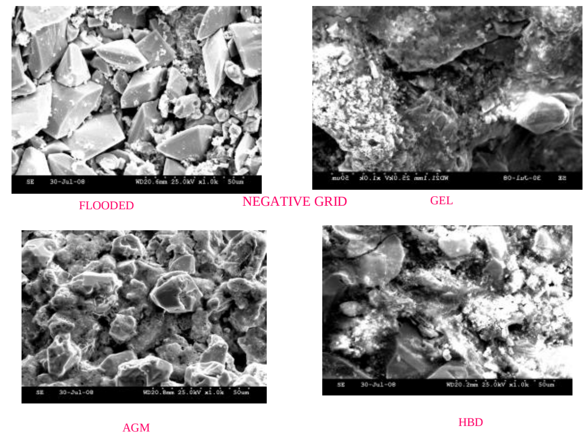
# 2.0 FAILURE ANALYSIS

**2.1 Failure analysis of the 12V/50Ah lead-acid batteries in used in solar stand alone street light applications for more than two years were investigated.** Batteries were cut and samples were taken for photomicrographs. The photomicrograph in fig.14 depicts the photographs of the elements. Shedding of positive active mass occurred in flooded positive plate, where as it did not occur in other plates.


Fig.14 Photomicrographs of positive and negative plates

Samples were taken from the grid and active mass, examined under Scanning Electron Microscope [JEOL]. Figs. 15 & 16 depict photomicrographs of positive and negative grid. Figs.17 & 18 depict photomicrographs of Positive and negative active mass.

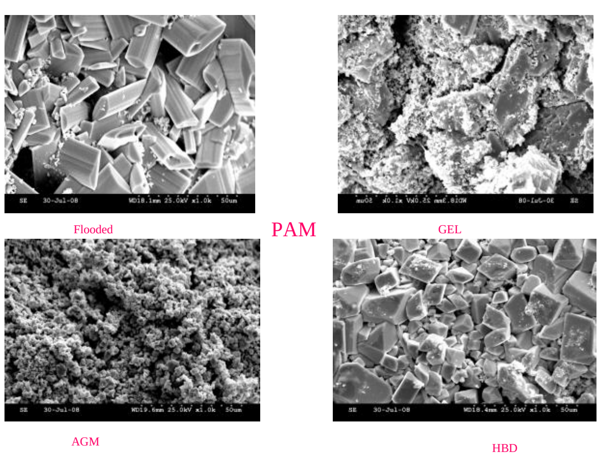


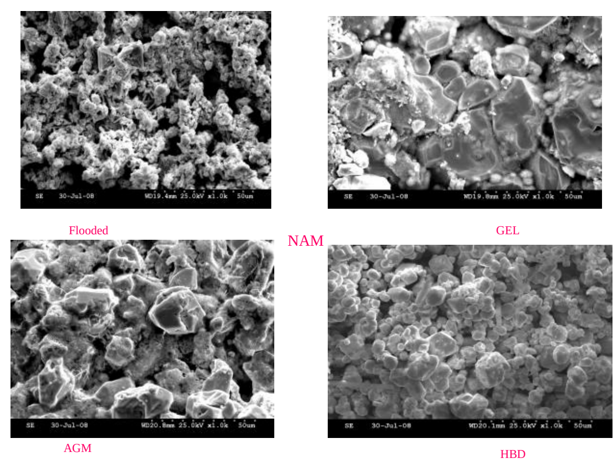




The figure shows the porous nature of the positive grid for VRLAB compare to the flooded

The figure shows the structure of the negative grid .The Hybrid structure indicate the presence of lead sulphate in small quantity and porous in nature

**Figs. 15 & 16 depict photomicrographs of positive [left] and negative grid [right]**




The figure shows the distribution of lead sulphate in the positive active material. Due to high compression of the AGM separator the lead sulphate is small in size in AGM VRLAB followed by the Hybrid VRLAB, flooded and GEL VRLAB

The figure shows the distribution of lead sulphate in the negative active material. The size of the lead sulphate crystals in the Hybrid VRLAB is lower, compare to the other types. Smaller the size of the crystal better for easy charging.

**Figs.17 & 18 depict photomicrographs of Positive and negative active mass.**

## 2.1.1. Conclusion:

From the photomicrographs it is seen that the suphation is the major failure mode in lead-acid battery for the solar stand alone lighting application

## 2.2. Studies on lead sulphate

A detailed study was undertaken to find how the lead sulphate crystal size varies in different specific gravity, discharge rates and duration.. For this study, Pb-Ca alloy grid having size: 11 cm x 11.5cmx 1mm were used. 16 cells were fabricated with each cell capacity was 2V/8Ah. The following unit operations shown in table-4 were carried out to fabricate the cells. The table-5 gives the parameters we used in this study.

**Table-4 Unit operations in lead-acid battery**

| Unit Operation | Process |
|---|---|
| 1.Mixing | Preparation of Paste by mixing Grey Oxide , 1.30 Sp.Gr Sulphuric Acid, Dist.$H_2O$, Dynel fibre and Carbon Black for positive plate and Grey Oxide , 1.30 Sp.Gr Sulphuric Acid, Dist.$H_2O$, Lignin ,$BaSO_4$ and Carbon Block for negative plate |
| 2. Pasting | Active mass is applied to the positive and negative grids |
| 3.Curing | Bonding between inactive mass and grid, at RT,100%RH |
| 4.Drying | After curing the plates are allowed to dry under natural condition. |
| 5. Formation | It is the electrochemical conversion of the inactive mass into active mass at positive and negative plate with lead dioxide and sponge lead respectively |

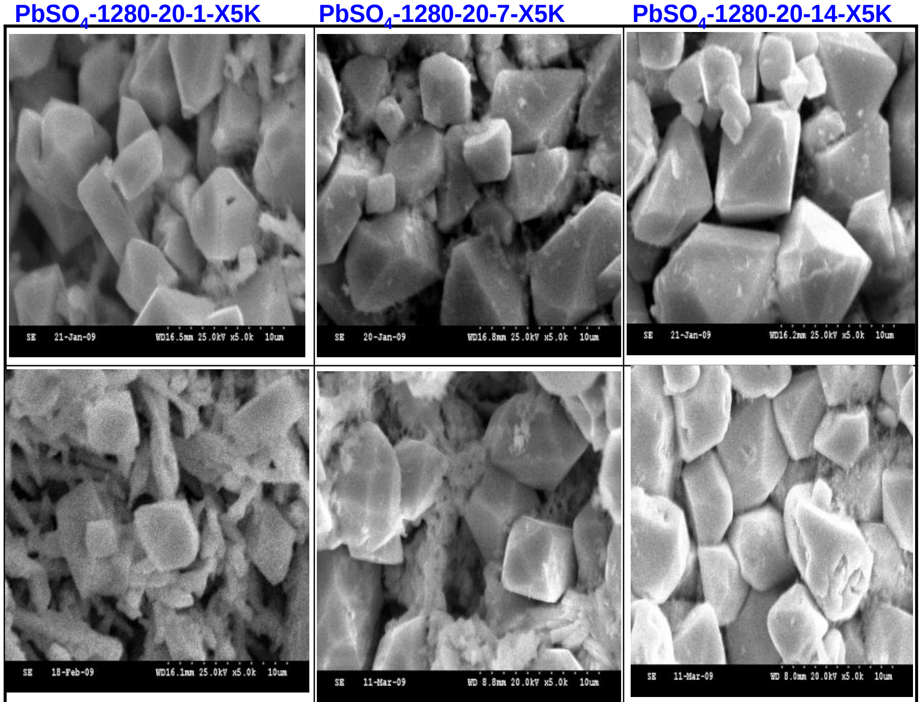
**The table-5 Parameters**

| | |
|---|---|
| Specific gravity of sulphuric acid | 1.280,1.260,1.240,1.220 |
| Discharge rate | 20h, 10h and 5 h |
| Idle period for sampling in the discharge state | 1, 7, 14, 21, 28 and 35days |

The cells were discharged at different rates and kept in the discharged state at room temperature. Periodically samples were taken from the negative plates, after the completion of idling period. These samples were washed with distilled water and its microstructure was observed in Scanning Electron Microscope.

The photomicrographs of figs.19-30 shows that the lead-sulphate crystals will undergo the dissolution and precipitation phenomenon when you keep the battery in the discharged state for longer duration.

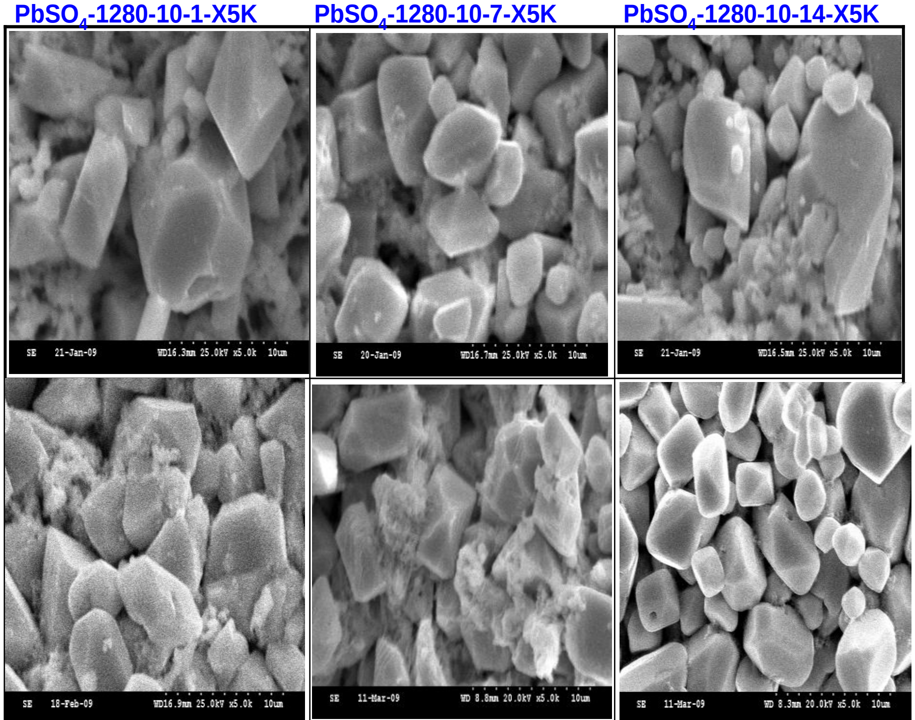
$PbSO_4$-1280-20-1-X5K $PbSO_4$-1280-20-7-X5K $PbSO_4$-1280-20-14-X5K



$PbSO_4$-1280-20-21-X 5K $PbSO_4$-1280-20-28-X 5K $PbSO_4$-1280-20-35-X 5K

**Fig.19 shows the leadsulphate crystals in 1.280, 20h rate and durations**

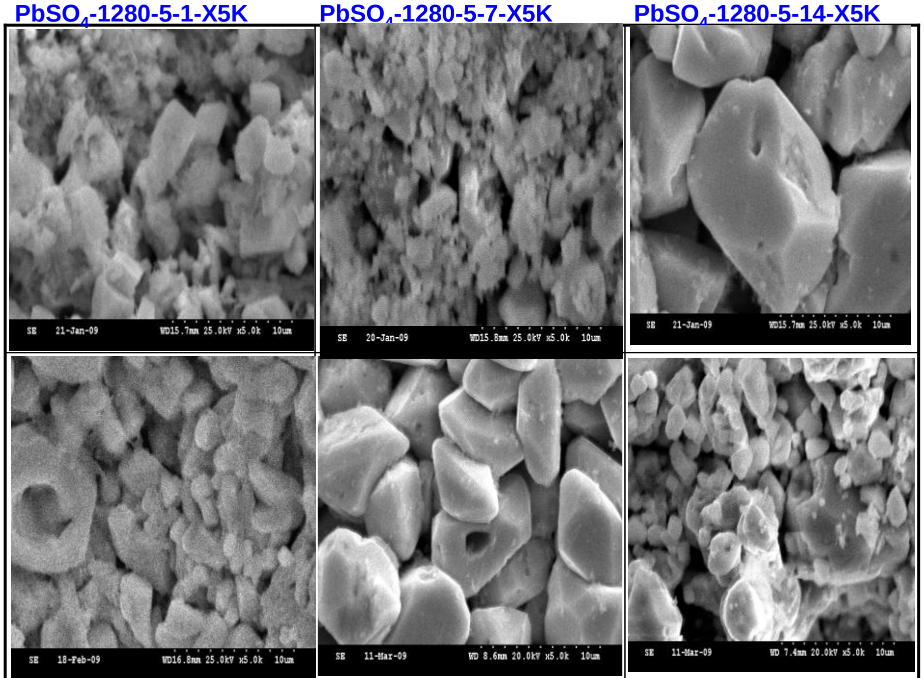
$PbSO_4$-1280-10-1-X5K $PbSO_4$-1280-10-7-X5K $PbSO_4$-1280-10-14-X5K



$PbSO_4$-1280-10-21-X 5K $PbSO_4$-1280-10-28-X 5K $PbSO_4$-1280-10-35-X 5K

**Fig.20 shows the lead sulphate crystals in 1.280, 10h rate and durations**

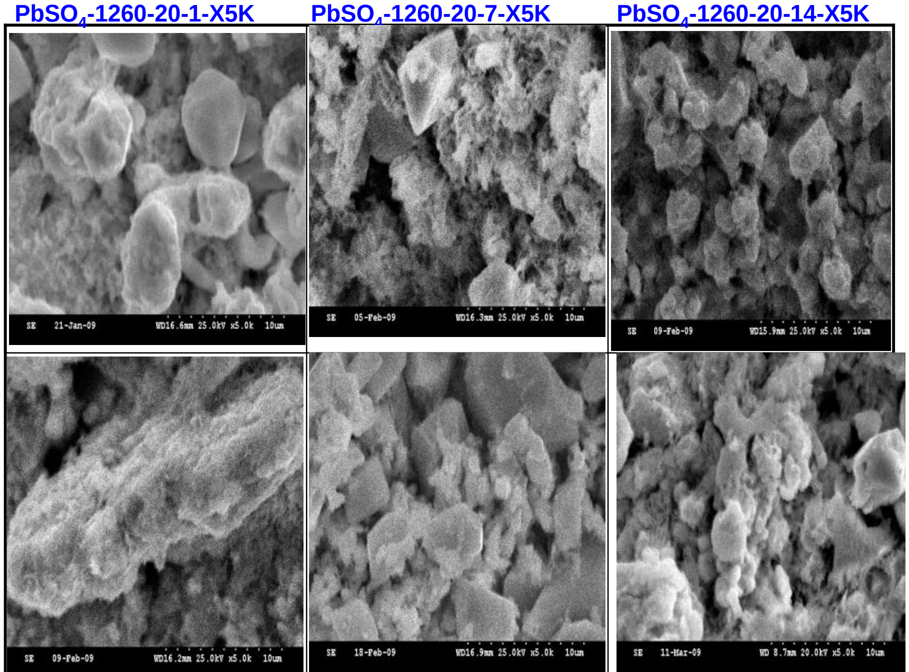
$PbSO_4$-1280-5-1-X5K $PbSO_4$-1280-5-7-X5K $PbSO_4$-1280-5-14-X5K



$PbSO_4$-1280-5-21-X 5K $PbSO_4$-1280-5-28-X 5K $PbSO_4$-1280-5-35-X 5K

**Fig.21hows the lead sulphate crystals in 1.280, 5h rate and durations**

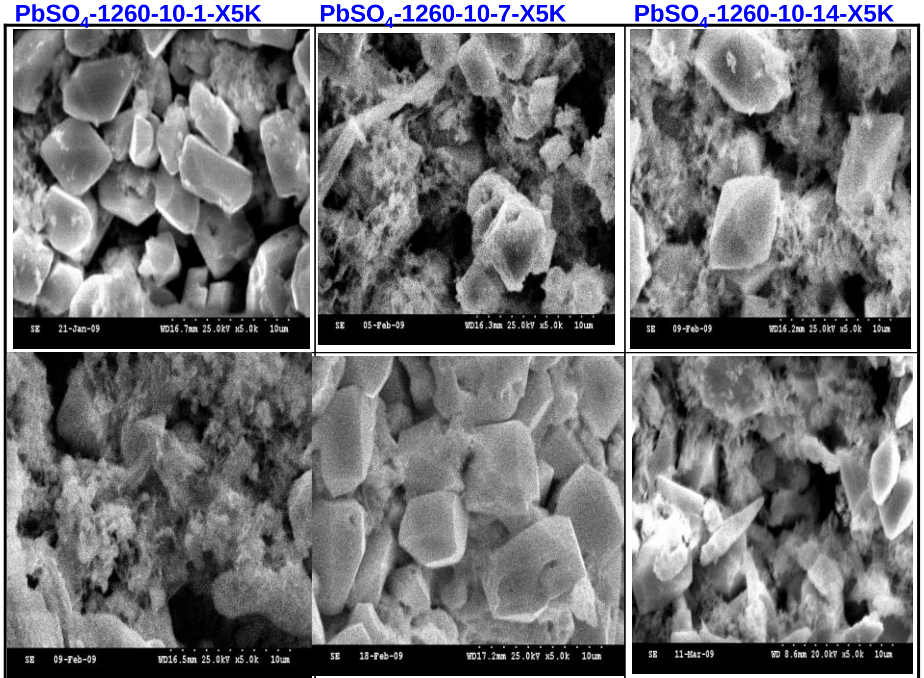
$PbSO_4$-1260-20-1-X5K $PbSO_4$-1260-20-7-X5K $PbSO_4$-1260-20-14-X5K



$PbSO_4$-1260-20-21-X 5K $PbSO_4$-1260-20-28-X 5K $PbSO_4$-1260-20-35-X 5K

**Fig.22Shows the lead sulphate crystals in 1.260, 20h rate and durations**

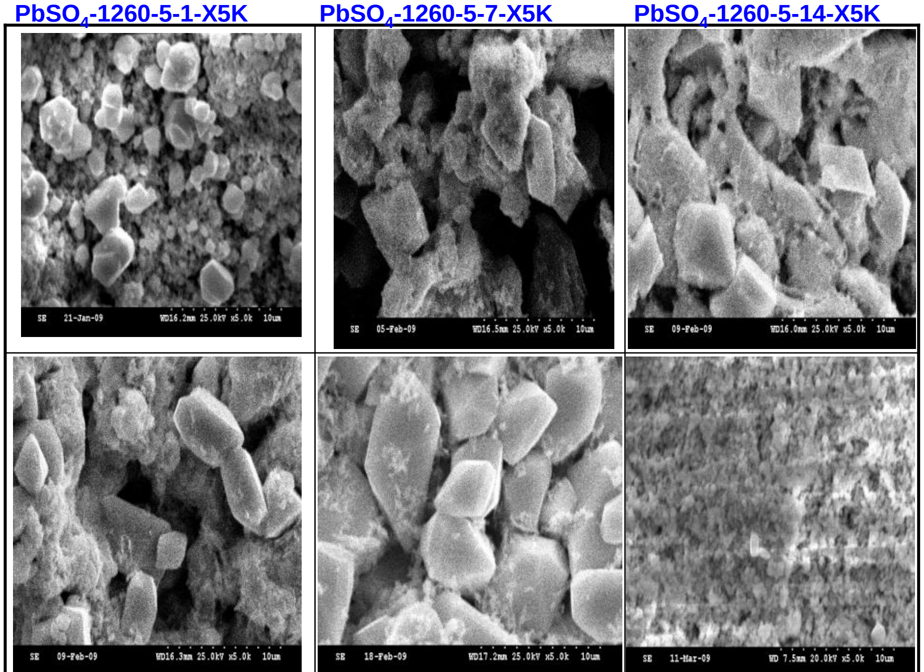
$PbSO_4$-1260-10-1-X5K $PbSO_4$-1260-10-7-X5K $PbSO_4$-1260-10-14-X5K



$PbSO_4$-1260-10-21-X 5K $PbSO_4$-1260-10-28-X 5K $PbSO_4$-1260-10-35-X 5K

**Fig.23Shows the lead sulphate crystals in 1.260, 10h rate and durations**

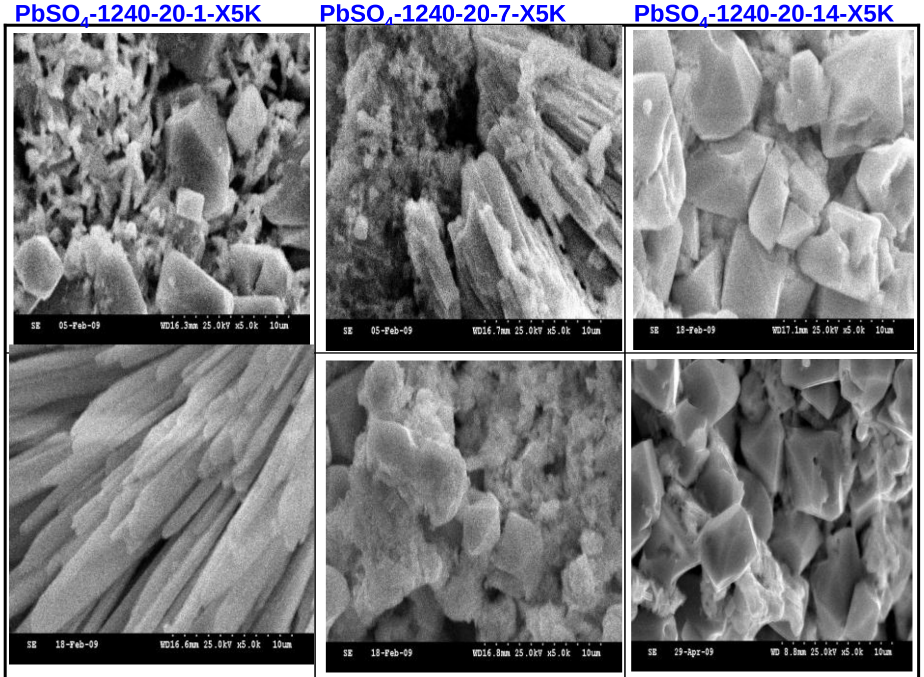
$PbSO_4$-1260-5-1-X5K $PbSO_4$-1260-5-7-X5K $PbSO_4$-1260-5-14-X5K



$PbSO_4$-1260-5-21-X 5K $PbSO_4$-1260-5-28-X 5K $PbSO_4$-1260-5-35-X 5K

**Fig.24Shows the lead sulphate crystals in 1.260, 5h rate and durations**

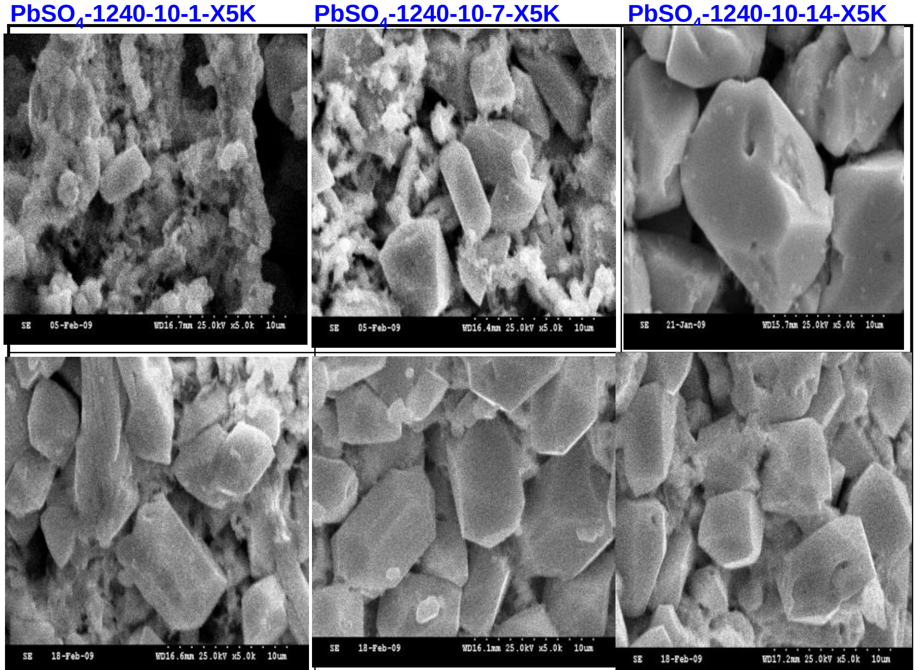
$PbSO_4$-1240-20-1-X5K $PbSO_4$-1240-20-7-X5K $PbSO_4$-1240-20-14-X5K



$PbSO_4$-1240-20-21-X 5K $PbSO_4$-1240-20-28-X 5K $PbSO_4$-1240-20-35-X 5K

**Fig.25Shows the lead sulphate crystals in 1.240, 20h rate and durations**

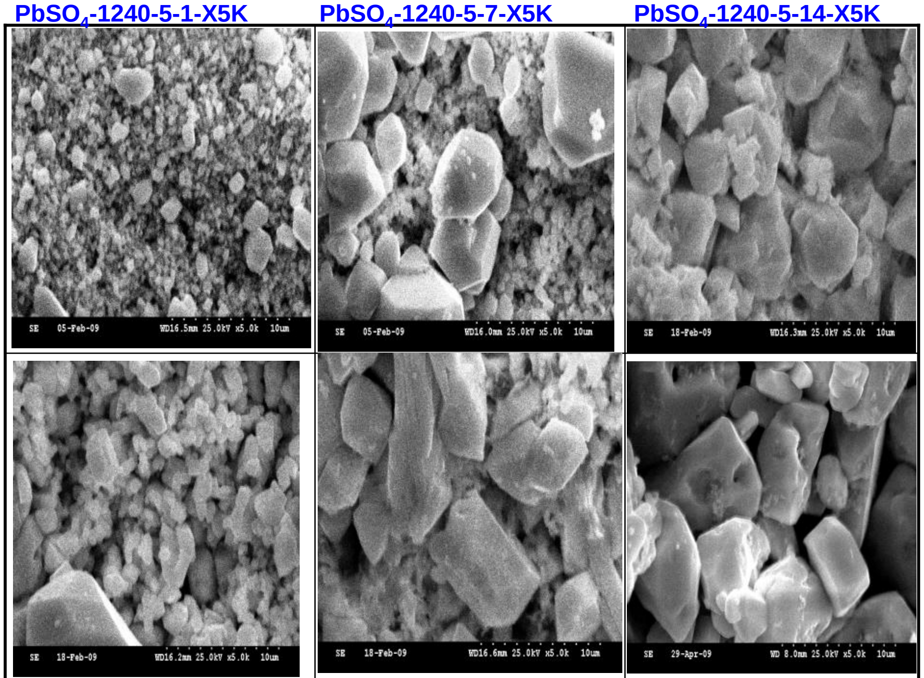
$PbSO_4$-1240-10-1-X5K $PbSO_4$-1240-10-7-X5K $PbSO_4$-1240-10-14-X5K



$PbSO_4$-1240-10-21-X 5K $PbSO_4$-1240-10-28-X 5K $PbSO_4$-1240-10-35-X 5K

**Fig.26Shows the lead sulphate crystals in 1.240, 10h rate and durations**

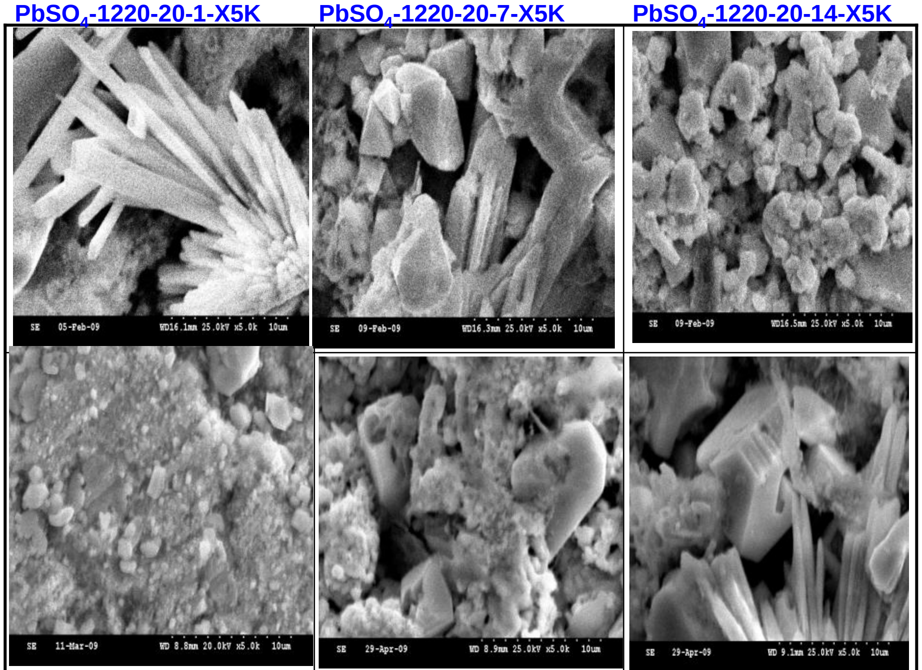
$PbSO_4$-1240-5-1-X5K $PbSO_4$-1240-5-7-X5K $PbSO_4$-1240-5-14-X5K



$PbSO_4$-1240-5-21-X 5K $PbSO_4$-1240-5-28-X 5K $PbSO_4$-1240-5-35-X 5K

**Fig.27Shows the lead sulphate crystals in 1.240, 5h rate and durations**

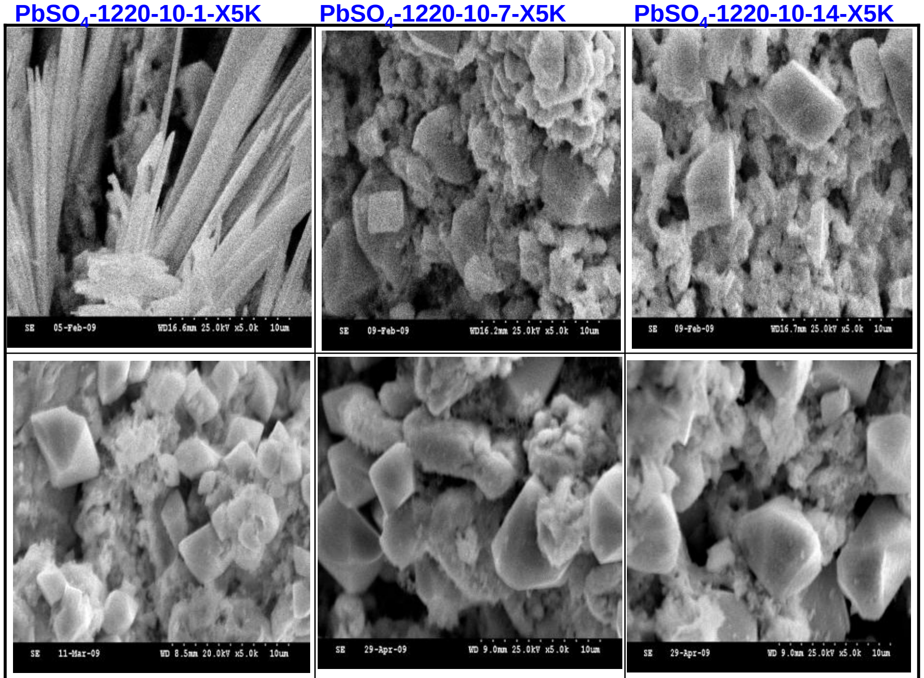
$PbSO_4$-1220-20-1-X5K $PbSO_4$-1220-20-7-X5K $PbSO_4$-1220-20-14-X5K



$PbSO_4$-1220-20-21-X 5K $PbSO_4$-1220-20-28-X 5K $PbSO_4$-1220-20-35-X 5K

**Fig.28Shows the lead sulphate crystals in 1.220, 20h rate and durations**

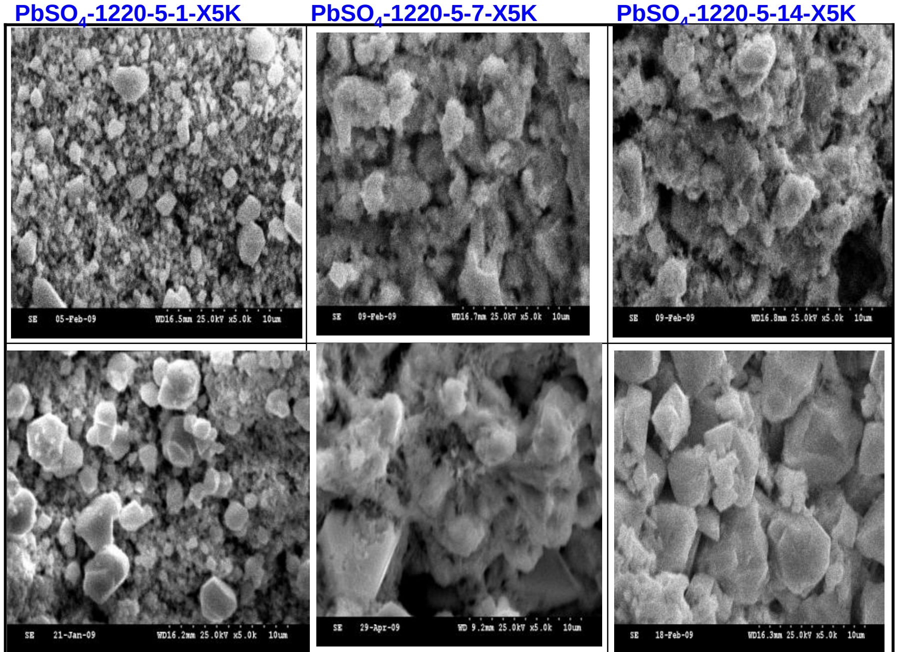
$PbSO_4$-1220-10-1-X5K $PbSO_4$-1220-10-7-X5K $PbSO_4$-1220-10-14-X5K



$PbSO_4$-1220-10-21-X 5K $PbSO_4$-1220-10-28-X 5K $PbSO_4$-1220-10-35-X 5K

**Fig.29Shows the lead sulphate crystals in 1.220, 10h rate and durations**

$PbSO_4$-1220-5-1-X5K $PbSO_4$-1220-5-7-X5K $PbSO_4$-1220-5-14-X5K



$PbSO_4$-1220-5-21-X 5K $PbSO_4$-1220-5-28-X 5K $PbSO_4$-1220-5-35-X 5K

**Fig.30Shows the lead sulphate crystals in 1.220, 5h rate and durations**

The relationship between number days, sp.gr. and lead- sulphate crystal size [micron] is shown in fig 31

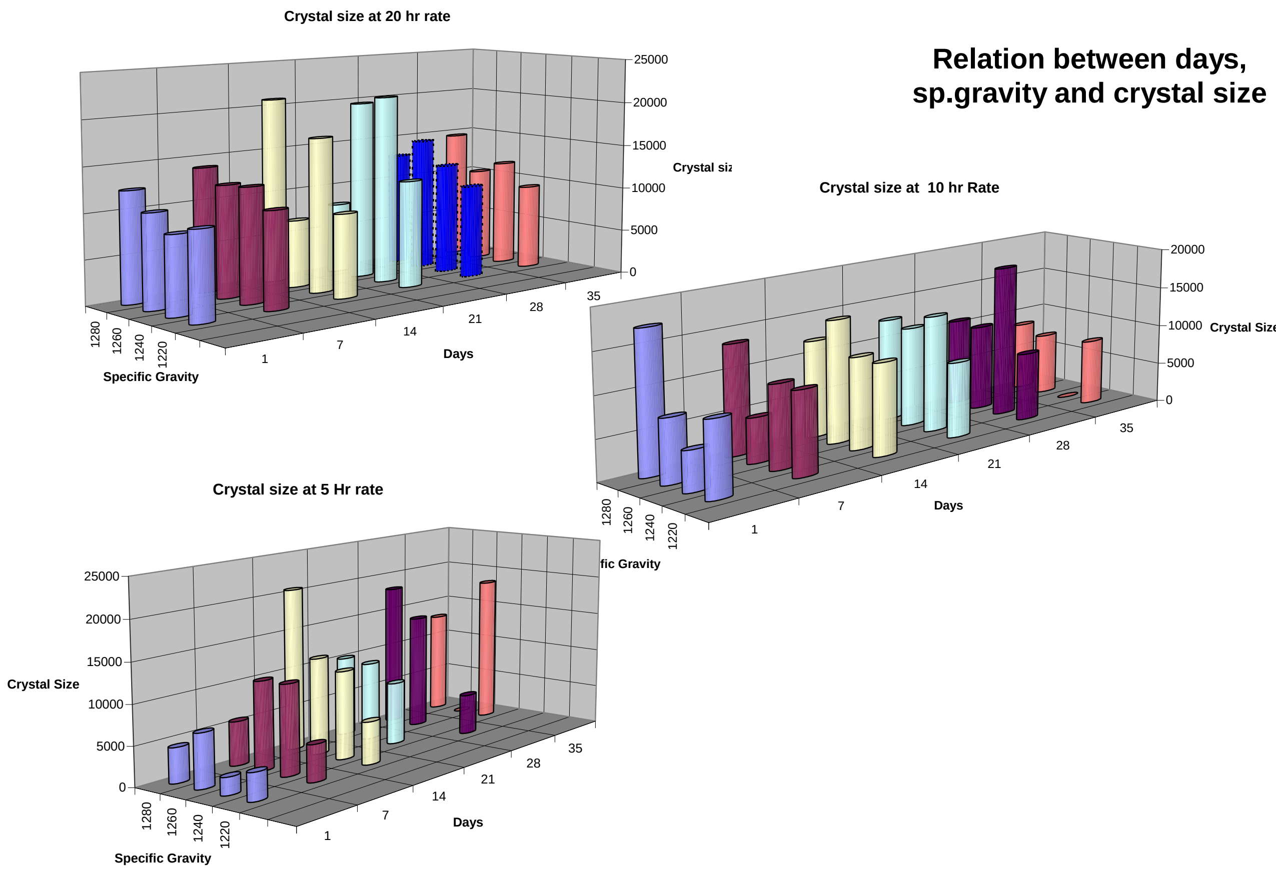



**Fig.31 Relationship between days, sp.gr and crystal size**

## 2.3 Conclusions:

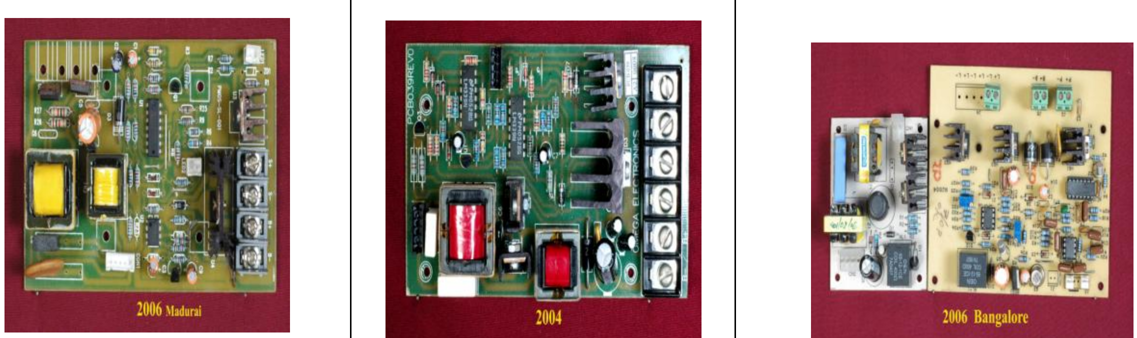
1. The crystallization mode of lead-sulphate changes from three dimensional to two modes as the specific gravity moves down from 1.280 to 1.220.
2. Sulphation is the major failure in LAB operated under PoSC operation such as SPV application

## 3.0 CHARGE CONTROLLER

In stand-alone photovoltaic [PV] systems, charge controllers regulate the current from the PV array in order to protect the battery from being overcharged and deep discharges. The charge controller is therefore the energy manager in a stand-alone PV system. Most controllers will initially allow all the current output from the PV array to pass to the battery, then, as the charging nears completion, will taper or interrupt the current according to the battery's ability to accept charge. It is an electronic circuit which monitors the charge in and out of the battery and, based on a set of voltage thresholds, regulates current flow in order to limit overcharge and over discharge. Although the controller is one of the least costly components in a stand-alone PV system, it strongly influences the long-term reliability and maintenance costs of PV system. Choosing the best controller for a particular system and application, and configuring it correctly are paramount. Controllers are generally built in either shunt or series type configuration.
To avoid accelerated ageing, VRLA batteries in PV systems should not be discharged below 40% state of charge {SOC} referring to the nominal capacity at $I_{20}$ [2].

### 3.1. Studies on the effect of charge controllers on the performance of 12V/50Ah AGM VRLAB

A study was conducted with respect to failure of lead - acid batteries due to the charge controller component in solar photovoltaic stand-alone lighting systems. In this study 12V/50 Ah VRLA (AGM design) battery was used. Three types of charge controller shown in fig.32 were procured from three different manufactures.




**[A]** **[B]** **[C]**

**Fig: 32 Photographs of charge controllers from different manufacturers**

Their manufacturing details are given in the table-6:

**Table-6. Manufacturing details of the charge controllers**

| A | B | C |
|---|---|---|
| Four wires system<br>(P+, P-, B+, B-)<br>Internal loop connections between (P- and B-)<br><br>It has five wire connector (Four wires to Bulb and One wire to GND)<br><br>Evening time:<br>When panel voltage is less than 2.4V light will glow.<br><br>Morning time:<br>When panel voltage reaches 2.5V light does not glow. (End of Discharge Voltage)<br>Lower Cut off Voltage: 10.83V<br><br>Components:<br>U1 – IC 339 – Comparator,<br>U2 – IC 393 – Comparator,<br>U3 – IC 3530 IRF<br>U4 – IC 2045 (3 legs, one is open)<br>U6 and U7 – IC 3055<br>*Transistors:*<br>Q1 – IC 558 (Timer IC)<br>Q2 – IC 558 (Timer IC)<br>Q3 – IC 431. | Six wires system<br>(P+, P-, B+, B-, S+, S-)<br>Internal loop connections between (P-, B-, and S), (B+ and S+)<br><br>It has five wire connector (Four wires to Bulb and One wire to GND)<br><br>Evening time:<br>When Panel voltage is 2.9V light will glow.<br><br>Morning time:<br>When panel voltage reaches 4.3V light will be switched Off.<br>(End of Discharge Voltage)<br>Lower Cut off Voltage: 10.5V<br><br>Components:<br>U1 – IC 339 – Comparator,<br>U2 – IC 393 – Comparator,<br>U3 – IC 3530 IRF<br>U6 and U7 – IC 3055<br>*Transistors:*<br>Q1 – IC 558 (Timer IC)<br>Q2 – IC 558 (Timer IC)<br>Q3 – IC 431. | Four wires system<br>(P+, P-, B+, B-)<br>Internal loop connections between (P- and B-)<br><br>It has four wire connector (Four wires to Bulb and no GND wire)<br><br>Evening time:<br>When panel voltage is less than 2.9V light will glow.<br><br>Morning time:<br>When panel voltage reaches 3.0V light does not glow.(End -of Discharge Voltage)<br>Lower Cut off Voltage: 10.54V<br><br>Components:<br>Q4 – IC 744N IRF<br>Q6 – IC 9540 IRF<br>D2 – MUR 1560 – Diode<br>*Transistors:*<br>Q2 – 2N 2222A<br>Q3 – 32N 2905<br>Q5 – BC 1076<br>D12 – IC 552 – Timer<br>REG1 – IC 7805<br>Constant Volt. Regulator IC (+05v).<br>*Small Size Board:*<br>Q1 and Q2 – IC 3055T |

These series type of controllers were fitted to solar stand alone lighting application. The performance of these controllers on cloudy and non cloudy days were shown in figs 33 and 34

Fig 33 charging curves on clear day

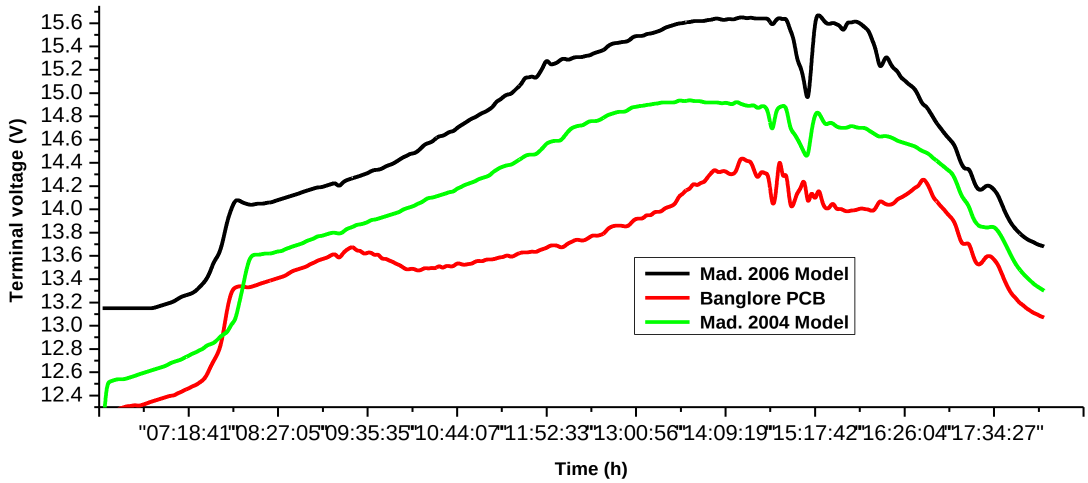
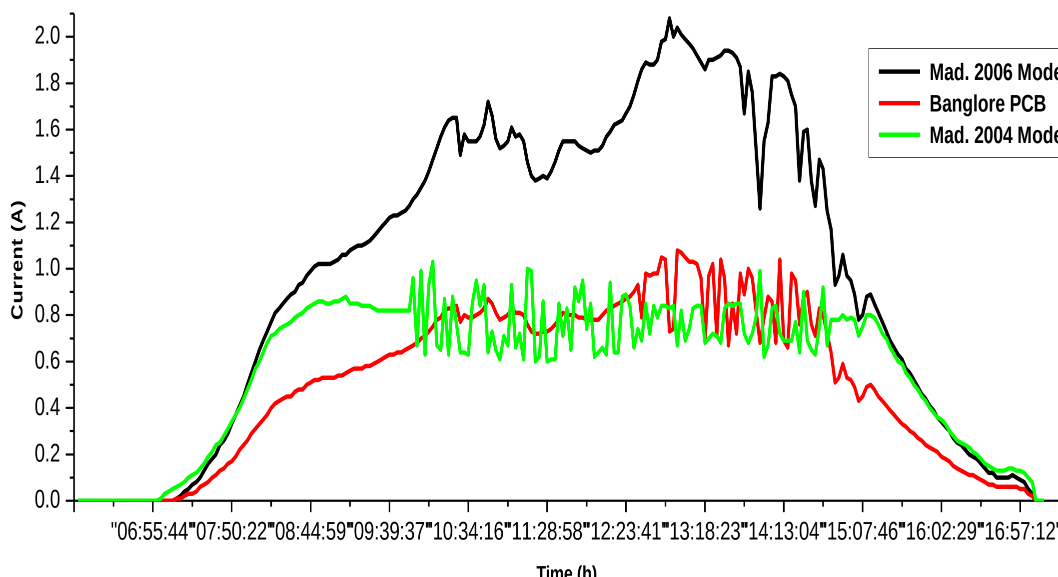



Fig 34 charging curves on a cloudy day




### 3.1.1 Conclusion:

It is seen that the charging current varies with different manufacturers. This affects the life of the battery. For any charge controllers it should be sized to regulate upto 130% of a module's nominal short circuit current. The size of the controller can be calculated by multiplying the $I_{sc}$ current of a module by the number of modules in parallel and the 1.3 safety factor [3]. The standby current which is consumed b the controller varies usually ranging from 1 to 20mA. In order to over come the aforesaid problem studies were conducted with pulse width modulation charge controller.

## 3.2 Pulse width modulation charge controller:

Pulse width modulation charge controllers with following specifications were fabricated in association by outsourcing with an agency at Coimbatore.. The circuit details of the controller are given below. The fig.35 depicts photograph of the controller

**CIRCUIT DETAILS**

Circuit board working in battery voltage.

- PCB board working current ,
- 
- With LCD display=140mA.
- Without LCD display=70mA.

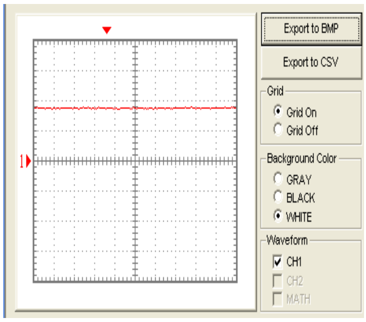
- MOSFET maximum operating current=15A.
- Three LED's are used for indicator
    - Yellow=load ON/OFF.
    - Green= low battery.
    - Red =intensity.
- PWM frequency = 300HZ.
- LED drive =THOSIBA IC ULN2803A.
- PC interface = IC ILX232N.
- MOSFET =IRFP250.
- Lamp current =1.3A.
- Battery voltage is below 7V that time the circuit is switched off
- At night time lamp only glow in battery voltage minimum 12.8V

**Fig.35 photograph of the PWM charge controller**

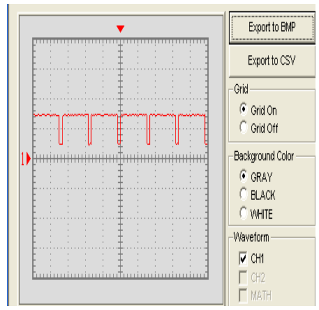
TESTING OF PIC CONTROL PWM CHARGE CONTROLLER

The figure 36 shows the pulses at different on & off time with respect to on charge voltage of the battery.

**BATTERY VOLTAGE IS BELOW 13V PWM CHARGING IS100 % ON TIME 0% OFF TIME**

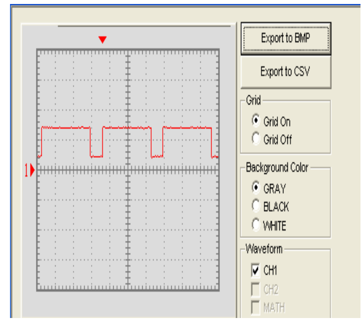



**BATTERY VOLTAGE IS 13.1V THEN PWM CHARGING 90% ON TIME 10% OFF TIME**



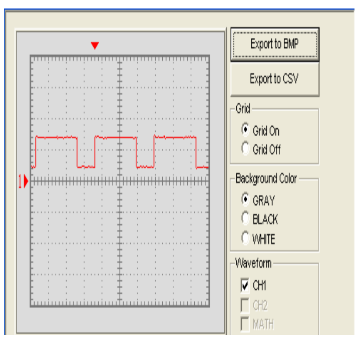

**BATTERY VOLTAGE IS 13.2V THEN PWM CHARGING 80% ON TIME**

**20% OFF TIME**

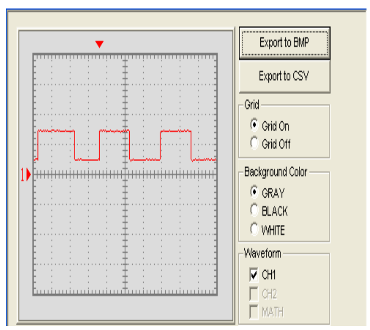



**BATTERY VOLTAGE IS 13.3V THEN PWM CHARGING 70% ON**

**TIME 30% OFF TIME**




**BATTERY VOLTAGE IS 13.3V THEN PWM CHARGING 70% ON TIME 30% OFF TIME**




**BATTERY VOLTAGE IS ABOVE 13.5V THEN PWM CHARGING 50% ON TIME 50% OFF TIME**

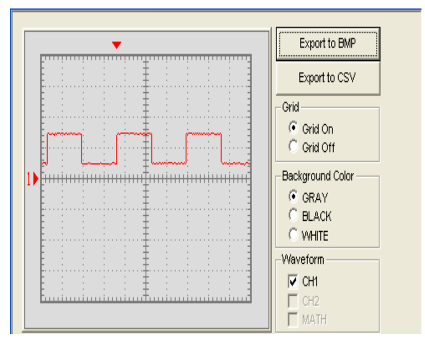



**Fig.36 depicts pulses at different on and off time**

Such kind of pulses keeps the battery in fully charged state. It also breaks irreversible lead sulphate and also passivation layer if any formed. l

The fig. 37 below shows the block diagram of PIC based PWM Charge controller designed and used in the solar stand alone lighting application

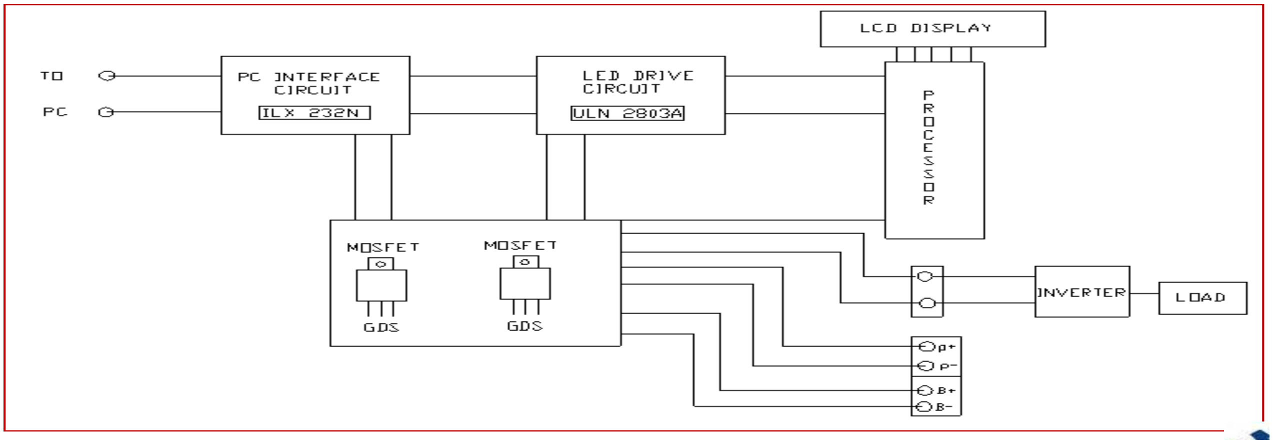


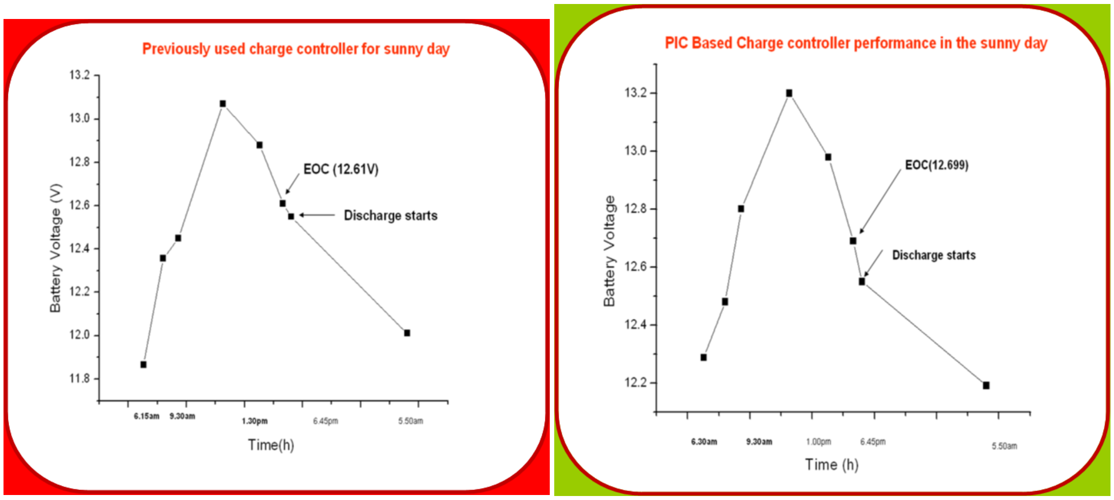

**Fig 37 Block diagram of PIC based PWM charge controller**

The table-7 gives the difference between designed PWM charge controller and the series type of charge controller.

**Table-7 difference between PWM and Series charge controller**

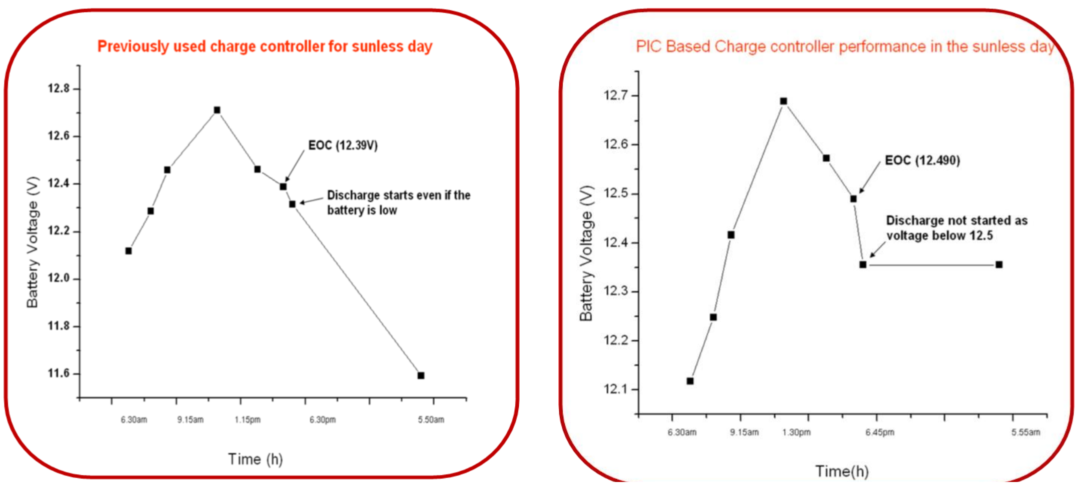
| **Operating Condition** | **Designed PWM charge controller** | **Series type Charge Controller** |
|---|---|---|
| Controlling System | PIC 16F876A | Switched Mode operation |
| Charge Mode | Pulse Charging | Normal charging |
| Operating Frequency | 300Hz | - |
| Discharge Mode | EOC Bv $\geq$ 12.5 , Lamp On | No Limit |

The figs 38 &39 shows the charge characteristics behavior of batteries using the designed PWM and series type controllers




**Series controller** **PWM controller**

**Fig. 38 Above 12.5V EOC voltage characteristics of charger controller**

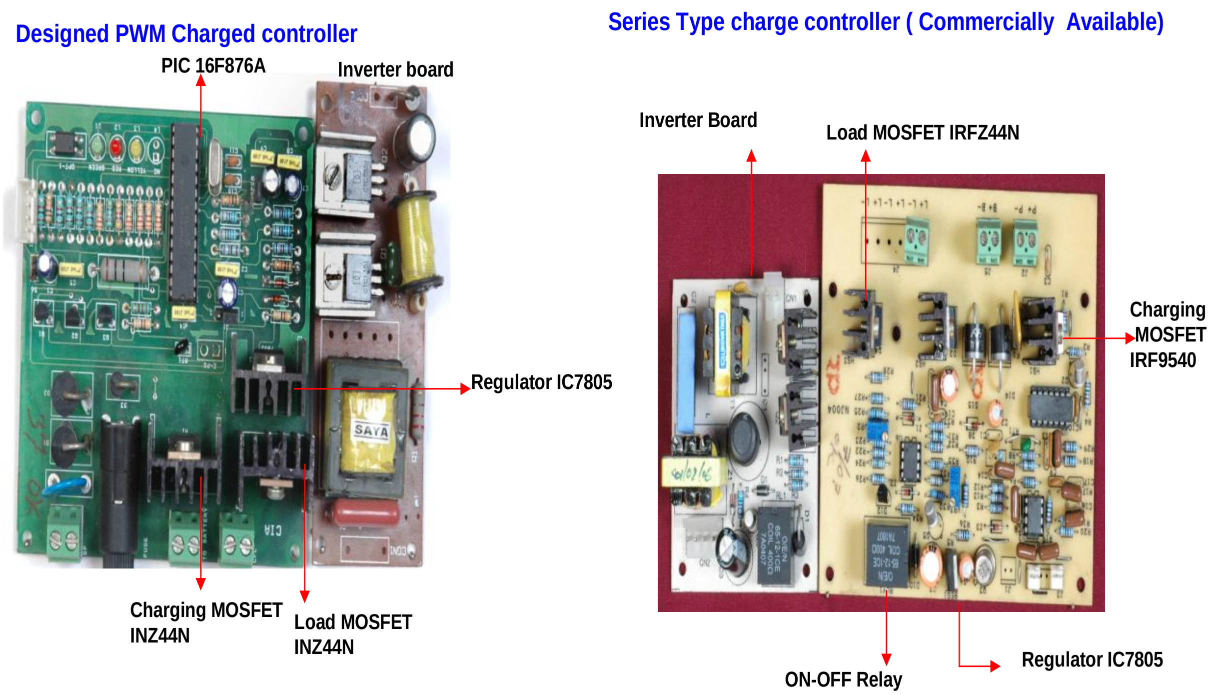



**Series controller** **PWM controller**

**Fig. 38 Below 12.5V EOC voltage characteristics of charger controller**

In the PWM charge controller, the discharge starts when the battery voltage is greater than or equal to 12.5V.This will avoid deep discharge of the battery and extends the battery life. However the discharge will proceed till its end of voltage is reached..

The difference in the manufacturing details of PWM and series type charge controller was given fig.39




| PIC Program control charging ON/OFF (PIC -16F876A) | Relay control charging ON/OFF |
|---|---|
| Battery Voltage 12.5V – lamp glow (evening time) | Battery Voltage 11.5V – lamp glow (evening time) |
| Two wires from inverter to lamp | Four wires from inverter to lamp |
| Pulse charging (Square wave pulse depended SPV & BATTERY VOLTAGE) | Normal Charging |
| PIC Program control discharging ON/OFF | Relay control discharging ON/OFF |
| Charge controller working in battery voltage | Charge controller working in panel voltage |
| Kitkat Fuse is used | Rewireable fuse is used |
| Battery voltage 11.5V below light off | Battery voltage 10.5V below light off 32 |
| Morning time Panel voltage 6.5V then lamp off | Morning time Panel voltage 4V then lamp off |

**Fig.39 Manufacturing details of PWM and Series type charge controller**

In order to tune the designed PWM charge controller, further modification was made and the details of the same were given in the table-8

Table-**8 Difference between designed PWM-1 and its modified version PWM-2**

| **DESIGNED PWM CHARGE CONTROLLER [PWM-1]** | **DESIGNED PWM CHARGE CONTROLLER [PWM-2modified]** |
|---|---|
| **Cut-off voltage 12.50 V** | **Cut-off voltage 12.50 V** |
| **Lower Cut-off voltage 11.50 V** | **Lower Cut-off voltage 11.00 V** |
| **Charging current pulse frequency 300 HZ** | **Charging current pulse frequency 1 KHZ** |
| **If battery voltage is less than or equal to 12.50V charging current pulse 100% going to the battery** | **If battery voltage is less than or equal to 12.50V charging current pulse 100% going to the battery** |
| **If battery voltage greater than or equal to 13.00 V Then the charging current pulse status is 50% on-time & 50% off-time.** | **If battery voltage greater than or equal to 13.00 V Then the charging current pulse status is 80% on-time & 20% off-time.** |
| **Discharge side protection fuse is not in there.** | **2A fuse is protection in the discharge side.** |

The fig 40 &41 gives the performance characteristics of designed PWM 1 and modified PWM2 with respect to charging current input to the battery and current generated by the panel using PWM-2 for fully charged and discharged battery

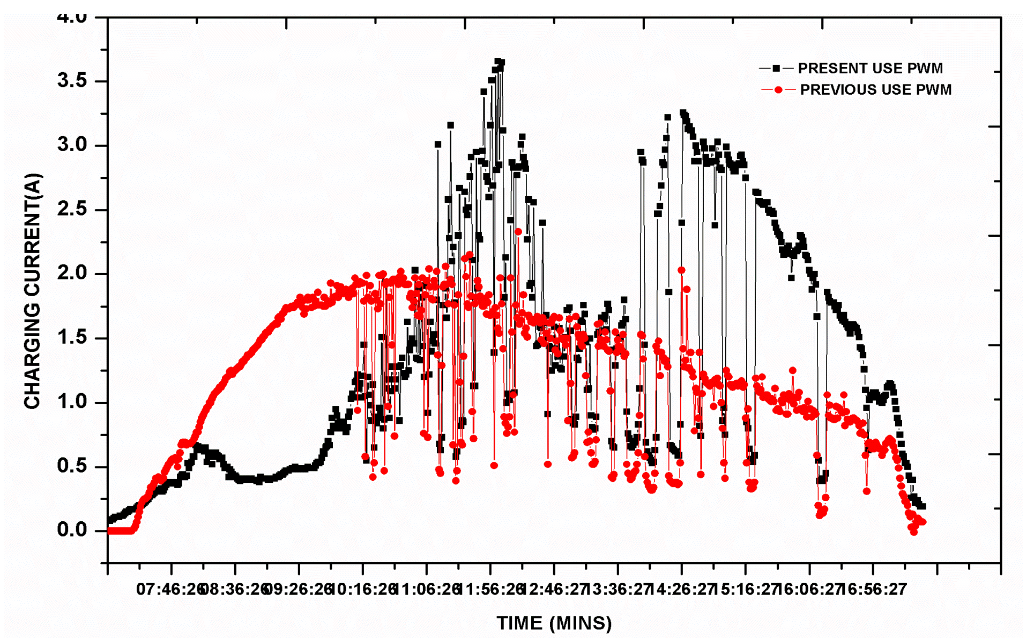



**Fig.40 Charging current generated by PWM-1 and PWM-2**

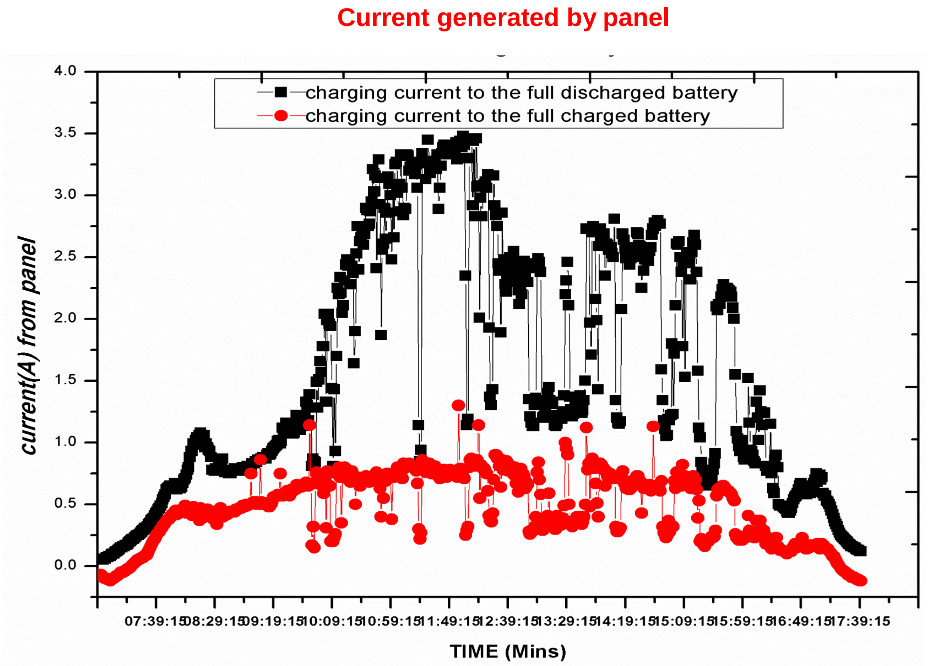



**Fig.41 Charging current generated by the panel using PWM-2 for fully
Fully discharged and charged battery**

The conductance of the battery with PWM and Series controllers were measured using Medtronic's conductance meter. It was found that the difference in the conductance value between EOC and EOD values were small in the case of PWM charge controller as compared with series type controller. This shown in fig.42.

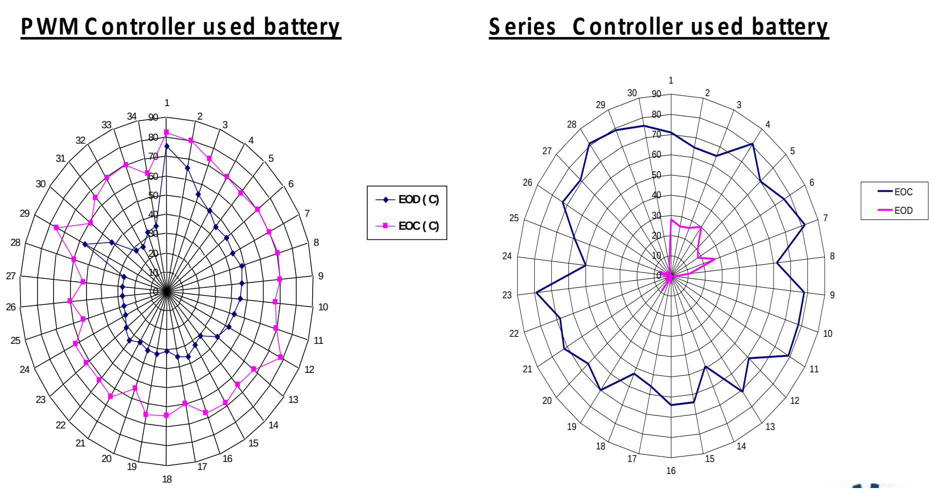



**Fig.42 conductance validation**

## 3.3 Conclusion:

The performance of PIC based PWM charge controller is better than the conventional series type controller

## 4.0 PV panel characteristics

In order to determine the characteristics of the PV module, the power vs. Voltage (PV) and current vs. Voltage (IV) curves must be constructed. The current and power outputs of photovoltaic modules are approximately proportional to sunlight intensity. At a given intensity, a module's output current and operating voltage is determined by the characteristics of the load and it is necessary to operate the PV at its Maximum Power Point. Three remarkable parameters namely Open Circuit voltage ($V_{oc}$), Short circuit current ($I_{sc}$), Maximum Power Point tracking ($V_{mp}$,$I_{mp}$) given by the manufacturer of the PV module are used for the prediction of PV characteristics of solar panel and panel power output for different level of radiation ranges from 100W/m² to 1000W/m² .

The proposed PV system simulation is composed of photovoltaic panel of 40W, storage battery of 12V/40Ah lead-acid battery and output resistive power of 11W. During night time and sunless days the battery will provide power to the load. The use of equivalent electric circuits makes it possible to model characteristics of a PV module [5]. Fig.43 depicts the electrical characteristics of PV module. The method used here is implemented in Matab/simulink. (MATLAB (R2008a) software).

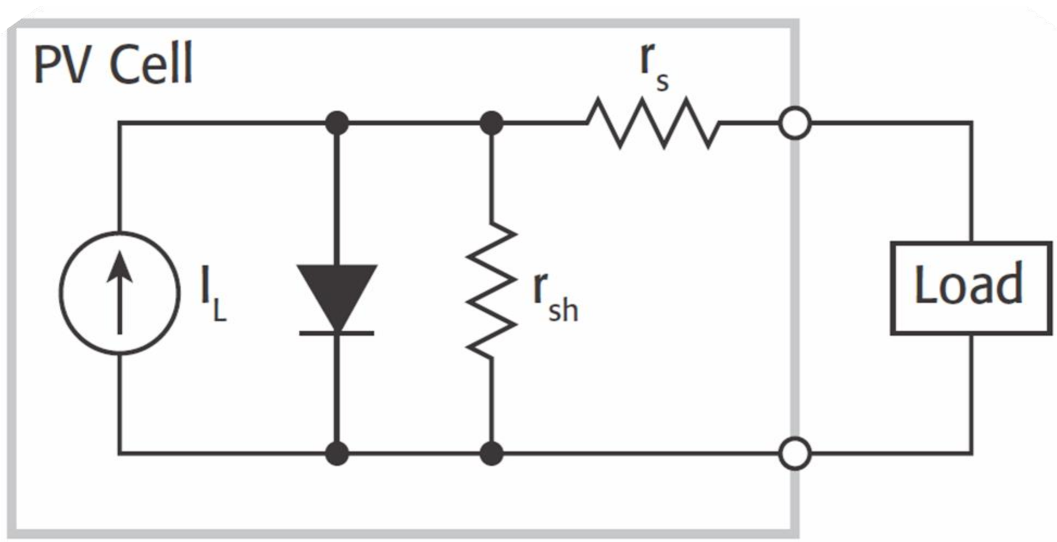



**Fig.43 Electrical characteristics of PV module**

### 4.1 Simulation of PV Module

Computer simulation program of PV module was developed for calculating the IV and PV characteristics at different level of radiation .Fig 44 shows the Screenshot of simulation of PV module**.** The Simulation part of PV Module consists of three parts namely

4.1.1 User friendly block - having basic information of the panel.
4.1.2 Input block – input parameters given by the manufactures data sheets.
4.1.3 Internal model block - designed model details.

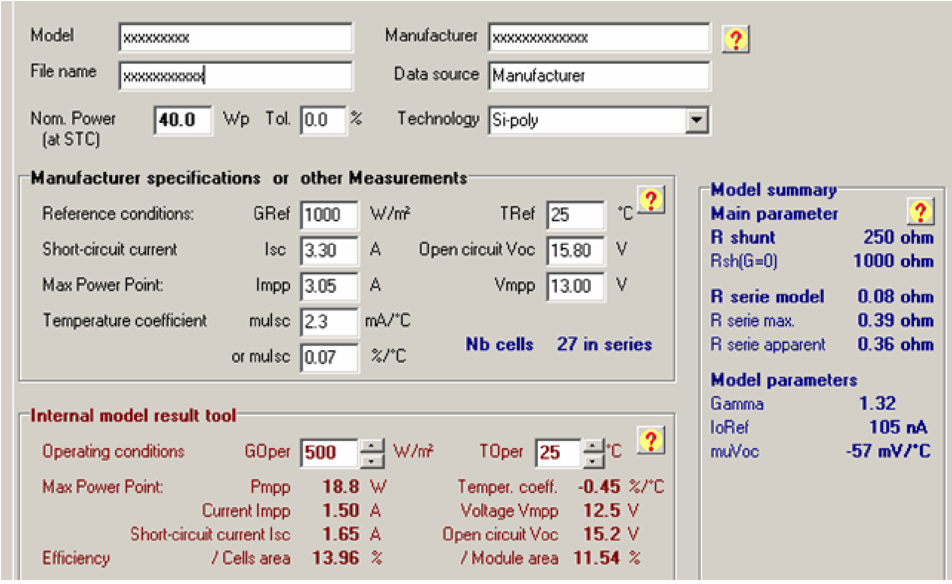



**Fig.44. Computer screen shot of simulation PV module**

### 4.1.1 In user Friendly block

This block is designed in such way that it holds only basic information about the simulation of the particular PV module, such as model, manufacturer, nominal power and technology of the panel.

### 4.1.2 Input Block

This block provides parameters available in manufacturer's data sheets. These parameters therefore include: the reference irradiation (GRref) and module temperature conditions (TRef) during measurements**,** short circuit current ($I_{sc}$) and open circuit voltage ($V_{oc}$) at the given conditions. Imp and $V_{mpp}$ are the operating point in the region of the maximum power point and ask**:** current temperature coefficient, by default it can be taken as about 0.05%/°C. After defining the basic parameters, the program still needs some additional parameters such as shunt and series resistance, to establish the internal model parameters of the PV panel. Finally, it calculates unknown Model parameters such as $I_{avg}$ for different level of radiation ranging from 100 to 1000 W/m² [6]

### 4.1.3 Internal Model Block

The main aim of this block is to develop simple and more realistic models for the photovoltaic Peak power and at the same time to use the information provided by the manufacturer's data sheet. This block design the PV model with the information given in the input block and shows the results for any specified operating conditions .This model is very useful for real-time applications where the power needs to be monitored and it is referred to obtain the maximum power at different level of radiation.

### 4.2 Estimation of Panel Power output

Calculation of unknown model parameters such as $I_{avg}$ for different levels of radiation ranging from 100 to 1000 W/m² is performed. On knowing the panel generated current

$I_{avg}$ for a particular level of radiation, panel power output can be calculated. There are some factors which affect panel power output .They are Output rating of the solar panel, intensity of solar radiation and hours of available light. The average current $I_{avg}$ generated by the solar panel is proportional to the ratio of the actual solar radiation to 1000 W/m2 multiplied by $I_{sc}$ [7]. Therefore, the average current would be

**$I_{avg}$ = (G /1000) W/m² * $I_{sc}$ (1) ----[1]**

G = Level of radiation (100 to 1000 W/m²). Fig 45 shows the relationship between panel short circuit current at different level of radiation

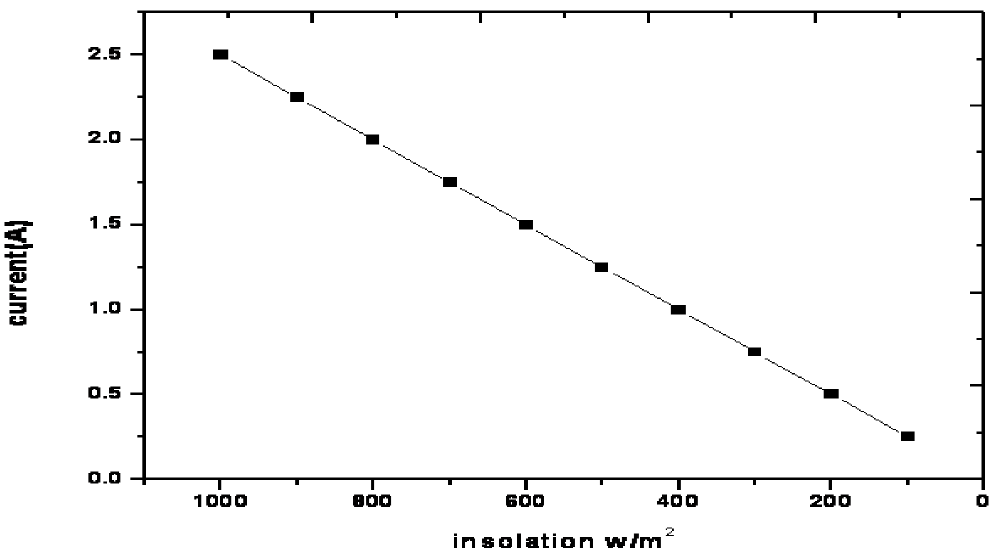
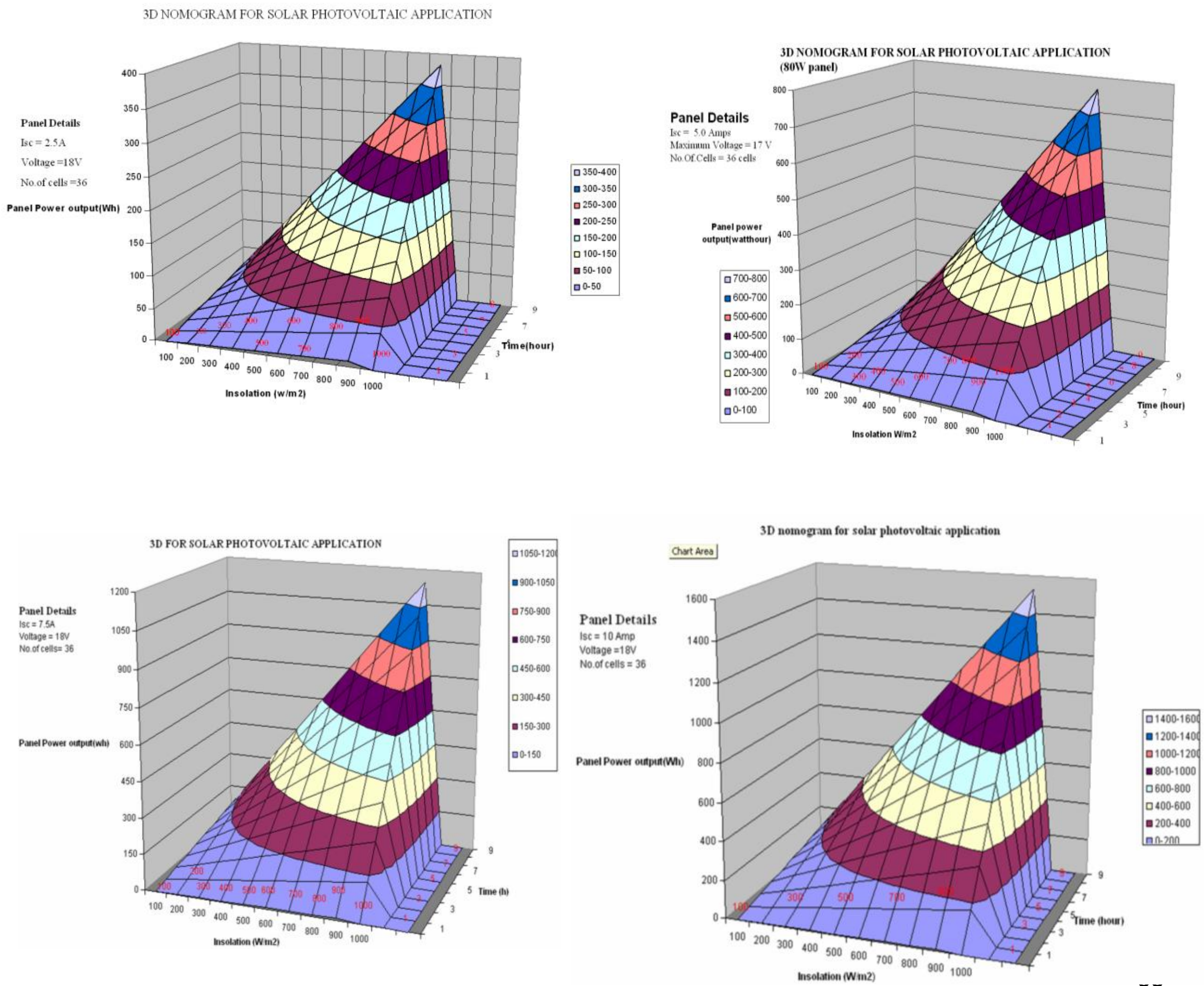



**Fig.45 Average current and insolation**

From this unknown parameter $I_{avg}$ of the PV module is predicted. In this proposed model, the radiance level is considered to vary from 100 to 1000 W/m².The curves of power–voltage[PV] and current-voltage [IV] of the photovoltaic panel are also carried out for varying levels of radiance.

### 4.2.1 Radiation Model in 3D Nomogram

Using this proposed model, we have created a database regarding the panel power output for various rated panels. This type of database is more suitable in making initial determination of Panel power output of the particular rated panel. The database is represented in 3D nomogram. These types of nomograms are very useful to the quality control engineer for analyzing the power output of group of panels. Fig. 46 shows the 3D Nomogram of PV Module with the Panel Power output of 40, 80,120 and 160 watts,[clockwise] by considering its short circuit current at different level of radiation**.** The simulated Panel Power output is compared with the field data**.**




**Figs.46 3-D nomograms of PV Module with the Panel Power output of 40, 80,120 and 160 watts, [clockwise]**

### 4.3. Validation

Based on the simulation study, a database device for solar radiation model is being designed to monitor parameters of PV stand alone system and to calculate the power generated by the total solar radiation falling on a panel during insolation per day. This database device is designed using microcontroller. Fig 47 shows block diagram of database device.

**Solar panel**
**Data Logger cum analyzer**

**Block diagram**

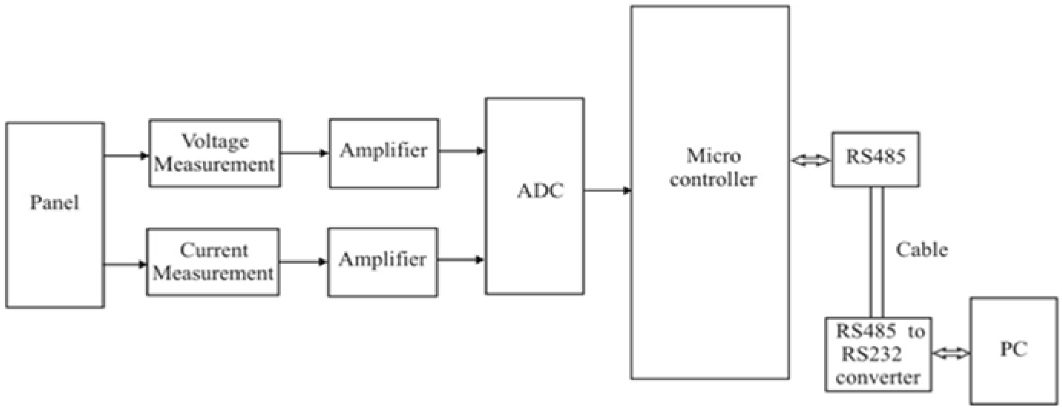



**Fig. Fig 47 shows block diagram of database device.**

.The database device contains two led's, red and green to display the status of the watt-hour generated per day. Watt-hour is the product of volts multiplied by amperes. Every solar panel is rated by their peak power or Watt-hour .By calculating the peak power of the panel, the watt –hour value for the whole day will be compared with the Wh generated /day**.** If it is lower than the required Wh, red led will glow otherwise green led will glow. On the next consequent days, when the Wh lost is achieved in addition to the present day Wh, and then green led will glow. The table -9 depicts the solar radiation model implemented for 11W CFL for solar street light application.

Table-9 solar radiation model for 11W CFL

**Solar Radiation Model**

- **The parameters to be measured are**
  - **Panel voltage**
  - **Panel current**
  - **Panel Temperature**
  - **Watt – Hour Generated**
- **Device contains two LED's**
  - **RED**
  - **GREEN**

**Watt –Hour Generated ≥ 210 Wh/ day ; Green LED will glow.**

**Watt –Hour Generated < 210 Wh/ day ; Red LED will glow.**

**On the next consequent days, when the Watt-hour lost is achieved in addition to the present day watt-hour, the green LED will glow**

The fig. 48 depicts the panel power output for 11W CFL of PV stand alone system using database device during the period Mar2011 to May 2011

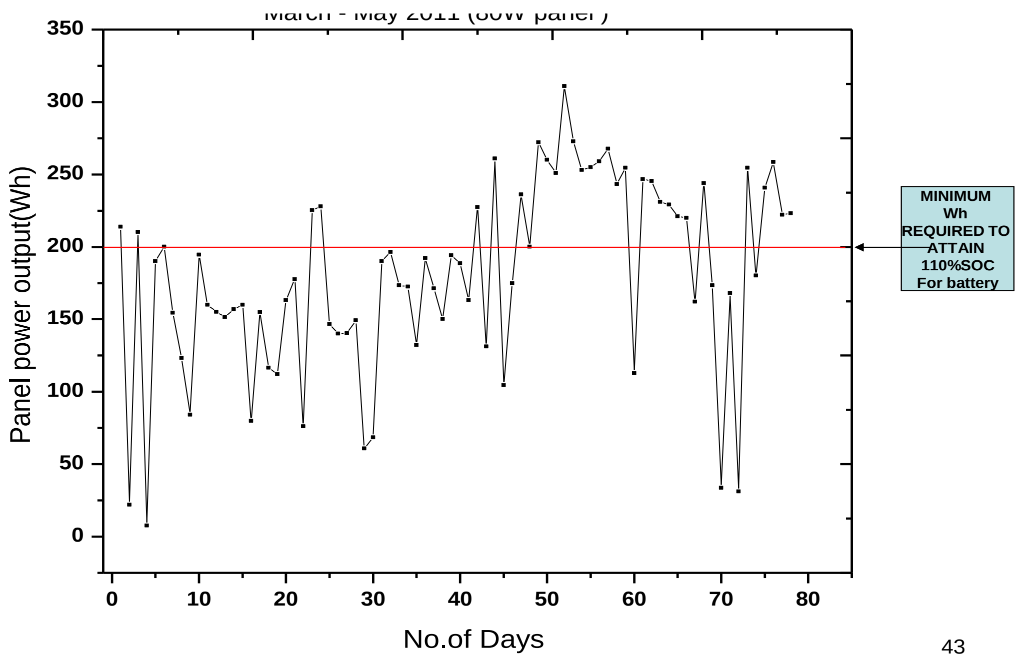



**Fig.48 Data base reading for 80W panel power output**

The Watt-hour generated by the data logger was compared with the designed PWM charge controller. This is shown in fig49.

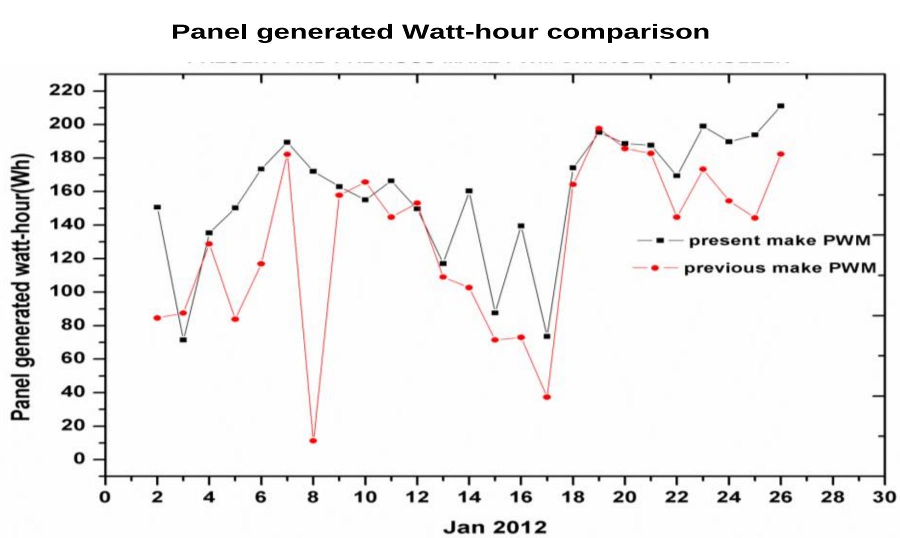



**Fig.49 Panel generated Watt-hour was compared with PWM charge controller**

Figs.50,51,52 depicts the how the voltage of the panel, temperature and panel current varies with time during insolation,

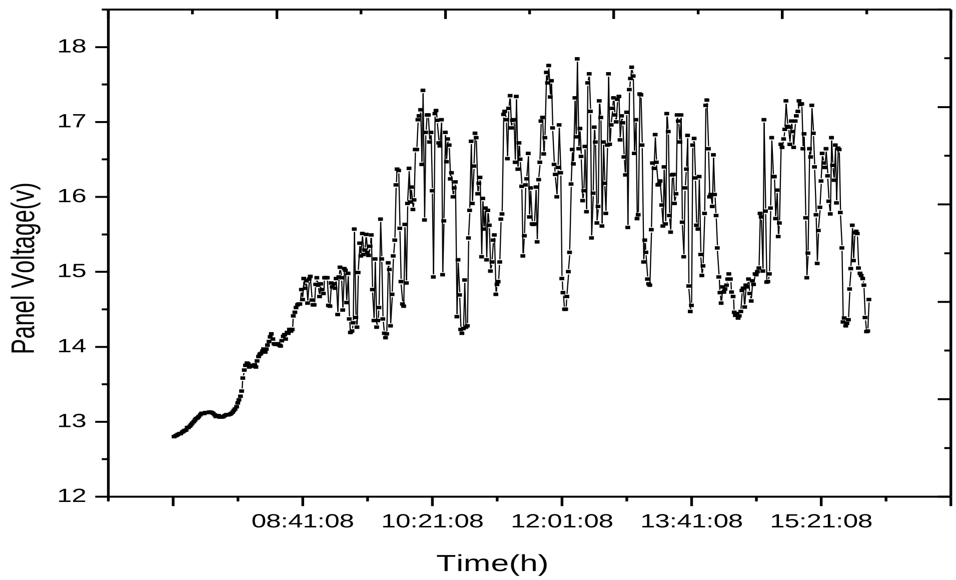



**Fig.50 Panel voltage vs. time**

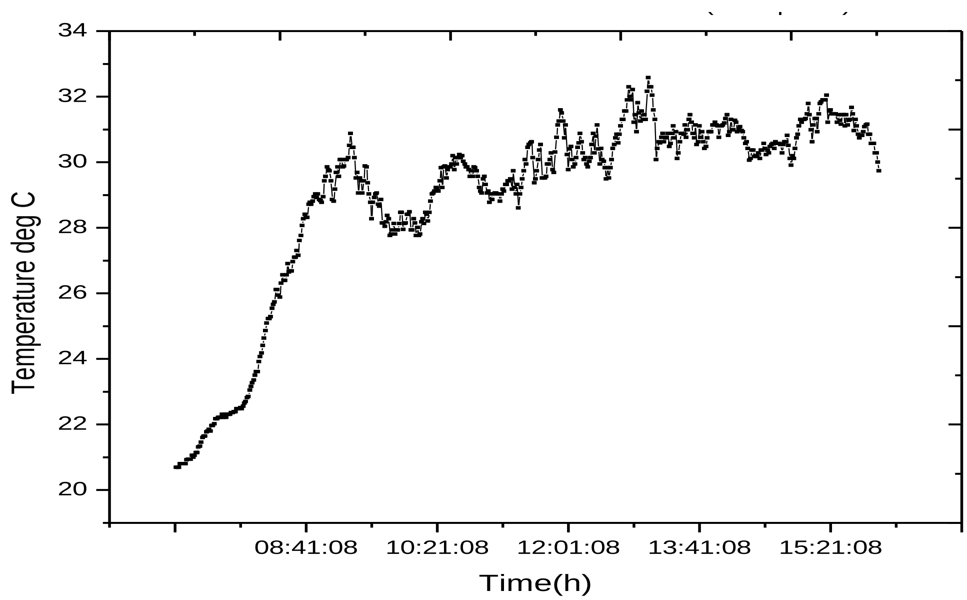



**Fig. 51 Panel temperature vs time**

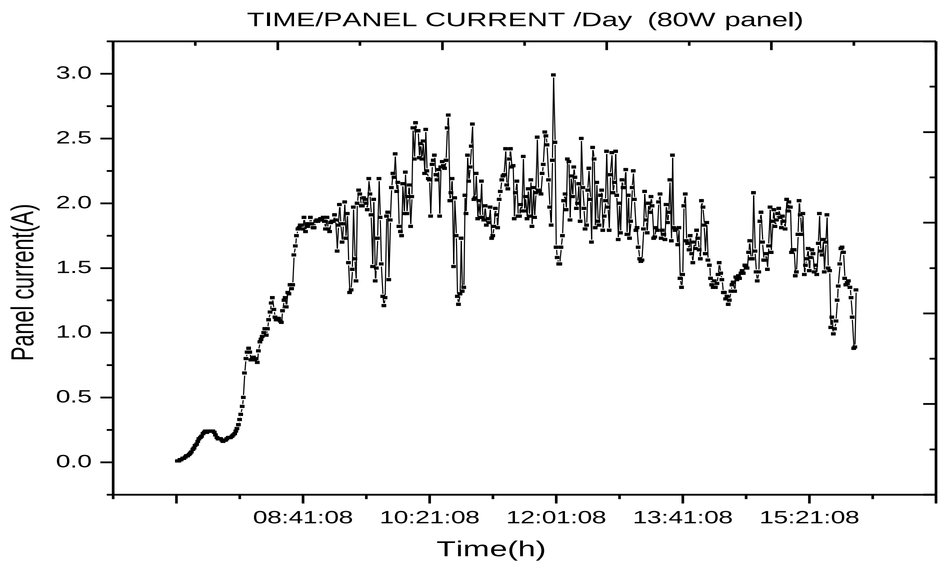



**Fig.52 Panel current vs time**

In our study we have used two sub-panels each consists of 36 silicon cells. Voltage at maximum power is 17V. The short circuit current ($I_{sc}$) is 2.5A. Maximum power 40+10%, W. 11 Watt CFL is used as the load which has operating voltage of 12V. The current consumption is 1.13 A. The dusk to dawn is 12 h/day and discharge output from the battery during this period is 1.13 *12 = 13.56 Ah /day. Provision is made to collect battery temperature (both ambient and cabinet), current, voltage, energy input and intensity of solar radiation using data logging system. Average current over particular sun hours is calculated using the formula (1) and Panel power output is calculated for different levels of radiation by knowing the average current and voltage as per the solar radiation model designed.

During monitoring, the radiation is in terms of lux*1000 in turn converted to W/m². The curve fitting is carried out using sigma plot so as to get relationship between measured and predicted data's. From Typical data on cloudy (sun less) day, maximum lux is 30,000/mm².and for clear (sunny) day, maximum lux is 90,000/mm². The results obtained from the simulation of solar radiation model and field data as per the database device are compared and the comparison found to be reasonable. Fig53&54 shows the Comparison of solar radiation model over local climatic data for sunless and sunny days respectively.

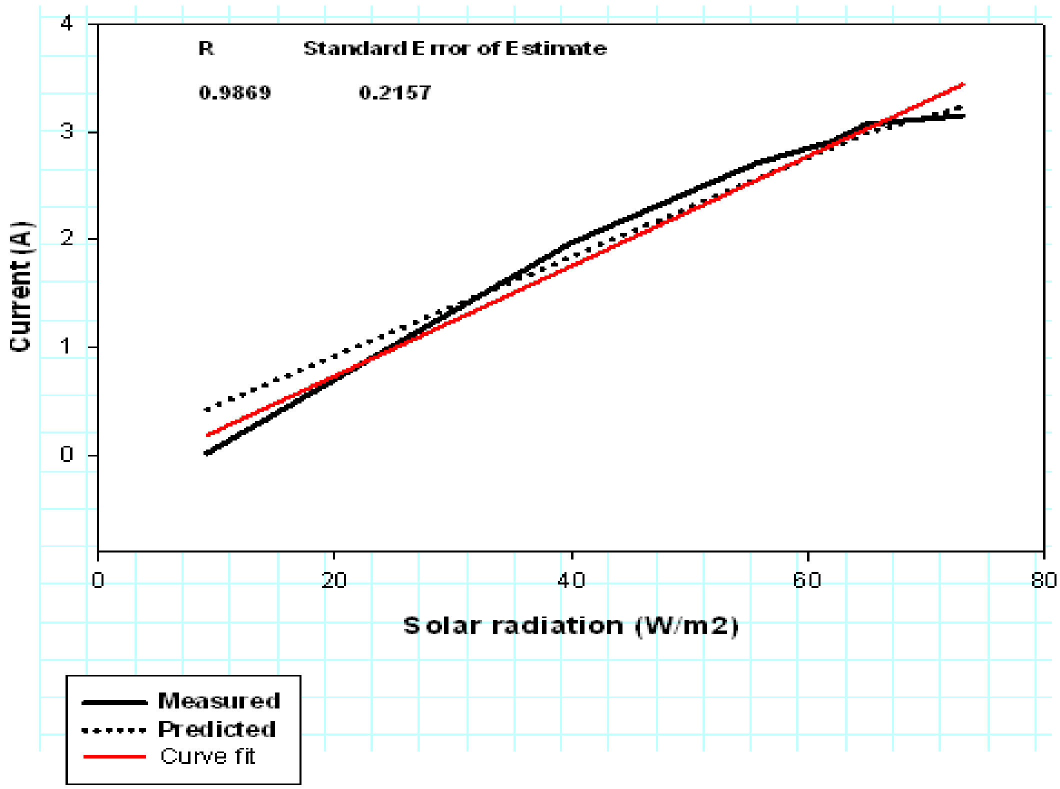



**Fig.53 shows the comparison of solar radiation model with local climatic data collected experimentally for sunless day.**

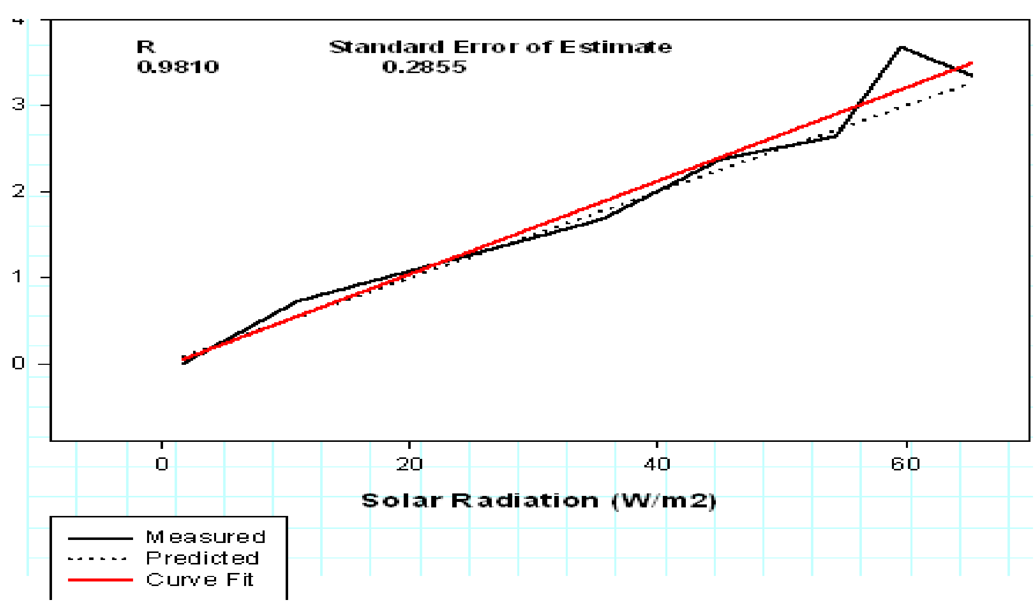



**Fig.54 shows the comparison of solar radiation model with local climatic data collected experimentally for sunny day.**

## 4.4 Conclusion

In this Study, panel current generated at any time is simulated and the behavior of a PV module at different level of radiance is designed. This conventional physical modeling technique does not require the knowledge of internal system parameters, involve less computational effort and offer a compact solution for multivariable problems. The proposed model has the advantage of using the information provided by manufacturer data sheets. Learning from the results of PV module characteristic a database device is designed and implemented for our solar local climatic data. Comparison also done and found its regression coefficient as 0.9810 for sunless day and 0.9869 for sunny day. This type of simulation can save a large amount of time and money. We
can often explore a large number of scenarios very quickly. The result will help system engineers to choose the right control strategies for panel and batteries

## 5.0 Temperature effect on solar batteries

In the SPV technology battery is the most critical component of the PV system. One of the decisive factors in determining the service life of the battery is the temperature, because the rate of most electrochemical process is approximately doubled when temperature is increased by 10°C above ambient temperature. A study was undertaken about temperature distribution with an infrared thermograph VRLA battery of different design capacities used for solar photovoltaic applications.

### 5.1 Thermal study of VRLAB:

In this study we used 12V/24Ah,50Ah,100Ah each of AGM VRLA, gelled – electrolyte VRLA and hybrid VRLA batteries.. The battery temperature was continuously monitored with the help of Infrared Thermal Imaging camera [make FLIR systems (Sweden) Model ThermaCAM E2 with Quick Reporter software used for capturing thermal images]. The battery was kept in the open atmosphere [ambient temperature] The IR images were recorded for every one hour interval from 9A.M onwards till midnight continuously for a week. The batteries were divided into 6 equal parts as shown in fig 55. and the temperature distribution in each area was measured with the IR camera

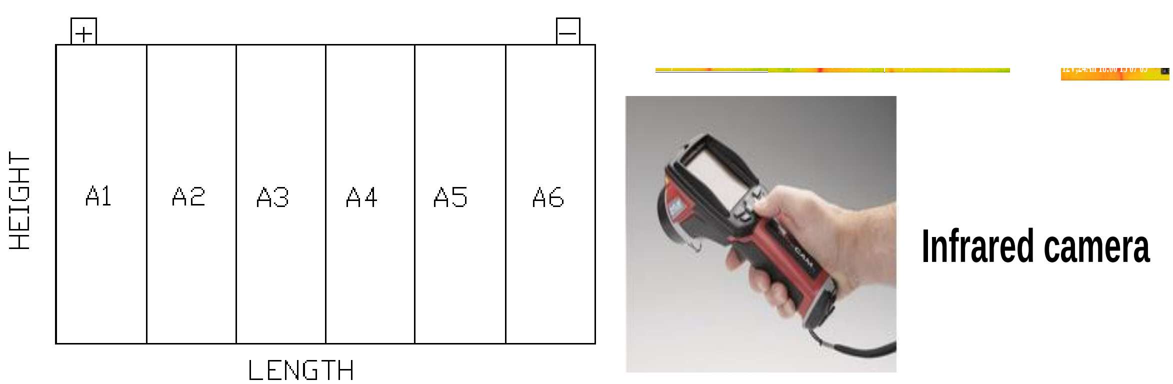



Fig 55 Each battery is divided into 6 compartments [left] and camera [right]

The dimensions of the batteries were given in table 10

Table 10: Dimensions of the batteries

| CAPACITY | LENGTH*BREADTH* HEIGHT (mm) |
|---|---|
| 12V/24 | 195*165*155 |
| 12V/50 Ah | 265*165*180 |
| 12V/100 Ah | 315*165*210 |

In this study we neglected the temperature rise during charging of the battery by solar insolation.The calculated quantity of the heat absorbed during day time solar radiation and heat radiated from the battery during night time which were given below.

***5.1.1. Heat dissipation:***

Heat is carried away from the battery as soon as its temperature exceeds the temperature of the environment. In this study the heat emission was split between heat radiation and heat transport by air convection mainly at the walls of the battery container. The amount of heat carried away by these processes was increased with difference between the temperature of the wall and the environment. On account of the limited thermal conductivity of the container material, the temperature inside the battery usually exceeds that of the outer surface. The table [11] gives thermal conductivity of the material used in the battery.

Table [11]: Thermal conductivity of battery materials

| Sl.no | Material | Thermal conductivity ($Wm^{-1}°C^{-1}$) |
|---|---|---|
| 1. | ABS(Full) | 0.188 – 0.334 |
| 2. | Borosilicate glass | 1.14 |
| 3. | Silica granules | 0.017 |
| 4. | Sulphuric acid | 0.415 |

***5.1.2. Heat emission*:**

It depends on

1. Heat transport through the container wall to the outer surface.
2. Heat loss by radiation.
3. Heat loss caused by flow of air around the battery.Fig56 depicts how heat flows out of the battery

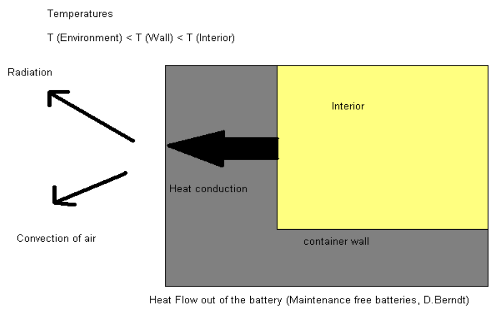



Fig [56] gives schematic view how heat flows out of the battery

### *5.1.3. Heat flow through the container wall into the battery*

The heat flow through the container wall is determined by the heat conductivity and the thickness of the container wall.

$dQ/dt= f * \lambda * \Delta T/d$………………….. (2)

Where dQ/dt refers to flow of heat per unit time, f refers to the surface area ($m^2$), λ refers to specific heat conductance ($Wm^{-1}\ °\ C^{-1}$), and ΔT is the temperature difference across the wall and d is the thickness of the container wall (0.006m).

Where,

$\Delta T= T_1-T_2$

$T_1$ = Ambient Temperature = 27 °C

$T_2$ = Surface Temperature (obtained through thermal images)

Table [12] shows the surface area of 24Ah/50Ah/100Ah VRLAB used in our study and Table [13] gives the heat flow calculated for different design / capacities of the batteries.

Table [12]: Surface area of VRLAB

| Surface area (f) in $m^2$ | | | |
|---|---|---|---|
| Type of battery | AGM | GEL | HYBRID |
| 24Ah | 0.30225 | 0.30225 | 0.30225 |
| 50 Ah | 0.0477 | 0.0477 | 0.0477 |
| 100 Ah | 0.06615 | 0.06615 | 0.06615 |

Table [13]: Calculated heat flow (dQ/dt)

| Heat flow through the walls ($Js^{-1}$) | | | |
|---|---|---|---|
| Type of battery | 24 Ah | 50 Ah | 100 Ah |
| AGM | 17.283 - 30.705 | 27.51 - 48.881 | 37.71 – 67 |
| GEL | 16.890 - 30.007 | 26.08 - 46.32 | 36.537 - 64.912 |
| HYBRID | 15.87 - 28.19 | 24.92 - 44.277 | 35.74 - 63.51 |

From the table it is clear that the heat adsorption by the hybrid batteries is lower than the other design / capacity batteries.

***5.1.4. Heat Emission by radiation:***

The major portion of heat absorbed by the battery is emitted by radiation according to Stefan Boltzmann law:

$q_{emis} = \sigma \epsilon (T_s - T_{sky})$……………….. (3)

Where $\sigma = 5.67 * 10^{-8}\ Wm^{-2}\ K^{-4}$ is the Stefan Boltzmann constant, $\epsilon$ is the mean emissivity of the surface, $T_s$ is the battery's surface temperature , and $T_{sky}$ is the effective sky radiant temperature which is given by

$T_{sky} = 0.9 * T_{air}$............................. (4)

Table [14] gives the calculated emissivity value for the different design / capacity of VRLAB.

Table [14]: Emissivity values

| Type of battery | $T_s$ (°C) | $q_{emis} = \sigma \epsilon (T_s - T_{sky})$($Wm^{-2}°C^{-1}$) |
|---|---|---|
| 24 Ah | | |
| AGM | 45.2495 | 0.2070 |
| Gel | 44.835 | 0.1988 |
| Hybrid | 43.759 | 0.1787 |

| 50 Ah | | |
|---|---|---|
| AGM | 45.407 | 0.21023 |
| Gel | 44.445 | 0.19140 |
| Hybrid | 43.675 | 0.1772 |
| 100 Ah | | |
| AGM | 45.197 | 0.2059 |
| Gel | 44.628 | 0.1948 |
| Hybrid | 44.248 | 0.1876 |

From the tables it is found that the $q_{emis}$ or emissive heat transfer from the battery is minimum for hybrid type and maximum for AGM with Gel in between the two.

***5.1.5 Heat transfer by flow of air:***

The free convection of air at the outer vertical surfaces of stationary batteries is given by

$dQ/dt = 1.3\ h^{-1/5}\ (T_{wall} - T_{air})^{5/4} Wm^{-2}$ if $h^3 (T_{wall} - T_{air}) < 0.2\ m^3$ deg……….. (5)

The temperatures $T_{wall}$ and $T_{air}$ are measured in °C. The height h of the container (in m) is important for convection flow. The heat dissipation by air convection depends on the temperature difference between the container surface and the surroundings. Table [15-17] gives the calculated values of dQ/dt for different design / capacity of VRLAB.

The ambient temperature used as $T_{air}$ is 27°C.

Table [15] – Values of dQ/dt for 24Ah VRLAB

| Type of battery | $T_{wall}$ | $dQ/dt (W\ m^{-2}\ K^{-1})$ |
|---|---|---|
| 24 Ah, AGM | 45.2495 | 71.173 |
| 24 Ah , Gel | 44.835 | 69.173 |
| 24 Ah, Hybrid | 43.759 | 63.982 |

Table [16] - Values of dQ/dt for 50Ah VRLAB

| Type of battery | $T_{wall}$ | $dQ/dt (W\ m^{-2}\ K^{-1})$ |
|---|---|---|
| 50 Ah, AGM | 45.407 | 70.652 |
| 50 Ah, Gel | 44.445 | 66.059 |
| 50 Ah, Hybrid | 43.675 | 62.435 |

Table [17] – Values of dQ/dt for 100Ah VRLAB

| Type of battery | $T_{wall}$ | dQ/dt($W\ m^{-2}\ K^{-1}$) |
|---|---|---|
| 100 Ah , AGM | 45.197 | 69.308 |
| 100 Ah , Gel | 44.628 | 66.616 |
| 100 Ah , Hybrid | 44.248 | 64.825 |

It is seen that hybrid batteries show minimum heat transport by air convection with AGM foremost in the group followed by Gel.

***5.1.6 Heat conduction via bottom of the containers and the connectors:***

The heat transfer through the bottom area or through the connecting wires (despite of high thermal conductivity) does not influence the equilibrium temperature of a battery. Most of the cables connect cells or blocks of similar temperature, which means that there is no net transfer between them. Further the heat transfer of the connectors to the air is reduced by electrical insulation.

## <u>5.2. Infrared images</u>

Fig.57 depicts infrared thermal images of the said batteries.

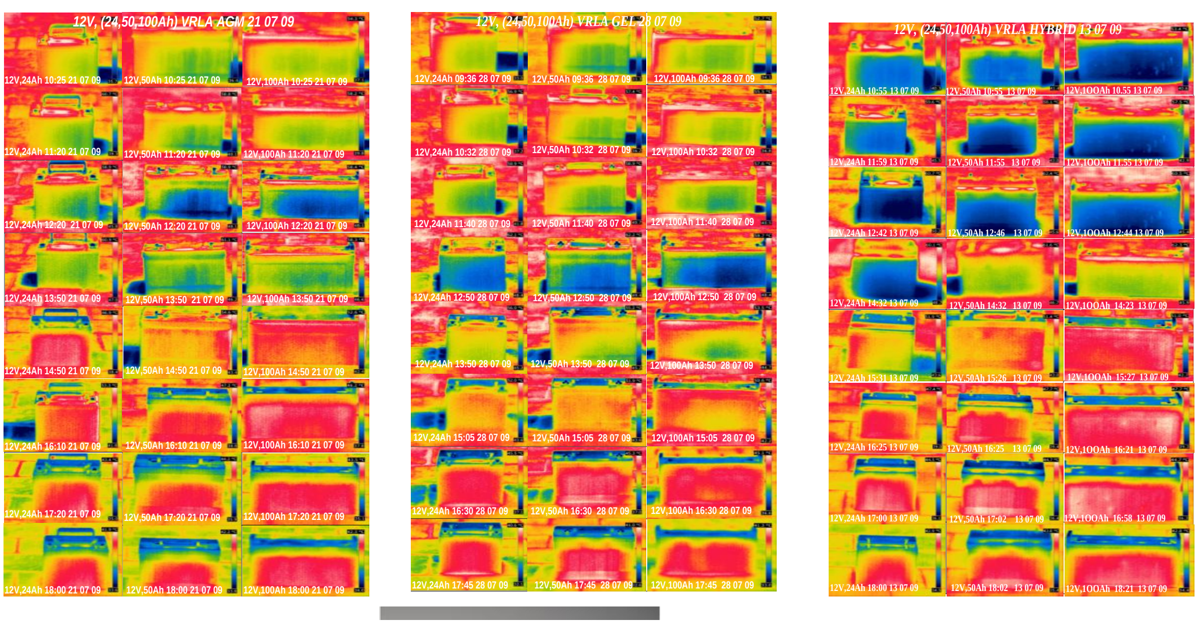
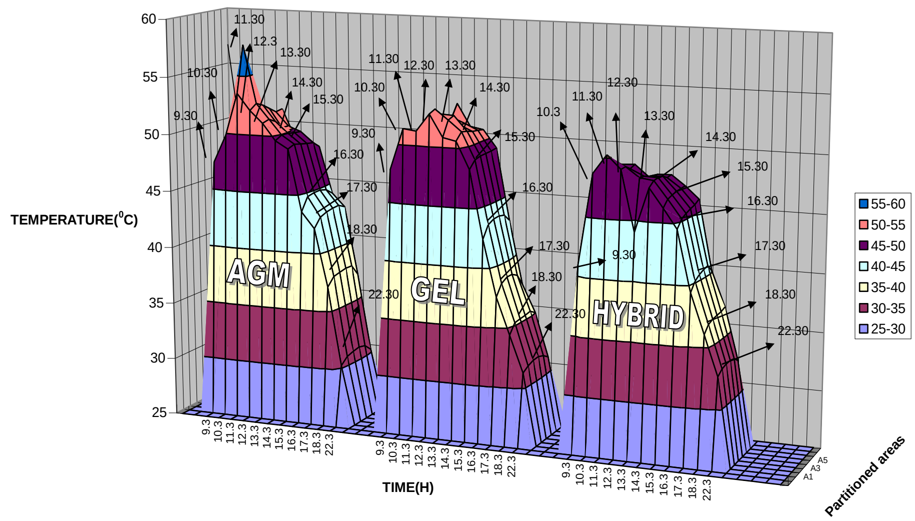



**Fig.57 Thermal images of VRLAB**

Based on the images and quick view reports software three dimensional graphs for the six partition areas are drawn for the said batteries. They are shown in figs58,59, and 60




**A Three dimensional graph relating to temperature vs. time for 6 partitioned areas**

**Fig. 58 For 12V/24Ah VRLAB**

**Three dimensional graph relating to temperature vs. time for 6 partitioned areas**

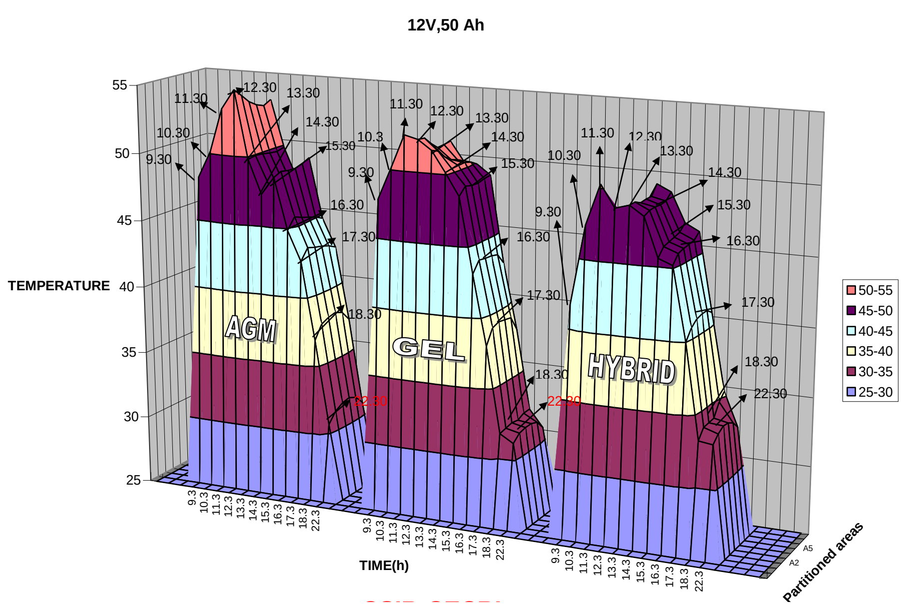



**Fig. 58 For 12V/50Ah VRLAB**

**A Three dimensional graph relating to temperature vs. time for 6 partitioned areas**

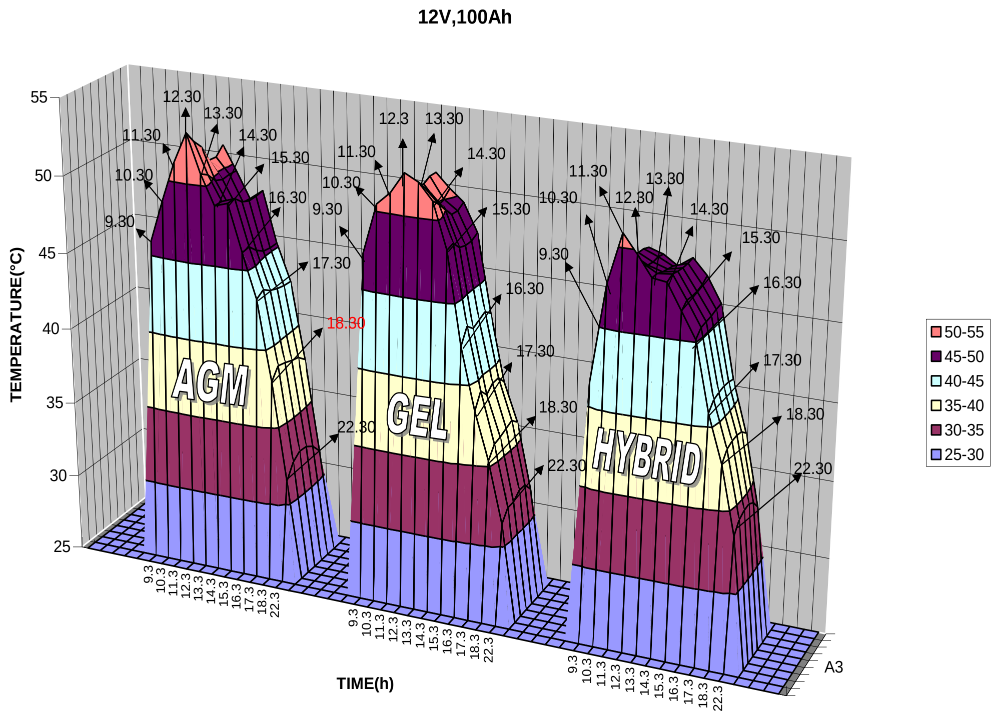



**Fig. 58 For 12V/50Ah VRLAB**

## 5.3. Results and Discussions:

. The nomograms in figs. [56-58] shows the average temperature maintained in each area of different designs of batteries. During day time up to 1300 hours the ambient temperature is higher than the battery surface temperature. So the heat is flowing through the container wall into the battery. The amount of heat entered into the hybrid battery is lower than the other battery design. It holds good for all capacities. This is due to the design of the hybrid battery which is a combination of silica gel and AGM.

## 5.4. Conclusion:

Whenever the rate of heating is fast, the rate of cooling is also fast. This is reflected in the AGM and Gel VRLA batteries. In the case of Hybrid VRLA, heat absorption rate is small and so the heat dissipation rate is also small. This is beneficial from the point when the ambient temperature goes below room temperature during the night the internal heat maintained by the Hybrid VRLA avoids freezing of the electrolyte. Such kind of batteries will perform better than the Gel and AGM batteries.

## 6.0. Knowledge dissemination and draft specification:

# Report

## Workshop on Storage batteries for SPV Application

**Venue: Hotel Green Park**
**Chennai**

**Date: 01.10.2010**

**Organized**

**By**

**CSIR-CECRI** **MNRE-SEC**

# Executive summary of the workshop

CSIR- Central Electrochemical Research Institute and MNRE-Solar Energy Centre has undertaken a project on Design and Development of Prudent Lead-acid battery for various Solar Photovoltaic Applications. The broad objective of the project is to optimize the battery performance in various PV applications by way of developing suitable lead-acid battery and their charging mechanism. The specific objective of the project is as follows:

- Failure analysis of the used batteries in the existing solar photovoltaic applications.
- Design and development of suitable lead acid batteries for various solar photovoltaic applications.
- Development of test protocols for batteries for solar photovoltaic applications.
- Exploring battery chemistries other than lead acid for solar photovoltaic applications.
- Study of existing circuit designs for charge controllers and optimizing their performance.

Dissemination of information thus generated through workshops and conferences both at national and international levels.

In this connection a one day workshop on storage batteries for SPV Application was organized by CSIR-CECRI and MNRE-SEC at Chennai on 1st October 2010. Six invited lectures and thirteen speakers from battery industries, end users presented their experience in line with theme of the workshop. Draft specification regarding batteries for solar photovoltaic system application [Prepared by CSIR-CECRI & MNRE- SEC] was discussed in the workshop.

### 6.1 FORE NOON SESSION [INVITED LECTURES]

Er.S.Ambalavanan, welcomed the chief guest and participants of the workshop.
Professor A.K.Shukla, Indian Institute of Science, is the chief guest, inaugurated the workshop and delivered the inaugural address. He also chaired the forenoon of the session of the workshop in which by the following invited speakers presented their invited lectures.

**Professor A.K.Shukla**
In his inaugural address he gave a brief presentation on conversion of sunlight to electricity through inorganic, organic and dye-sensitized solar cells. It was followed by a presentation on the role electrochemistry in lead-acid battery. Professor highlighted the advantages of Valve Regulated Lead-acid battery such as maintenance free, no electrolyte stratification, recovery from deep discharge, low temperature applications and can be used in any orientation. The added advantage of lead-acid battery is lead from spent

batteries is fully [99+] recyclable. With regards to other battery chemistries professor touched upon the following aspects:

1. Nickel- Iron Battery

   Corrosion/self discharge of iron electrodes, electrolyte management and sealed type are the research and development areas to be studied. He mentioned that Pt-$O_2$ catalyst can be used for hydrogen-oxygen recombination

2. Soluble lead-redox flow batteries which are a form of rechargeable battery with replacing the electrolyte liquid in a similar way to refueling fuel tanks for internal-combustion engines, while simultaneously recovering the spent material for re-energization. In contrast to rechargeable batteries its power and energy density are independent of each other
3. A brief presentation of his on going work of lead-di-oxide /AC hybrid ultra capacitors, its performance and cycle-life test. was also made

**Dr.Vijayamohan K Pillai**

He started his presidential address by an interrogative remark that can batteries fulfill the challenges of solar photovoltaic energy storage? The speaker also compared the different battery technologies in terms of volumetric and gravimetric energy density and production cost as shown in figs 59. & 60.

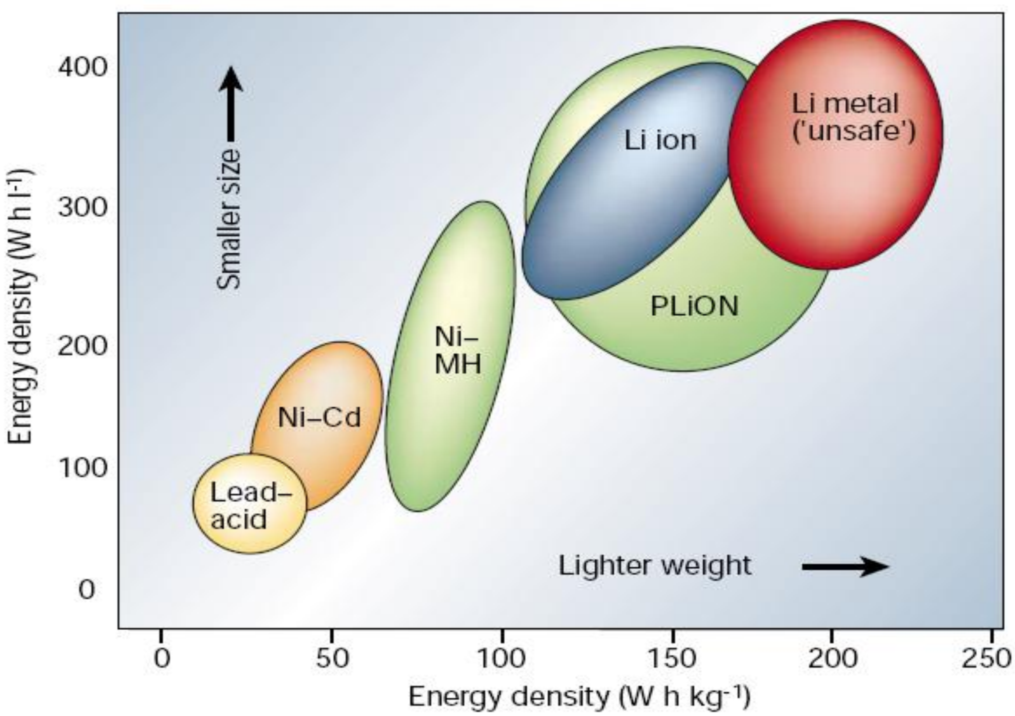



**Fig.59 Volumetric and Gravimetric energy densities of storage systems**

| Battery Type | Current Cost (USD/ kWh) |
|---|---|
| Li-ion | 600-700 |
| NiMH | 300-400 |
| Lead-acid | 70-90 |

**Fig.60 Production cost of storage system**

The following table-18 gives the selection criteria for batteries used in SPVapplication compatibility to Indian conditions.

**Table -18 selection criteria for batteries**

| **BATTERY** | **1** | **2** | **3** | **4** | **5** | **6** | **Figure of Merit** |
|---|---|---|---|---|---|---|---|
| Pb-Acid Conventional automotive | 00 | 0 | 0 | 00 | 00 | 1 | **-7** |
| Pb-Acid MF flooded electrolyte | 1 | 1 | 0 | 0 | 1 | 1 | **2** |
| Pb-Acid MF gelled Electrolyte | 1 | 1 | 1 | 00 | 0 | 1 | **1** |
| Pb-Acid MF VRLA Absorbed Electrolyte | 1 | 1 | 1 | 0 | 1 | 1 | **4** |
| Ni-Cd Pocket plates | 1 | 00 | 1 | 1 | 1 | 0 | **1** |
| Ni-Cd Sintered Plates | 1 | 00 | 00 | 1 | 1 | 00 | **-3** |
| Ni-Fe | 00 | 1 | 1 | 1 | 1 | 1 | **3** |
| Ni-MH | 1 | 00 | 00 | 1 | 1 | 00 | **-3** |
| Li-ion | 0 | 0 | 0 | 1 | 1 | 0 | **-2** |

He briefly talked about the red ox flow batteries, ultra capacitors, use of Nano technology in for SPV applications.

**Dr.O.A.S.Sastry**

In his key note address he explained the concept of smart grid [localized grid], where the battery plays a major role. He briefly mentioned the establishment of good smart grid with the help of batteries at solar energy centre. He is of the opinion that the designer of the PV system and battery should discuss for proper matching of the load, battery and PV system. With regards to charge controller he has cited different types of charge controllers are available in the market, but in SPV application one cannot boost voltage

when we require because we don't know whether sun is there or not during particular day. He has also mentioned about the project undertaken by SEC and CECRI in designing batteries and mentioned that the laboratory results are encouraging. With regards to testing standards, India always follows European standards but these standards are not suitable for Indian conditions.
In this connection SEC and CECRI with off grid guidelines, combined designed test standards for lead-acid batteries. He also suggested that test centers should be formed all over the country to meet the requirement of implementation Jawaharlal Nehru Solar mission technology.

**Dr.P.C. Pant**

He presented the nature of renewable energy supplies and its real challenges. Conditions in PV systems are shallow cycle operation, autonomy, reserve, limited amount of charging energy available. The main function of the battery in PV system is to act as buffer storage, to eliminate mismatch between available PV power and power demand. To get longer life of battery in PV system more expensive battery, with higher capacity, proper charge controller and temperature compensation are required. He also mentioned that attempts have been made by MNRE-CSIR to develop specifications for lead-acid batteries based on failure analysis of batteries in SPV, effect of different charging mechanism on battery performance, monitoring and evaluation of different types of batteries in actual field conditions, studying various standards and then modifying standard to suit Indian requirements. The copies of standards were circulated to all the battery and PV industries for their comments including SESI. Comments received were incorporated in the draft now here for discussion and inviting suggestions to enable us to freeze the standards by end of this workshop with the recommendation that the draft be adopted by BIS for batteries for PV application by giving suitable BIS number. He also informed that recommendation should include forming more test laboratories with capacity to undertake third party testing as per these specifications.

**Er.S.Ambalavanan**

In his first part of the lecture he presented about the work undertaken in the collaborative project between CSIR-CECRI and MNRE-SEC. He presented the results obtained in the study undertaken in different design and capacity of lead-acid battery collected in the established solar stations I&II at CECRI, failure analysis of various designs of lead-acid battery, nomograms giving the relationship between capacity, state of charge and sunny and sunless days, size of lead sulphate crystals in different specific gravity, discharge period and idle period, studies on the effect of charge controllers on the performance of VRLAB, fabrication and testing of PIC control based Pulse Width Modulation controllers, use of conductance in predicting the life of the battery, thermal analysis of different design of lead-acid battery used in SPV application. Finally he presented the solar radiation model developed for PV stand alone lighting system.

In the second part of the presentation he presented the draft specification for lead-acid batteries to be used for SPV application under Indian conditions. In that presentation he widely covered the various international standards for storage batteries used in PV system, comparison of degradation -7 test procedures based on the mode of failure, review of existing procedures and reason for inclusion of test procedures in the draft specification.

**Dr.S.Gopukumar**

Presented about the work to be undertaken by CSIR National Solar Mission. It was followed by research work undertaken in the development of efficient electrode materials for lithium ion battery suitable for photovoltaic energy storage system. He mentioned about a proposal to develop Li-ion batteries of 3.6V/650mAh capacity for LED lights in farmers cap

### 6.2 Afternoon Session

**Dr.V.Yegnaraman, Director, CECRI released the CD of the CSIR BATTERY PERFORMANCE and EVALUATION CENTRE. He mentioned about the battery testing facilities created at the centre. This centre will cater to the needs of battery testing in SPV application**

It was followed by presentations by the participants from the industry in sharing the problems of lead-acid battery used in SPV application. The afternoon session was chaired by Dr.P.C.Pant of MNRE and his team. Dr.P.C.Pant requested the speakers to comment on the draft specification circulated to them.

**M/S.Amararaja Batteries Limited:**

Presented the suitability of VRLAB for SPV applications. It is best suited to operate under partial state of charge because electrolyte stratification does not occur due to immobilization of acid in the separator and plates, followed by strong wicking action of the separator ensures uniform concentration of acid throughout the plate surface, low self discharge, capable to accept low rate of charging currents and operation at sub zero temperature. They have developed unique grid design for quick charge acceptance, better cycle life and improved paste composition for better adhesion to grid. They recommended charge controller settings in the battery path for overcharge voltage regulation, regulation to reconnect the voltage, low voltage disconnect and reconnect and current limit as 2.35VPC, 2.22VPC, 1.916VPC and 2.083VPC, 10-18%of rated battery capacity respectively. With respect to out door cabinet they recommend double skin MS construction, air circulation on both ends of the sheet with radiation arrested at the outer layer itself and use of sun reflective paint. This enhances the life of the battery by 20-25% with the existing load. Comments on draft specification sent to them have been received. They suggested that the title of draft specification should carry the name of lead-acid battery.

**M/S.Amman Batteries Limited**

Tubular lead-acid battery is best suited for the SPV application. Their batteries give 30 months life. Regarding comments on draft specification it will be sent within seven days

**M/S.Exide Industries Limited**

Battery for SPV application remains in a partial state of charge [PSoC] and storage battery designs with better charge acceptance and deep discharge application are suited for the above mentioned conditions. They recommended low maintenance flooded tubular product which requires topping up once in six months for monoblocs having antimony level in spine is less than 3% and lead-calcium negative. Regarding the comments on draft specification it will be sent within seven days.

**M/S.Energy Leader Batteries India Limited:**

They suggested the following points for consideration

1. Multiple step charging of solar batteries
2. Optimum design of lead acid batteries for SPV application
3. Various design aspects of lead-acid batteries and its suitability for SPV application

Regarding the comments on draft specification it will be sent within seven days.

**M/S.Hyderabad Batteries Limited**

In SPV application with low rate of charging/discharging, acid stratification and sulphation are the failure modes. The battery is subjected to extreme high and low temperature and it operates between 30 and 80% state of charge. Among VRLAB, Gel VRLAB contains more electrolyte, good recovery from deep discharge, resist sulphation short, accommodation of the expansion of frozen electrolyte at low temperature and good heat dissipation at high temperature. A comparison was made between AGM VRLAB and TUBULAR GEL VRLAB, show in table-19

**Table-19 comparison of different VRLAB**

| S. No. | Parameter | Tubular Flooded | Flat Plate AGM VRLA | Tubular Gel |
|---|---|---|---|---|
| 1 | Water top up not required | X | ✓ | ✓ |
| 2 | Factory charged and ready for use | X | ✓ | ✓ |
| 3 | Long cycle life | ✓ | X | ✓ |
| 4 | Deep Discharge recovery | X | X | ✓ |
| 5 | PSOC operation | X | X | ✓ |
| 6 | Low Self discharge | X | ✓ | ✓ |
| 7 | No acid stratification | X | X / ✓ | ✓ |
| 8 | Less sensitive for high temperature | ✓ | X | ✓ |

They concluded that tubular Gel is the design that meets all the requirements of SPV application

They also suggested that the following points for inclusion in the draft specification:

1. Deep discharge recovery test may be included
2. Internal resistance and Short circuit test
3. Unbalanced over discharge test
4. Safety valve opening test for VRLA
5. Test at Zero deg.C.

Comments on draft specification from them had een received

**M/S.Kirloskar Batteries Limited:**
They have designed and developed high performance low maintenance battery to meet the condition of SPV application. Due to use of special alloys for the grids, conducting paths and special additives in active materials, charging efficiency of 95% minimum is achieved at both low and high rate of charge.
The following points in the draft specification needs clarification
1.10% SOC test is not clear and needs further clarification
2. What is the purpose of Softening Test?
3. The number of tests should be limited to minimum and five years life guarantee should be specified for the batteries
Regarding the comments on draft specification it will be sent within seven days.

**M/S.NED Energy Limited:**
The ampere-hour efficiency under SPV conditions for AGM VRLAB, HYBRID VRLAB, and TUBULAR GEL VRLAB AND TUBULAR LMLA is 80%, 80%, 75% and 73% respectively. The cyclic life test units @80% DOD at $50^0$C for the above batteries are 7,10,12,10 respectively. They rated the percentage of score for the said batteries are 77%, 83%, 93%, 50% respectively. Life condition at 50-60% SOC and deep discharge recovery should be addressed. They submitted the comments about the draft specification circulated earlier

**M/S.Sakthi Electronics:**
Their presentation highlighted the general field problems such as difficult to maintain fully charged condition and recover from deep discharged condition during non sunny days, low acceptance of charge by the batteries at low charging currents, improper use by the customers by adding additional D.C.load. They also suggested the remedial action such as user of purest material for retention of charge, right mix of oxide, carbon to enhance conductivity, special additive to aid in better charging and to recover from sulphation. Comments on draft specification from them have been received

**M/S. Sharana Batteries:**

Suggested the following

1. The application is more like traction battery
2. Design feature should include tubular lead-acid battery
3. It should sustain deep discharge for longer duration

Regarding the comments on draft specification it will be sent within seven days

**M/S.Bharat Heavy Electrical Limited**

Presented the case study of battery performance carried at Rakhalpur 110KWp SPV plant in Sundarban islands, in West Bengal. It has two sets of 240V/800Ah battery bank and capacity at 80%DOD is 1280Ah at $C_{10}$ rate with daily load of 80A for 5h. Each battery bank is charged with 2X25KWp PV array. MPPT based with PWM charge controller, having protection against deep discharge and over charge. The village load is 15KW from 5.30PM to 10.30PM. They observed that the batteries are getting charged at $C_6$ rate with varying input currents and discharge at $C_4$ to $C_8$ rate depending on load and site requirement. Due to continuous environmental changes and continued monsoon would make the cells deep discharge, mismatching of cells and provision of on site DG set charging of battery to overcome the said problems.

**M/S.Tamilnadu Electricity Board**

They presented large scale energy storage in power sector- challenges, trends, and future optional, wind and solar energy, distributed generation, peak load shaving are the critical areas need for economic and efficient large scale energy storage. Non availability of solar energy at nights when the peaking load happens and intermittent and unpredictability of wind energy are major areas of concern while harnessing solar and wind energy. Flow batteries of Vanadium redox batteries have been utilized for large scale energy storage abroad. They also put forth questions on the following aspects:

- ❖ Does the existing Battery technology help us to meet the tremendous need of storage systems anticipated with the evolution of Smart Grid?

- ❖ Do the existing manufacturing technologies in Batteries sufficient to harness the rapidly fluctuating power of Wind Energy?

- ❖ What could be the maximum life cycle that could be expected with the current Batteries especially of Lead Acid and at what DOD? Are there ways to increase it? If so to what extent?

- ❖ How exactly to quantify the Sulphation in the plates of the Batteries which acts as the prime factor in reducing the life of the Batteries?

- ❖ Are we only working with the conventional Batteries to tap the enormous amount of Solar & Wind energy in our country? Do we have other technologies that have been established / under research?

**TATA BPSOLAR**

Suggested the following points for inclusion in the draft specification

1. Different design technologies are available for the lead-acid batteries. The life or warranty differs depending on the design. Specify minimum requirement for life for the different design
2. User acceptance of $C_{10}$ discharge test and the ratio between $C_{10}$ to $C_{120}$ should be 1.5. The capacity of the battery should be marked on the container both for $C_{10}$ and $C_{120}$
3. Size of the container as specified in BIS standard need may be left to the manufacturers choice
4. Charging regime for the higher operating temperature

## 6.3 conclusions

Dr.VijayaMohanan concluded that application of Sodium-Sulphur battery is dropped for large scale storage system. Other systems can be considered with improvement .Follow up action of all your comments will be incorporated in the draft specification. Dr.P.C.Pant mentioned that the corrected draft specification will be sent to BIS for further action. He also suggested that CECRI should help SEC in upgrading their test facilities and also explore in opening up new test centers all over the country to meet the requirement of implementation Jawaharlal Nehru Solar mission technology. Suggestions are received from the lead-acid battery industries to collect data of tubular lead-acid battery for SPV application

## 6.4
## Survey of International standards for Storage batteries used in stand alone PV systems

| S.No | Standards | Name | Remarks |
|---|---|---|---|
| 1. | International Electro technical commission (IEC )– 61427 [Brussels] | Secondary cells and batteries for solar photovoltaic energy systems – general requirements and methods of test. | Gives general information relating to the requirements of secondary batteries used in PV solar system, methods of test used for the verification of battery Performance,-VIZ capacity, cyclic endurance and mech.endurance.It does not include battery sizing, method of charge (or) PV system design. |
| 2. | NFC 58-510(1992) (French Standard) | Lead Acid secondary batteries for storing electrical energy generated by a photovoltaic 2system. | It comprises a glossary defining the main parameters, description on battery operational characteristics and test methods, accuracy of measurement instruments, faradic efficiency, cycling, overcharge capacity and mech. endurance. |
| 3. | AS 4086.1.1993 (Australian Standard ) | Secondary batteries for use with stand -alone power systems – general requirements | Requirements for secondary batteries for use with stand alone power systems, supplied with power from one or a combination of PV array, a wind generator or diesel generator, standard specifies requirements for all types of batteries including LAB,Ni-cd and covers both vented and sealed cells. Tests designed to verify capacity, efficiency and life of batteries. |
| 3a. | AS 4086.2.1997 | Secondary batteries for use with stand alone power systems – installation and maintenance | Requirements for the installation and maintenance of secondary batteries installed in stand alone power systems. |
| 4. | JIS –C 8971(Japan 1993) | Measuring procedure of residual capacity for lead -acid battery in PV system | ---------- |
| 4a. | JIS –C 8972(Japan 1997) | Testing Procedure of long discharge rate Lead Acid battery for PV | Describes the testing Procedure for lead acid batteries which have |

| | | | |
|---|---|---|---|
| | | **systems** | **been discharge over a long period in PV system.** |
| **5.** | **IEEE937-1987 (R1993)(USA)** | **IEEE recommended practice for installation and maintenance of lead –acid batteries for PV systems.** | **Design considerations and procedures for storage, location mounting, ventilation, assembly and maintenance of lead acid batteries for PV system.** |
| **5a.** | **IEEE1013-1990(USA)** | **IEEE recommended practice for sizing lead –acid battery for PV** | **Recommends methods for sizing both vented and valve regulated LAB for stand –alone PV system.** |
| **6.** | **CSA F382(Canada)** | **Characterization of storage batteries for PV systems.** | **Recommendations on specifying, testing, reporting battery performance currently being revised and its re-acceptance is pending.** |
| **7.** | **CENELEC (European standardization body for electrical standards)** | **--------** | **Standard making process similar to IEC. A number of IEC standards have been adopted as CENELEC standards with identical numbers [i.e. IEC 6xxxx is numbered EN 6XXXX]** |
| **8..** | **Under writers Laboratory (UL)USA** | **It issues safety regulations** | **Not concerned with performance but with safety.** |
| **9.** | **British standards** | **No British PV standards are being developed** | **A number of IEC standards relating to PV have been Published as identical British standards (numbered BSEN6xxxx).** |

**6.5**

# Indian Standard

# Specification (Draft)

# Secondary Cells & Batteries for Solar Photovoltaic (SPV) Application.

**By**

**Central Electrochemical Research Institute**
**[Council of Scientific & Industrial Research]**
**Karaikudi**

**Solar Energy Centre**
**Ministry of New and Renewable Energy**
**New Delhi**

**June 2011**

# CONTENTS

## Indian Standard

## SECONDARY CELLS AND BATTERIES
## FOR RENEWABLE ENERGY STORGAE
## GENERAL REQUIREMENTS AND METHODS OF TEST

### 1. Scope

This Indian Standard gives general information relating to the requirements of the secondary batteries used in photovoltaic energy systems (PVES) and to the typical methods of test used for the verification of the battery performances. This specification deals with cells and batteries used in photovoltaic application.

This Indian Standard does not include specific information relating to battery sizing, method of charge or PVES design.

This standard is applicable to all types of secondary batteries.

### 2. Normative References

The following referenced documents are indispensable for the application of this document. For the dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

IS 1651 & IS 13369, Stationary lead-acid batteries – Vented types – General requirements and methods of test.

IS 15549, Stationary Valve regulated lead-acid batteries specification.

IS 15767 (2008) / IEC 62259, Secondary cells and batteries containing alkaline or other non-acid electrolytes-Nickel cadmium prismatic secondary single cells with partial gas recombination.

BIS 10893 & 10918, Secondary cells and batteries containing alkaline or other non-acid electrolytes – Vented nickel-cadmium prismatic rechargeable single cells.

IEC 61951 – 1, Secondary cells and batteries containing alkaline or other non-acid electrolytes-Portable sealed rechargeable single cells-Part 1: Nickel cadmium.

IEC 61951 – 2, Secondary cells and batteries containing alkaline or other non-acid electrolytes-Portable sealed rechargeable single cells-Part 2: Nickel-metal hydride.

IEC 61960, Secondary cells and batteries containing alkaline or other non-acid electrolytes-Secondary lithium cells and batteries for portable applications.

## 3. Terms And Definitions

For the purpose of this document, the definitions and terms for secondary cells and batteries given in IS 1885 (1986) and IEC 61427 shall apply.

## 4. Conditions of use

This clause specifies the particular operating conditions experienced by secondary batteries in photovoltaic applications during their use.

### 4.1 Photovoltaic energy system

The photovoltaic energy system with secondary batteries referred to in this standard can supply a constant, variable or intermittent energy to the connected equipment **(**lighting systems, communication systems etc.).

### 4.2 Secondary cells and batteries

Secondary cells and batteries mainly used in photovoltaic energy systems are of the following types:

- Vented (flooded);
- Valve-regulated

The cells and batteries are normally delivered in filled & charged or unfilled & uncharged.

In case of partial gas recombination, Ni-Cd cells & batteries shall be delivered in filled and charged or filled & discharged.

For optimum service life, the battery manufacturer's instructions for initial charge of the battery shall be followed.

#### 4.2.1 Material and Construction

**General**

All the materials used in the manufacture of stationary batteries for photovoltaic system shall be the best of their respective kind, free from flaws and defects and shall conform to the relevant Indian standard, if any.

### 4.3 General operating conditions

Batteries in a typical PV system operating under average site weather conditions may be subjected to the following conditions:

#### 4.3.1 Autonomy time

The battery is designed to supply energy under specified conditions for a period of time, typically from 3 days to 15 days, with or without solar radiation.

NOTE – When calculating the required battery capacity, the following items should be considered, e.g.:

- Required daily/seasonal cycle (there may be restrictions on the maximum depth of discharge, DOD shall be limited to 80% at the end of autonomy)
- Time required to access the site
- Ageing
- Operating temperature
- Future expansion of the load

#### 4.3.2 Typical charge and discharge currents

The typical charge and discharge currents are the following:

- Maximum charge current: C/10 A
- Average discharge current determined by the load: C/120 A.

NOTE 1- Depending on the system design, the charge and the discharge current may vary in a wider range.

NOTE 2- In some systems the load current must be supplied at the same time as the battery charging current

#### 4.3.3 Daily cycle

The battery is normally exposed to a daily cycle as follows:

a. Charging during daylight hours.
b. Discharging during night-time hours.

A typical daily usage results in a discharge between 2% - 20% of the battery capacity.

### 4.3.4 Seasonal cycle

The battery may be exposed to a seasonal cycle of state of charge. This arises from varying average-charging conditions as follows:

- Periods with low solar irradiation, for instance during rainy season / monsoon season causing low energy production. The state of charge of the battery can go down to 20% of the rated capacity.
- Periods with high solar irradiation, e.g. in during other seasons, this will bring the battery up to the fully charged condition, with the possibility that the battery could be overcharged.

### 4.3.5 Period of high state of charge

Typically, In Indian operating conditions, batteries will be operated at high state of charge between 80 to 100% of rated capacity during seasons other than the monsoons, unless batteries & systems are not properly sized.

A voltage regulator system normally limits the maximum battery voltage during the recharge period. When generation voltage exceeds beyond the limits, the controller should trip-off and reconnect back as soon as the generation voltage comes to normal range to avoid any delay in charge cycle. Charge controller should be sized accordingly to keep the battery & load always safe & getting charged.

The system designer normally chooses the maximum charge voltage of the battery (as applicable to each battery technology) as a compromise allowing to recover to a maximum state of charge (SOC) as early as possible in the seasons other than the monsoon but without substantially overcharging the battery.

The overcharge increases the gas production resulting in water consumption in vented cells. In valve regulated lead acid cells, the overcharge will cause a lesser increase of water consumption and battery internal temperature there by reduction in battery life.

Typically the maximum charge voltage is 2.4 V per cell for lead-acid batteries and 1.55V per cell for vented nickel-cadmium batteries (refer manufacturers recommendations). These values are applicable for the reference temperature specified by the manufacturer.

For the other batteries the values shall be given by the battery manufacturers. Charge voltage compensation shall be used according to the battery manufacturer instructions if the battery operating temperature deviates significantly from the reference temperature.

The expected life-time of a battery in a PV system even kept regularly at a high state of charge may be considered less than the published life of the battery used under continuous float charge.

### 4.3.6 Period of sustained low state of charge

During periods of low solar radiation, the energy produced by the photovoltaic array may not be sufficient to fully recharge the battery. The state of charge will then decrease and cycling will take place at a low state of charge. The low solar irradiation on the PV array may be a result of the geographical location combined with the monsoon, snow periods, heavy clouds, rains or accumulation of dust on photovoltaic array.

### 4.3.7 Electrolyte stratification

Electrolyte stratification may occur in lead-acid batteries. In vented lead acid batteries, electrolyte stratification can be avoided by electrolyte agitation or periodic overcharge whilst in service. In valve regulated lead-acid (VRLA) batteries, electrolyte stratification can be avoided by design or by operating them according to the manufacturer instructions.

### 4.3.8 Storage

Manufacturer’s recommendations for storage shall be observed. In the absence of such information, the storage period may be estimated according to the climatic conditions as shown in the Table 1 as below.

**Table 1 – Limit values for storage conditions of batteries for photovoltaic applications**

| Battery type | Temperature range | Humidity | Storage period for batteries | Storage period for batteries |
|---|---|---|---|---|
| | | | With electrolyte | Without electrolyte |
| Lead-Acid | -20 to +50$^0$C | <95% | Up to 6 months | 2 years |
| Nickel-Cadmium (Pocket plate type) | -20 to +50$^0$C (standard electrolyte) | <95% | Up to 6 months | 1-3 years (fully discharged, drained and sealed) |
| | -40 to +50$^0$C (high density electrolyte) | <95% | | |
| Nickel metal hydride | -40 to +50$^0$C | <95% | Up to 6 months | N/A |
| Lithium Ion * | -20 to +50$^0$C | <95% | Up to 12 months | N/A |

With electrolyte, a Lead-Acid or Nickel-cadmium battery shall be stored at full state of charge.

*It shall be always be checked with the manufacturer.

A loss of capacity may result from exposure of a battery to high temperature and humidity during storage.

Note: The temperature of a battery stored in a container in direct sunlight, can rise to 60$^0$C or more in daytime. Choice of shaded location or cooling should avoid this risk.

### 4.3.9 Operating temperature

The temperature range during operation experienced by the battery at the site is an important factor for the battery selection and the expected lifetime.

Manufacturer's recommendations for operating temperatures and humidity shall be observed. In the absence of such information, operating temperatures and humidity may be those shown in the Table 2 as below.

**Table 2 – Limit values for operating conditions of batteries for photovoltaic applications**

| Battery type | Temperature range | Humidity |
|---|---|---|
| Lead-Acid | -20 to +50$^0$C | <95% |
| Nickel-Cadmium (standard electrolyte) | -20 to +50$^0$C | <95% |
| Nickel-Cadmium (high density electrolyte) | -40 to +50$^0$C | <95% |
| Nickel-metal hydride | -20 to +50$^0$C | <95% |
| Lithium-ion and other electro chemistries | To be checked with the battery manufacturer | To be checked with the battery manufacturer |
| NOTE 1- The manufacturer should be consulted for temperature outside this range. Typically the life expectancy of batteries will decreases with increasing operating temperature<br><br>NOTE 2- Low temperature will reduce the discharge performance and the capacity of the batteries. For details, the manufacturer should be consulted. | | |

### 4.3.10 Charge control

Excessive overcharge does not increase the energy stored in the battery. Instead, overcharge affects the water consumption in vented batteries and consequently the service interval. In addition, valve-regulated lead-acid batteries may dry out resulting in a loss of capacity and or overheating.

Overcharge can be controlled by use of proper charge controllers. Most lithium-ion batteries will not accept any overcharge without damage or safety problems, and they normally come with a BMS (Battery Management System) that prevents this, independently from this charge controller.

The parameters of the regulator shall take into account the effects of PV generator design, the load, the temperature and the limiting values for the battery as recommended by the manufacturer.

Vented lead-acid or nickel-cadmium batteries including those with partial gas recombination shall have sufficient electrolyte to cover at least the period between planned service visits. Overcharge in valve-regulated batteries shall be carefully controlled to reach optimum lifetime.

The water consumption is measured during the cycle test (see 8.4.5) and can be used together with the system's design information to estimate the service intervals.

Recommended Voltage Settings in Charge Controller shall be as per manufacturer recommendations. Voltage compensation shall be applied when operating at different temperatures.

#### 4.3.11 Physical protection

Physical protection shall be provided against consequences of adverse site conditions, for example, against the effects of:

- Uneven distribution and extremes of temperature
- Exposure to direct sunlight (UV radiation)
- Air-borne dust or sand
- Explosive atmospheres
- Flooding, water vapour condensation and water spray.
- Earthquakes
- Shock and vibration (Particularly during transportation)

## 5 General requirements

### 5.1 Mechanical endurance

Batteries for photovoltaic application shall be designed to withstand mechanical stresses during normal transportation and handling. Additional packing or protection shall be used for off-road conditions.

Particular care shall be taken while handling unpacked batteries & Manufacturer's instructions shall be followed. In case of specific requirements regarding mechanical stresses, such as earthquakes, shock and vibration, these shall be individually specified or referred to the relevant standard.

### 5.2 Charge efficiency

The charge efficiency is the ratio between the quantity of electricity delivered during the discharge of a cell or battery and the quantity of electricity necessary to restore the initial state of charge under specified conditions.

NOTE – The quantity of electricity is expressed in Ampere-hours(Ah).

Where no data is available from the battery manufacturer, the following efficiencies as given in Table 3 may be assumed.

**Table 3 – Battery Ah-efficiency at different state of charge at the reference temperature and a daily depth of discharge of less than 20% of the rated capacity**

| **State of charge (SOC) %** | Efficiency lead-acid cells % | Efficiency Ni-Cd and Ni-MH cells % | Efficiency Li-Ion cells % |
|---|---|---|---|
| 90 | >85 | >80 | >95 |
| 75 | >90 | >90 | >95 |
| <50 | >95 | >95 | >95 |

The test method should corresponds to efficiency at 90% state of charge listed in 8.6

Note: Charge efficiency of Lead acid and Ni-Cd cells reduces at high SOC as compared to lower SOC.

### 5.3 Deep discharge protection

Lead-Acid batteries shall be protected against deep discharge to avoid capacity due to irreversible sulphation. This could be achieved by using a system, which monitors the battery voltage and automatically disconnects the battery before it reaches its maximum depth of discharge (see manufacturers recommendations).

Vented and partial gas recombination Nickel-cadmium batteries do not normally require this type of protection.

For the other types of batteries, the manufacturer’s recommendation shall be followed.

### 5.4 Marking

Cells or monobloc batteries shall follow the instructions of the applicable standards defined in clause 7.2.

### 5.5 Safety

Refer to applicable local regulations and the manufacturer’s instructions for procedure to be observed during installation, commissioning, operation, taking out of service, and disposal.

### 5.6 Documentation

Refer to manufacturer’s documentation for the transport and storage, commissioning, putting into service, operation and maintenance.

The manufacturer shall advice if there are special considerations for the initial charging of batteries with only the photovoltaic array available as the power source.

## 6 Functional characteristics

The batteries shall be characterized by their:

- Rated capacity (see 8.1)
- Endurance test (see 8.2)
- Charge retention (see 8.3)
- Cycling endurance in photovoltaic application (extreme conditions) (see 8.4) (Or)
- Sulphation test (see 8.5)
- Efficiency test (90%SoC) (see 8.6)

## 7 General test conditions

### 7.1 Accuracy of measuring instruments

When testing batteries, the parameters and accuracy values shall be in accordance with relevant clauses of the IS standards listed in 7.2

The accuracy of the measuring instruments shall be in compliance with the relevant Indian Standard listed in 7.2

### 7.2 Standards to be referred for testing

Tests for which detailed procedures are not given in this standard, established procedure given in the following standards are to be adopted:

- IS 1651& IS 13369 for stationary lead-acid batteries (vented types);
- IS 15549 for stationary lead-acid batteries (valve-regulated types);
- JIS 8702 for portable lead-acid batteries (valve-regulated types);
- BIS 10893 & BIS 10918 for vented nickel-cadmium battereies;
- IS 15767 : 2008 / IEC 62259 for nickel cadmium prismatic rechargeable single cells with partial gas recombination;
- IEC 61951-1 for portable nickel-cadmium batteries;
- IEC 61951 – 2 for portable nickel metal hydride batteries;
- IEC 61950 for portable Lithum batteries.

## 8 Test method

### 8.1 Capacity test

Test samples shall be set up in accordance with the applicable standards in 7.2. Tests to verify the rated capacity shall be performed using a current of $I_{10}$

(A) for lead-acid batteries, $I_t/5$ (A) for nickel-cadmium and Ni-MH batteries, or $I_{10}$(A) for other batteries, according to the relevant clauses in the IS standards listed in 7.2

For the capacity using a current of $I_{120}$(A) for lead-acid batteries and other batteries, the discharge shall be in accordance with parameters stated in Table 4 and the charging procedure shall be carried out according to the relevant clauses in the IS listed in 7.2

**Table 4 – Typical capacity ratings of batteries in photovoltaic applications**

| Capacity Ah | Current A | | Discharge period hrs | Final voltage V/cell | Final voltage V/cell |
|---|---|---|---|---|---|
| | Lead-acid | Nickel-cadmium and Ni-MH | | Lead-acid | Nickel-cadmium and Ni-MH |
| $C_{120}$ | $I_{120}$ | $I_t/120$ | 120 | 1.85 | 1.00 |
| $C_{10}$ | $I_{10}$ | - | 10 | 1.80 | - |
| $C_5$ | - | $I_t/5$ | 5 | - | 1.00 |

**$I_{10}$ = $C_{10}$ / 10 hr** - Discharge current @ **10 hr** rate
**$I_{120}$ = $C_{120}$ / 120 hr** - Discharge current @ **120 hr** rate

**Requirement**: As per the standards mentioned in clause no. 7.2

## 8.2 Endurance test

Test samples shall be tested according to the applicable standards described in 7.2.

## 8.3 Charge retention test

Test samples shall follow the procedures of the applicable standards described in 7.2.

## 8.4 Cycle endurance in photovoltaic application (extreme conditions)

In photovoltaic applications the battery will be exposed to large number of shallow cycles but at different state of charge. The cells or batteries shall therefore comply with the requirements of tested below, which is a simulation of the photovoltaic energy system operation.

The cycle endurance test is an accelerated simulation in extreme conditions of the battery operation in a photovoltaic energy system and shall be conducted by submitting the cells or monobloc batteries to a period of 150 cycles (50 cycles with the phase A and 100 cycles with the phase B).

Samples shall be selected for conducting this test as per Clause no. 9.1

Start the test with fully charged battery. Bring the battery to a temperature of 40ºC±3ºC and stabilize for 16h. Maintain the battery at 40ºC±3ºC throughout the test.

Total cycles per unit = 150 (Phase A 50cycles + Phase B 100 cycles).

### 8.4.1 Phase A: Shallow cycling at low state of charge

**Lead –acid batteries**

a) Discharge the batteries with a current $I_{10}$ (A) during 9 hrs or until 1.75 v /cell is reached.
b) Recharge 3hrs with a current 1.03 x $I_{10}$ (A)
c) Discharge 3hrs with a current $I_{10}$ (A)

**Nickel – Cadmium and Ni-MH batteries**

a) Discharge the batteries with a current $I_t$/10(A) during 9 hrs or until 1.0 v /cell is reached.
b) Recharge 3hrs with a current 1.03 x $I_t$/10(A)
c) Discharge 3hrs with a current $I_t$/10(A)

**Other batteries**

a) Discharge the batteries with a current $I_t$/10(A) during 9 hrs or until the specified end voltage is reached.
b) Recharge 3hrs with a current 1.03 x $I_t$/10(A)
c) Discharge 3hrs with a current $I_t$/10(A)

For both battery types, repeat b) and c) 49 times. Recharge the battery to the fully charged condition according to the manufacturer recommendations and continue the phase B. phase A is summed up in Table 5.

**Table 5 – Phase A shallow cycling at low state of charge**

| | Discharge time h | Charging time h | Lead-acid current A | Ni-Cd and Ni-MH current A |
|---|---|---|---|---|
| a) | 9 | | $I_{10}$ (A) (or stopping at 1.75 V/cell) | $I_t$/10(A) (or stopping at 1.00 V/cell) |
| b) | | 3 | 1.03x $I_{10}$ (A) | 1.03x $I_t$/10(A) |
| c) | 3 | | $I_{10}$ (A) | $I_t$ /10 (A) |
| Repeat b) to c) 49 times and continue to phase B<br>For the other types of batteries manufacturers shall specify the end voltage | | | | |

### 8.4.2 Phase B: Shallow cycling at high state of charge

**Lead –acid batteries**

a) Discharge the battery for 2hrs with a current 1.25x $I_t$/10 (A).
b) Recharge 6hrs with a current $I_{10}$ (A). The charge voltage shall be limited to 2.4 V/cell unless otherwise specified by the manufacturer.

**Nickel- cadmium, Ni-MH and other batteries**

a) Discharge the battery for 2hrs with a current 1.25x $I_t$/10*(A).*
b) Recharge 6hrs with a current $I_t$/10*(A)* . The charge voltage shall be limited to
1.55 V/cell unless otherwise specified by the manufacturer.

For both battery types, repeat b) and c) 99 times and then perform a capacity determination according to 8.4.3. Phase B is summed up in Table 6.

**Table 6 – Phase B Shallow cycling at high state of charge**

| | Discharge time<br>h | Charging time<br>h | Lead-acid current<br>A | Ni-Cd and Ni-MH current<br>A |
|---|---|---|---|---|
| a) | 2 | | 1.25 $I_{10}$ (A) | 1.25 $I_t$/10*(A)* |
| b) | | 6 | $I_{10}$ (A)<br>(charge voltage limited to 2.4V/cell unless otherwise specified by the manufacturer) | $I_t$/10(A)<br>(charge voltage limited to 1.55V/cell unless otherwise specified by the manufacturer) |
| Repeat a) to b) 99 times | | | | |

### 8.4.3 Capacity check

After the phase B, the battery is cooled down to the temperature defined in the relevant standard as described in 7.2 and stabilized at this value for 16hrs. The capacity test $C_{10}$ for Lead acid and $C_5$ for Nickel-cadmium & Ni-MH batteries is carried out according to the relevant standard as described in 7.2.

### 8.4.4 End of test condition

- Capacity is checked after each period of 150 cycles (phases A+B).
- The value of actual capacity determined in 8.4.3 shall be recorded.
- The cycle life shall be expressed in number of 150 cycle (A+B) sequences completed.
- The test is finished.
    - During the phase A: when the cell voltage measured in discharge is lower than 1.5V/cell for lead acid batteries and 0.8V/cell for Ni-Cd and Ni-MH batteries. For other batteries, the minimum voltage shall correspond to a safe value for each cell of a battery system and shall be given by the battery manufacturer.
    - After the phase B: when the checked capacity measured in 8.4.3 is lower than 80% of the rated capacity.

Note- Each period of 150 cycles corresponds approximately to 1 year of life expectancy in site condition.

### 8.4.5 Water consumption of flooded battery types and cells with partial gas recombination

During the endurance test, vented type batteries may topped up with water. The amount of water added shall be measured and reported.

### 8.4.6 Requirement

The minimum number of complete (A+B) sequences (150 cycles) achieved shall be 3 [three]. At the end of the test the $C_{10}$ or $C_5$ capacity shall not be less than 80% of the rated one for Lead Acid and Nickel Cadmium batteries respectively.

## 8.5 Sulphation Test – Applicable for Lead acid batteries only

8.5.1 The test sequence consists of three stages: (Stage A and Stage B) and one capacity measurement at $C_{10}$.

8.5.2 Prior to the capacity measurement, the battery has to be discharged at $I_{100}$ down to end voltage specified by the manufacturer. Then fully charged and maintained during 48h at 2.35VPC (Flooded) or 2.30 VPC (VRLA) or as per manufacturer recommendations for other batteries.

8.5.3 Stage A: Battery undergoes shallow cycles with 3h discharge at 6.6 $I_{100}$ rate and recharge
for 4h at 4.85 $I_{100}$ rate until low voltage threshold specified by the manufacturer is reached.

8.5.3.1 The charging regime is not sufficient to fully charge the battery so that the state of charge of the battery progressively decreases. The number of cycles needed to reach the low voltage threshold ranges from 30 to 80 Cycles depending on the battery type.

8.5.4 Stage B: The battery undergoes shallow cycles with the same discharge regime as in stage A and recharging at the I= 5.45 $I_{100}$ rate so that the state charge of the battery progressively increases with cycling .The number of cycles in stage B is by definition the same as in stage A.

8.5.5 Several test sequence are repeated until an end of test criterion is reached. The total test sequences should be more than five [5].

8.5.6 Prior to cycling the electrolyte temperature is maintained at 40ºC. ± 3°C and topping with distilled water can be done for vented type batteries throughout the test as and when required and it shall be reported.

8.5.7 The figure below gives the standard cycling procedure.

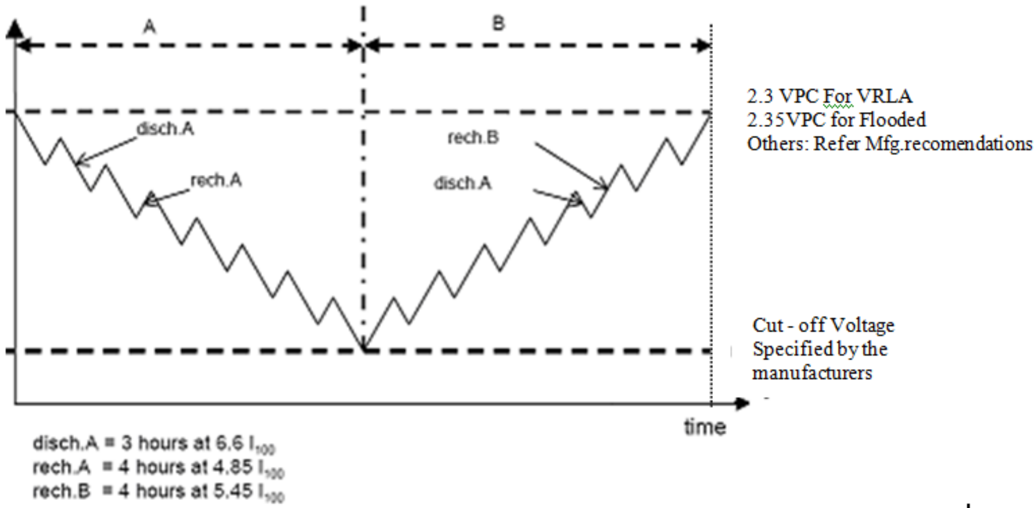



**Fig: Standard cycling procedure**

Requirement: Min. 5 such sequences to be met before the battery fail to deliver 70 % of the rated capacity as per Cl. No:8.1.

## 8.6 Efficiency at 90% state of charge

To determine battery efficiency at 90% state of charge as follows:

a) Prepare the battery for test in accordance with the below.

All tests shall be carried out on new and fully charged cells or batteries. A battery is considered to be fully charged when, during charging in accordance with the manufacturer’s recommendations, the voltage and current readings remain stable for the three consecutive hourly readings.

b) Maintain a battery temperature and allow the battery to stand for 20hr to 24hr.

c) Discharge the battery at the 0.1 $C_{10\ \text{rate}}$ ± 1% for a time given by the following equation:

$$\mathbf{t = \frac{1.5 \times C_{120}}{C_{10}}}$$

Where,

$t$ = discharge time, in hours

$C_{120}$ = capacity of the battery at the 120h rate of discharge, in Ah

$C_{10}$ = capacity of the battery at the 10h rate of discharge, in Ah

d) Record the voltage $V_e$ at the end of the discharge period.
e) Recharge the battery at the 0.033 $C_{120}$ rate ± 1% for 3± 0.05 h. The battery temperature shall be maintained at 30± 2ºC during the recharge.

f) Allow the battery to stand between 20hr and 24hr at a temperature of 30± 2ºC
g) Discharge the battery at the $0.1C_{10}$ rate ± 1%.

End the discharge when the battery reaches the final voltage $V_e$ measured in step (d) and record the time $t_d$ of the discharge in hours.

Determine the efficiency at 90% state of charge in accordance with the following equation:

$$E = \frac{T_d \times C_{10} \times 100}{C_{120}} \%$$

Where
*E* = efficiency, expressed as a percentage
$t_d$ = time of discharge to final voltage Ve, in hours
$C_{10}$ = capacity of the battery at the 10 h rate of discharge, in ampere hours
$C_{120}$ = capacity of the battery at the 120 h rate of discharge, in ampere hours

Requirement: The battery shall deliver the efficiency level as mentioned in Cl. No: 5.2, Table-3.

## 9 Recommended use of tests

### 9.1 Type test

Type tests are:
- the rated capacity test and the charge retention test
- the endurance test
- the cycling endurance test in photovoltaic application (extreme condition) OR Sulphation Test (applicable for Lead Acid batteries only).
- Efficiency at 90% State of charge.

The minimum number of samples shall be as specified in the relevant standards listed in 7.2

The endurance test in photovoltaic application shall be performed with a minimum of two cells (or two battery packs, or two 6-cells blocks for lead-acid batteries)

### 9.2 Acceptance test

#### 9.2.1 Factory test

The acceptance test shall be agreed between the customer and the supplier. Compliance to marking, labeling rated capacity may be verified.

#### 9.2.2 Commissioning test

A commissioning test is recommended to prove the integrity of the installed battery system by means of a capacity test @ 10 hr rate.

………………………. …………*End of Document*
……………………………………………

## 7.0 Others:

### 7.1 Papers presented

**ISAEST 2010**

- **PIC based PWM Charge controller for solar photovoltaic lighting system – R.Saravanamuthu, U. Mahesh Pandi, E.Jensi Miriam, P.Seenichamy, P.C.Pant *, S.Ambalavanan**

**NCE -15**

- **Studies on the Effect of Process Parameter On Lead Sulphate Crystal Size in Lead - Acid Battery Negative Plate.**
  **G.Gopu, P.C.Pant and S.Ambalavanan**

- **Performance Prediction of Photovoltaic Energy Source System Using Mat lab.**
  **E.JensiMiriam, P.C Pant , S. Ambalavanan.**

- **Studies on Thermal Images of Valve Regulated Lead – Acid Batteries for Solar Photovoltaic Stand-Alone Lighting Applications**
  **M.Saravanan, P.C.Pant, S.Ambalavanan**

- **Real-Time simulator of solar panel power generation – an ANN approach .**
  **E.JensiMiriam, P.C Pant , S. Ambalavanan.**
  **IET[UK] Renewable power generation . – Paper under Review .**

### 7.2 HRD:

Two staffs **[**S/Shri. Parveen Kumar & Adarsh Kr. Pandey] from, Solar Energy Centre, MNRE, were trained in the field of lead-acid battery
Their details are given below

During training following topics have been covered and hands on training in the Bitrode life cycle tester is given. Their details are given below:-

| Date | Topics | Topics |
|---|---|---|
| | Before noon | After noon |
| 23-03-2009 | Basics Of Battery | Charging of Battery |
| | Property of Electrolyte | Different Methods Of Charging |
| 24-03-2009 | Formation of Electrodes of Lead-Acid Battery | Testing of Lead –Acid Battery |
| | Valve regulated Lead-Acid Battery | Visit of XPS,SEM and XRD lab at CECRI |
| 25-03-2009 | Failure Analysis of Battery | Visit of Solar Power plant |
| | Visit of AAS, NI-MH Battery Lab at CECRI | |

The following materials are given to them by CECRI:
(1). Assembly, Testing, Care and Maintenance lecture notes
(2). Handbook of Electrochemistry
(3). Cadmium reference electrode to find the potential of positive and negative plates

## 8.0 Conclusions

- **The studies reveal that the performance of VRLAB is better than LM flooded LAB for solar street light stand alone application. It is also comparable with flooded tubular LAB.**
- **Sulphation is the major failure in LAB operated under PoSC operation such as SPV application**
- **Water loss in flooded LAB is higher than VRLAB in the said application**
- **At low Sp.Gr.1220, the growth of lead sulphate crystal initially is in 2-d whereas for higher Sp.Gr the growth is 3-d.**
- **The performance of PIC based PWM charge controller is better than the conventional series type controller**
- **The life of lead-acid battery is decided by the watt-hour ratio between storage battery and solar panel. This ratio is 1:2.4 for a load of 11W used in solar stand alone street light application**

## 9.0 Scope for future work

1. **Use of modified negative electrode with half carbon paste for negative electrode to reduce sulphation**
2. **Use of additives such as carbon nanotubes, ionic liquids to reduce sulphation in the electrodes**

## 10.0 References:


1. Comparative performance study of lead-acid batteries for photovoltaic stand-alone lighting systems- B.Hariprakash, S.K.Martha, S.Ambalavanan, S.A.Gaffoor, A.K.Shukla, and J.Appl.Electrochem. (2008)38:77-82

2. Influence of the charge regulator strategy on SOC and life time of VRLA battery in house hold PV systems, Hong Yang, Hewang, Guangde chen and Guoming W, solar energy Mar2005

3. Report IEA PVPS T3-05:199, Recommended practices for charge controllers, Eric.P.Usher and Michael M.D.Ross, Aug1998].

4. D.R Clark, S.A. Klein and W.A.Bckman. 1984, A method for estimating the performance PV systems. Solar Energy, 33, (6), 551-555,

5. Singh, V.N., Singh, R.P., 1983. A method for the measurement of solar cell series resistance. J. Phys. D Appl. Phys. 16, 1823–1825.

6. User Guide of Davis solar panel, estimating power from a solar panel, Available from :http://www.davisnet.com/product_documents/weather/app_notes/apnote_9.pdf

## Acknowledgement

1. Secretary, Ministry New and Renewable Energy, New Delhi
2. Director, Central Electrochemical Research Institute, Karaikudi
3. Dr. Bibek Bandyopadhyay, Adviser MNRE and Head Solar Energy Centre
4. Dr. O.S.Sastry, Director, Solar Energy Centre
5. Prof. A.K.Shukla, Indian Institute of Science, Bangalore
6. M/s. Ned Energy Limited, Hyderabad
7. M/s. Sakthi Electronics Limited, Bangalore
8. M/s. Crisp System, Coimbatore
9. M/s. K-Pas Electronics, Chennai
10. M/s. Indocell, Chennai
11. M/s. Industrial Electronics Corporation, Madurai