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ANALYSIS OF PV BASED BATTERY CHARGING UNIT

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Abstract- The need for renewable energy sources is on the rise because of the acute energy crisis in the world today. Solar Energy is a vital untapped resource in a tropical county like ours. The main hindrance for the penetration and reach of solar PV system is their low efficiency and high capital cost. In this paper, experimental charging of the battery with Maximum Power Point Tracking (MPPT) and the Non-MPPT strategy with the photovoltaic solar panels. The batteries are charged as separate energy storage devices utilizing the Non-MPPT charging first after that by the MPPT charging strategies. A comparison is made between two charging methods for the energy storage device. The experimental results explain and overall improvement in the charging rate is quite significant utilizing the MPPT strategies for the batteries.

Index Terms— Photovoltaic Panel; Mathematical Model of Solar PV; MPPT; Temperature and Irradiation; Battery

I. INTRODUCTION

All Nowadays, the world is increasingly experiencing a great need for additional energy resources so as to reduce dependency on conventional sources, and photovoltaic (PV) energy could be an answer to that need. However, the performance of PV depends on solar radiation, ambient temperature, and load impedance. These all factors are affected on output of solar PV. In this paper, shows the experimental performance done on the battery charging and discharging by using MPPT at various conditions. The main objective of the battery charging is provided back-up power to load whenever non-convectional energy fails.

As electrical and electronic devices become increasingly essential parts of modem society, we are ever more dependent on our sources of electrical power. Batteries are one of the few practical methods of storing electrical energy. As such, they are vital components in electrical and electronic devices ranging from portable electrical shavers to satellites in space. Recent advances in battery technology, both in new battery types and in improvements to existing batteries, have fueled a surge in battery applications. As battery applications become more diverse and more critical to system operation, it is especially important that system designers and users understand the fundamentals of battery function. [2]

The system system's operating point is at the intersection of the I-V curves of the PV array and load, when a PV array is directly connected to a load. The Maximum Power Point (MPP) of PV array is not attained most of the time. This problem is overcome by using an MPPT which maintains the PV array's operating point at the MPP. The occurrence of MPP in the I-V plane is not known priory; therefore it is calculated using a model of the PV array and measurements of irradiance and array temperature. Calculating these measurements are often too expensive and the required parameters for the PV array model are not known adequately. Thus, the MPPT continuously searches for MPP. There are several MPPT continuously searches algorithms that have been proposed which uses different characteristics of solar panels and the location of the MPP. [2]

A battery-charging approach that has been widely applied in PV systems is based on directly connecting the solar array to the battery bank. As shown in Fig.1, for a six-cell battery, the battery is supplied by the maximum available PV current, which depends on the battery state of charge. When a preset overcharge limit is reached, the battery is disconnected from the power source. In a similar version, the full PV array current is supplied to the battery until the battery voltage increases to a voltage regulation set point.[1]

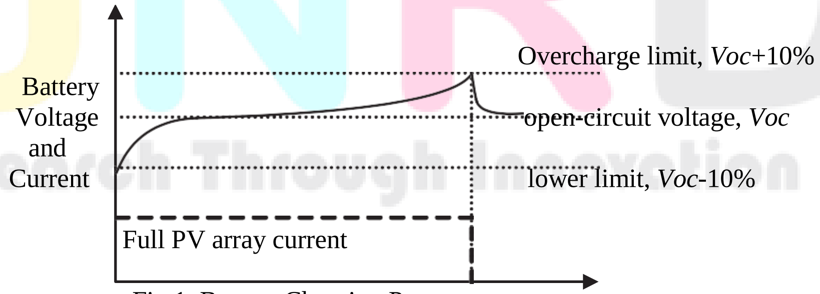

Fig.1. Battery Charging Process

II. FACTORS AFFECTING EFFICIENCY OF BATTERY AND SOLAR CELL

In order to select batteries for standalone PV system, it is imperative that we have to know about their conjuration execution aspects, features, operating temperatures, cycle life and necessities. Data in the accompanying segments is planned as an audit of essential electrical battery qualities and phrasing as is generally utilized as a part of the outline and provision of batteries in systems.

A. SOC:

The State of charge of battery is represented as SOC. This is very important parameter for battery; it defines as the amount of energy present in the battery represented in percentage of energy available in electrical fully charged battery

Facts about SOC:

1. SOC increases when battery is in charging process, and
2. SOC decreases when battery is in discharging process. [1]

B. Battery lifetime (Cycles):

It is very difficult to predict the exact lifetime of battery because battery depends upon various parameters such as DOD, charge/discharge rates, cycles, and variations of temperatures in batteries. In PV systems Lead-Acid types of batteries last longer than 16yrs as compare to other type of batteries. Whereas under similar under conditions other type of battery like NI-Cd batteries last longer than 16 yrs. [1]

C. Cell Temperature:

Temperature plays an important factor in determining solar cell efficiency. Photon generation increases with increase in temperature. Simultaneously the reverse saturation current increases rapidly and reduces the band gap that affects both current and voltage but effect on voltage is more pronounce. The open-circuit voltage (Voc) and short-circuit current (Isc)
are the two major parameters used to characterize solar cells. With the change in value of cell temperature the simultaneous change in open circuit voltage and current can be seen. As the value of temperature rises the efficiency will be reduced simultaneously. So the cell will be operated at standard temperature which is 25 degree Celsius according to the variation in temperature, we will get change in cell efficiency [2].

D. Energy Conversion Efficiency:

Energy Conversion efficiency simply means the percentage of power converted and collected, when a solar cell is connected to an electrical circuit. The amount of energy converted from the sunlight to the Electrical energy can be given by the energy conversion efficiency. There are two methods to improve energy conversion efficiency, one is reduction of the reflection of incident light with an antireflection coating, and the other is optical confinements of incident light with textured surfaces.[3]

E. Solar Irradiance:

The overall performance of solar cell varies with varying Irradiance and Temperature with the change in the time of the day the power received from the Sun by the PV panel changes. The voltage and current both being a function of the light falling on the cell, there exists a complex relationship between irradiation and output power. At lower irradiation levels these mechanisms show an increasing percentage of the total power generated. Too much irradiation causes saturation of cells, and the number of free electrons or their mobility decreases greatly [3]. The irradiance and spectral distribution vary greatly from day to day. Resulting into flow of current. The PV cell current is strongly dependent on the solar radiation.

III. EXPERIMENTAL SETUP AND RESULTS

Typically a solar cell can be modeled by a current source and an inverted diode connected in parallel to it. It has its own series and parallel resistance. Series resistance is due to hindrance in the path of flow of electrons from n to p junction and parallel resistance is due to the leakage current.

A. Mathematical Modeling:

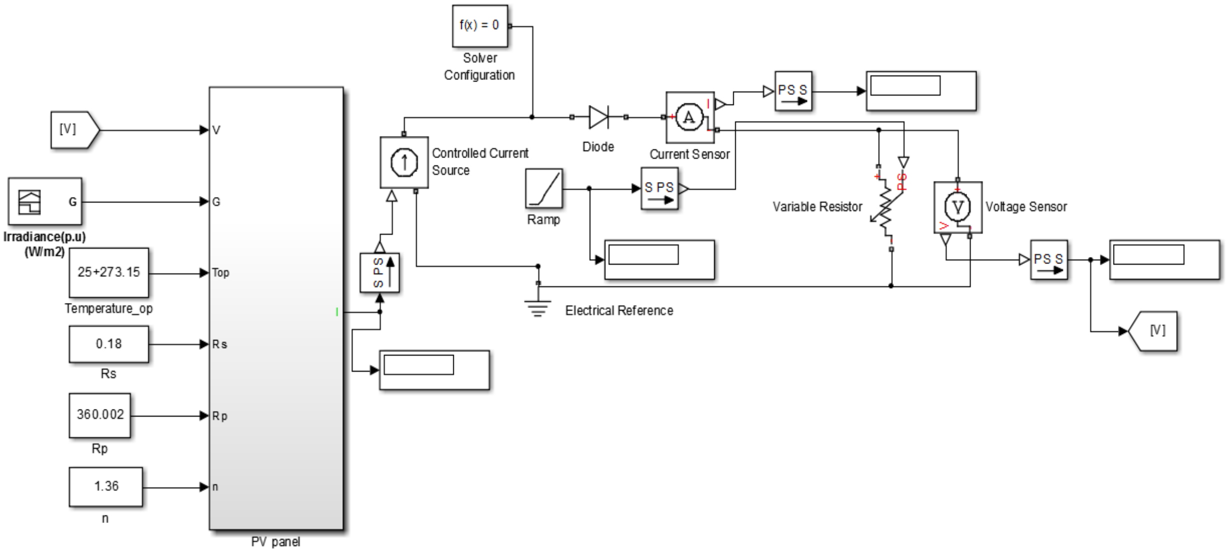

Fig. 2. Mathematical Modeling of Solar

This mathematical modeling done by using below equations.

1. Module Reverse Saturation Current [8]:

$$Irr = \frac{Iscr}{e^{\left\{\left(q*\frac{Voc}{K}*Ns*A*Trk\right)-1\right]}}$$

2. Module saturation current varying with cell Temperature [8]:

$$Id = Irr*\left(\frac{Tak}{Trk}\right)^3 * e\hat{}\left[\left(Eg*\frac{q}{K}*A\right)*\left(\frac{1}{Trk}-1/Tak\right)\right.$$

3. Module Photo Current. [8]:

$$Ipv = \left[Iscr + \left(Ki*(Tak - Trk)\right)\right]*\left(\frac{S}{1000}\right)$$

4. Current output of PV Module [8]:

$$Io = Np * Iph - Np * Id * \left[e^{\left\{\left(\frac{q}{Ns} * A * K * Tak\right) * (Vo + Io * Rs)\right\}} - 1 \right]$$

Abbreviations are:
Io = Output current of PV module
Vo = Output voltage of PV module
Trk = Reference temp of module in K
Tak = Operating temp of module in K
S = Illumination in W/cm2
Q = Electron Charge = 1.6*10^(-19)
A = Identity Factor = 1.3
K= Boltzmann constant = 1.3805*10^(-23) J/K
Eg= Band Gap of Si = 1.12eV
Iscr = Short circuit current at 25C& S=1000
Ns = No of sells in series
Np = No of cell in parallel
Ki=Short circuit temperature coefficient at Iscr=0.0013 A/C
Rs = Series resistance of PV module
Ipv = Light generated current of PV Module
Id = Saturation current of PV module
P-V and I-V curve from Simulation:

From the model given above the solar cell is simulated into MATLAB and for that the PV and IV curves are taken from the XY scope which are given below. These curves will be used to be compared with the results of experimental analysis result.

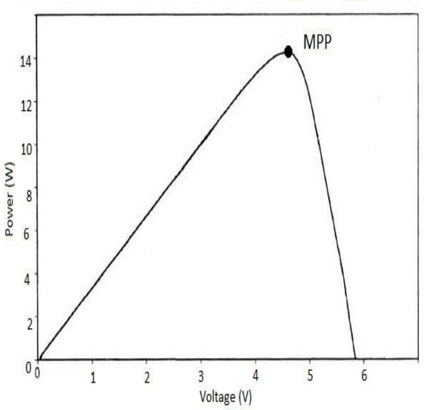

Fig. 4. P-V Graph of Solar PV

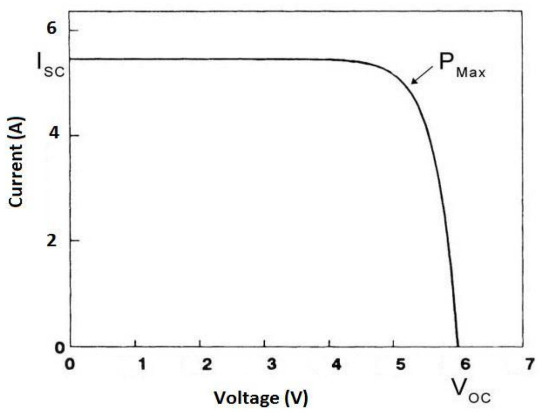

Fig. 5. I-V Graph of Solar PV

B. MPPT Techniques:

A typical solar panel converts only 30 to 40 percent of the incident solar irradiation into electrical energy. Maximum power point tracking technique is used to improve the efficiency of the solar panel. According to Maximum Power Transfer theorem, the power output of a circuit is maximum when the Thevenin impedance of the circuit (source impedance) matches with the load impedance. Hence our problem of tracking the maximum power point reduces to an impedance matching problem.

In the source side we are using a boost convertor connected to a solar panel in order to enhance the output voltage so that it can be used for different applications like motor load. By changing the duty cycle of the boost converter appropriately we can match the source impedance with that of the load impedance. There are different techniques used to track the maximum power point. Few of the most popular Techniques are: [4]

1. Perturb and observe (hill climbing method)
2. Incremental Conductance method
3. Short circuit current
4. Open circuit voltage

In Perturb and Observe method, Perturb & Observe (P&O) is the simplest method. In this we use only one sensor, that is the voltage sensor, to sense the PV array voltage and so the cost of implementation is less and hence easy to implement. The time complexity of this algorithm is very less but on reaching very close to the MPP it doesn't stop at the MPP and keeps on perturbing on both the directions. When this happens the algorithm has reached very close to the MPP and we can set an appropriate error limit or can use a wait function which ends up increasing the time complexity of the algorithm. [4]

However the method does not take account of the rapid change of irradiation level (due to which MPPT changes) and considers it as a change in MPP due to perturbation and ends up calculating the wrong MPP. To avoid this problem we can use incremental conductance method.

In Incremental Conductance method, Incremental conductance method uses two voltage and current sensors to sense the output voltage and current of the PV array.
If the operating point lies to the right of the Power curve then dP = dV < 0; dI = dV < I = V
If operating point lies to the left of the power curve then dP =dV > 0; dI=dV > I=V.
In Short circuit current method, under varying atmospheric conditions, Impp is approximately linearly related to the PV array.

$$Impp = k2 * Isc$$

Where k2 is proportionality constant. Just like in the fractional VOC technique, k2 has to be determined according to the PV array in use. The constant k2 is generally found to be between 0.78 and 0.92. Measuring ISC during operation is problematic. An additional switch usually has to be added to the power converter to periodically short the PV array so that ISC can be measured using a current sensor. [4]

Flow chart of INC method is shown below: [2]

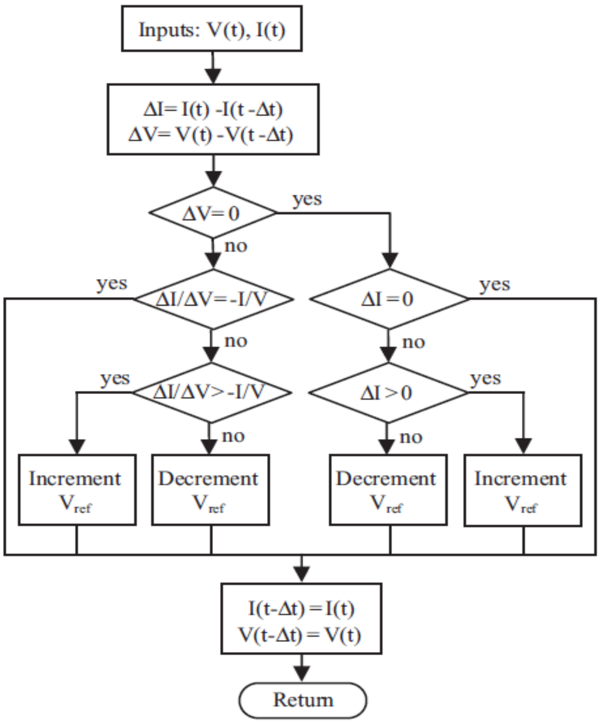

Fig. 6. Flow chart of INC Method

In Open circuit voltage method, the near linear relationship between Vmpp and Voc of the PV array, under varying irradiance and temperature levels, has given rise to the fractional Voc method.

$$Vmpp = k1 * Voc$$

where k1 is a constant of proportionality. Since k1 is dependent on the characteristics of the PV array being used, it usually has to be computed beforehand by empirically determining Vmpp and Voc for the specific PV array at different irradiance and temperature levels. The factor k1 has been reported to be between 0.71 and 0.78. Once k1 is known, Vmpp can be computed with Voc measured periodically by momentarily shutting down the power converter. However, this incurs some disadvantages, including temporary loss of power.

C. Experimental Implementation:

The system's operating point is at the intersection of the I-V curves of the PV array and load, when a PV array is directly connected to a load. The Maximum Power Point (MPP) of PV array is not attained most of the time. This problem is overcome by using an MPPT which maintains the PV array's operating point at the MPP. The occurrence of MPP in the I-V plane is not known priory; therefore it is calculated using a model of the PV array and measurements of irradiance and array temperature. Calculating these measurements are often too expensive and the required parameters for the PV array model are not known adequately. Thus, the MPPT continuously searches for MPP. There are several MPPT continuously searches algorithms that have been proposed which uses different characteristics of solar panels and the location of the MPP.

The Non-MPPT charging means the MPPT circuitry is not used in this charging. The Non-MPPT charging for the batteries is shown in the experimental setup carried out using a simple buck-boost converter that uses LM2596 & LM2577. The bi-directional converter made by LM2596 & LM2577 was set at the desired voltage levels during the charging of the batteries. The same DC-DC was used while charging batteries with the solar panels. The converter output voltage has a broad range of 0–40 V in both buck and boost mode. Fig shows the basic buck-boost converter topology used in the hardware along with the different rating solar panels.

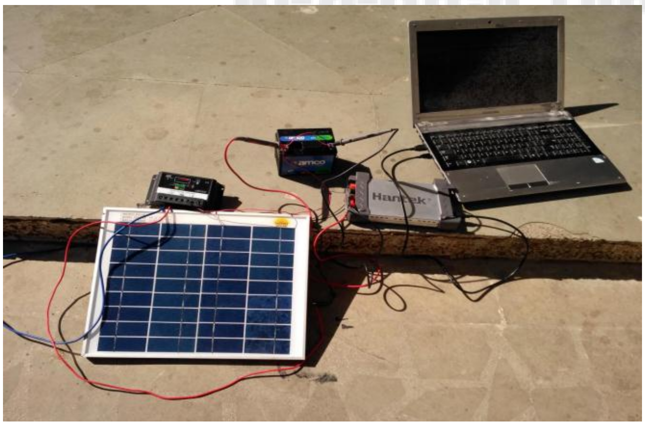

Fig. 7. Charging of battery with MPPT

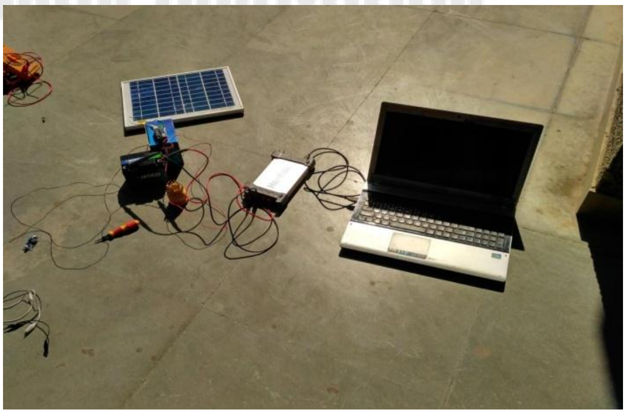

Fig. 8. Charging of Battery without MPPT by 15 Watt Panel

The Buck-Boost topology is shown in below fig:

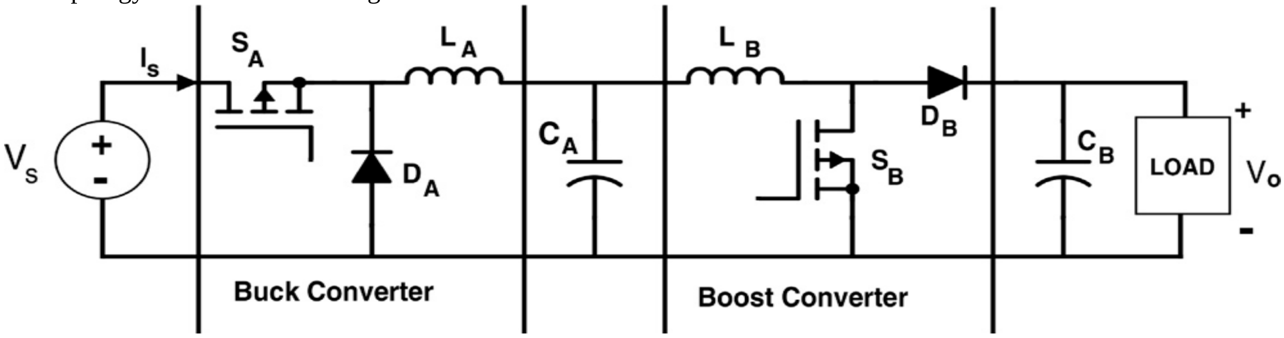

Fig. 8. Buck-Boost Topology

When buck converter is in operation output voltage of converter is lower than PV array input voltage. Power flow is controlled by means of on/off duty cycle of the switching transistor. This converter topology can be used in conjunction of high array voltages and lower battery voltages. Care should be taken that one more series panel in each string would normally be the case for a directly connected systems, should be used.

When boost converter used in operation the output voltage of converter is higher than solar array. Typically one panel less in each series string of PV panels, a compared with directly coupled system, should be used for this converter topology. Again this does not imply that more or less panels are required, only the set up should be alerted. Power flow is again controlled by means of the on/off duty cycle of the switching transistor. This converter topology can be used in conjunction with high battery voltages and lower array voltages. No extra blocking diode is necessary when the boost topology is used.

The basic function of the Maximum Power Point Tracking (MPPT) technique is to match the load impedance with the internal impedance (the source impedance) to transfer the maximum power from the source to the load according to the maximum power transfer theorem. The current and voltage signals from the PV panel are sensed, and they are passed through first ADC to convert them into digital signals and then, through the MPPT algorithm to generate Vref. The ADC output of Vpv is compared with the Vref at the proportional voltage controller to calculate the duty cycle, which in turn will actuate PWM, to give modulated signals to the DC – DC converter. The DC – DC converter performs the duty to buck or boost the voltage coming as input from solar panel output, depending upon the requirement, to achieve the Maximum Power Point (MPP) (basically changes the duty cycle) There are various algorithms to realize the MPPT like; Perturb and Observe (P & O), Incremental Conductance (INC), Short Circuit Current (SCC), Open Circuit Voltage (OCV). Out of these algorithms, an incremental conductance (INC) algorithm is the most attractive and straightforward to implement in the hardware. The whole research work hereunder confirms that the INC is used in the hardware, and the meaning of algorithm now onwards is INC.

The advantage of using INC over P & O is; incremental conductance can track the rapidly increasing and decreasing irradiance conditions with higher accuracy than perturb and observe. This algorithm requires the current and voltage sensors to determine the MPP. The A data logger is used in the experiments to log the observations at 1 s, 2 s and 5 s respectively for the Non-MPPT and the MPPT charging at the V.

The resultant graph is shown in the above fig. Battery charging process done by solar panel with Non-MPPT circuitry and with MPPT circuit. From graph it is very clear that charging rate of voltage is increase by using MPPT. Time requirement for charge the battery is also decreases.

Some calculation is described below for battery charging process with MPPT and without MPPT.

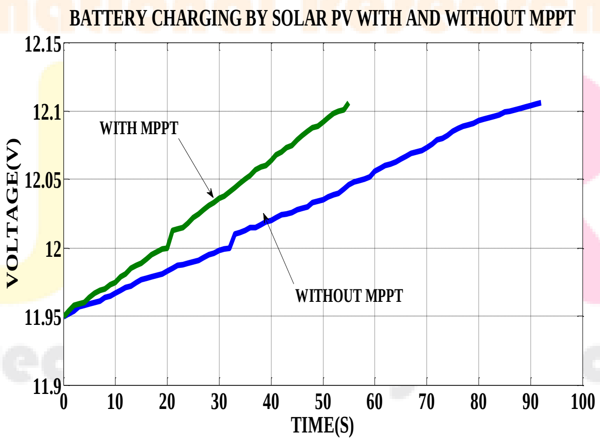

Fig 9 Battery charging with solar panel

By using 15W solar panel first charged battery, the open circuit voltage is 18.20V and short circuit current is 0.66A.

• Initial Charging Current of Battery without MPPT = 0.342 Ampere
• Initial Voltage = 11.95 Volt
• Voltage after 93sec = 12.106 Volt

Initial Charging Current of Battery with MPPT = 0.414 Ampere

• Time taken by an MPPT to charge the battery =56 second
• Rate of improvement in charging current

= (0.414-0.342)/(0.342)*100

= 21.01%

• Rate of improvement in charging rate(Time)

= (93-56)/(93)*100

= 39.78%

Battery charging at various Irradiations:

The 830W/m2 irradiation measured on 5W solar panel by use of solar power meter. Battery charging current of this irradiation without MPPT is 0.097A and with MPPT is 0.53 A. The 910W/m2 irradiation measured on 5W solar panel by use of solar power meter. Battery charging current of this irradiation without MPPT is 0.123A and with MPPT is 0.543 A.

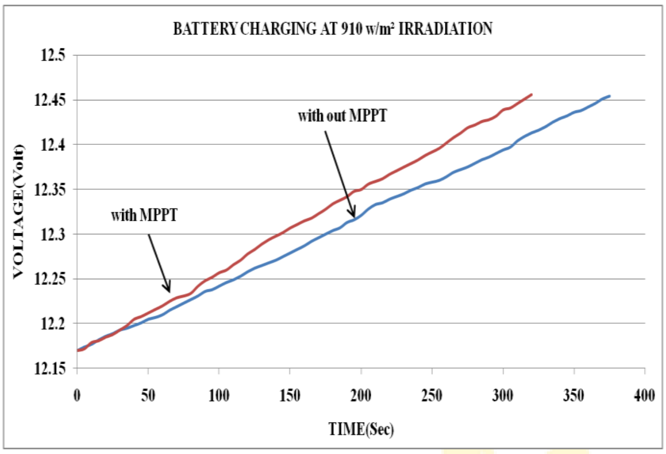

Fig 10 Battery charring at 910 W/m² irradiation

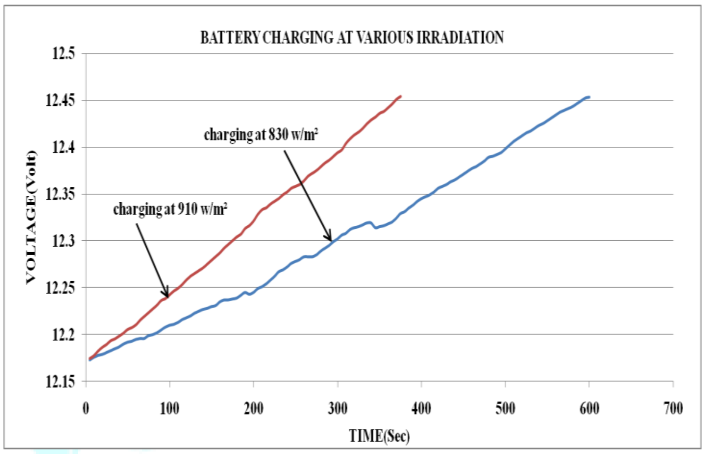

Fig 11 Battery charging at various irradiations

Battery charging at various Temperatures:

Battery charging current of 28° C without MPPT is 0.097A and 33° C without MPPT is 0.302 A

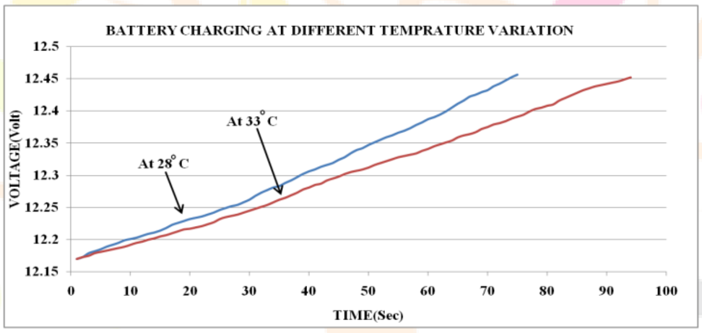

Fig. 12. Experimental Graph at various temperatures

IV. CONCLUSION

After working on the charging strategy of battery with MPPT action and without MPPT action this charged battery can be used at night, during rainy days and in winters. Therefore, it is our wish to make the PV system more efficient so that it can help for betterment of life. Rate of charge of current increases as well as time for required to charge the battery is minimized. This experiment is done in off grid system only. After the results of irradiation and temperature, it can be conclude that, in irradiation as its increase, battery charging is faster. Now as temperature is increase, power gets down and battery charging is slower because the substance of solar panel is moderate at lower temperature and as temperature is increase they are vibrate from its original value.

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