International Journal of Engineering Research and General Science Volume 5, Issue 2, March-April, 2017
ISSN 2091-2730

Maximum Power Point Tracking for PV Systems & simulations based on Perturb &Observe technique

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Abstract— The efficiency of a PV panel is very low (about 20-40%).In this paper, we examine a solar charge controller based on MPPT. Various algorithms techniques for implementing the MPPT are discussed in brief. Further P&O algorithm is discussed in detail. The required hardware is also mentioned. The approach of this paper is to understand the need for MPPT, its various techniques and simulating the MPPT based controller by using P&O algorithm.

Index Terms— Boost Converter, DC-DC converter, MPPT, Perturb & Observe (P&O), PV (Photo-Voltaic).

INTRODUCTION

A solar panel converts only 20-40% of energy incident on it, into electrical energy. A charge controller hence becomes vital for increasing the solar efficiency. Now, different charge controllers based on various techniques are used for this purpose such as those based upon PWM, MPPT etc. PWM controller though being economical are found to be less efficient than MPPT controller under certain conditions. Moreover for applications above 150 W MPPT based controllers are used since PWM controllers have a constant harvesting efficiency regardless of size of PV module. A MPPT based controller is a high frequency DC-DC converter that changes the carrying DC input from solar panel & convert it into high frequency AC and then rectifies it to such a value of DC voltage & current which exactly matches the panels to battery bank.

There are different techniques for MPPT such as Perturb and Observe, Incremental conductance (hill climbing method), Fractional Short Circuit Current, Fractional Open Circuit Voltage, Fuzzy Control, Neural Network Control etc. Among all the methods Perturb and observe (P&O) and Incremental conductance are most commonly used because of their simple implementation, lesser time to track the MPP and several other economic reasons.

Under abruptly changing weather conditions (irradiance level) the maximum power point changes continuously, in such a case P&O based controller takes it as a change in MPP due to perturbation rather than that of irradiance and hence ends up in calculating wrong MPP [1]. This problem can be avoided by using Incremental Conductance method, since this technique takes two samples of voltage and current to calculate MPP [2]. However despite increase in efficiency, the complexity & cost of implementation also increases. So again a trade-off between complexity and efficiency needs to be considered. When multiple solar modules are connected in parallel, another analog technique indicated by acronym TEODI [3] is also very effective which is based on "equalization of output operating points in correspondence of forced displacement of input operating points of two identical PV system". It is very simple to implement and has higher efficiency under stationary as well as time varying atmospheric conditions.

STANDALONE PHOTOVOLTAIC SYSTEM COMPONENTS

a) Photovoltaic cell

A photovoltaic cell or photoelectric cell is a semiconductor device that converts light to electrical energy by photovoltaic effect. If the energy of photon of light is greater than the band gap then the electron is emitted and the flow of electrons creates current.

However a photovoltaic cell is different from a photodiode. In a photodiode light falls on n-channel of the semiconductor junction and gets converted into current or voltage signal but a photovoltaic cell is always forward biased.

b) PV module

Usually a number of PV modules are arranged in series and parallel to meet the energy requirements. PV modules of different sizes are commercially available (generally sized from 60W to 170W). For example, a typical small scale desalination plant requires a few thousand watts of power.

c) PV modelling

A PV array consists of several photovoltaic cells in series and parallel connections. Series connections are responsible for increasing the output voltage of the module whereas the parallel connection is responsible for increasing the output current in the array.

Typically a solar cell can be modelled 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.

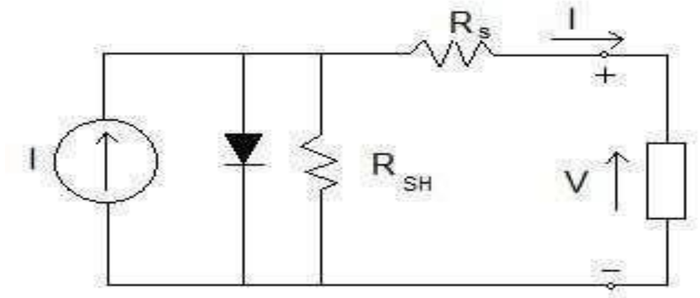

Fig. 1 Single diode model of a PV cell

In this model we consider a current source (I) along with a diode and series resistance (R_s). The shunt resistance (R_{SH}) in parallel is very high, has a negligible effect and can be neglected. The output current from the photovoltaic array is :

$$I = Isc - Id \quad (1)$$

but $$I_d = I_o (V_d/kT - 1)$$

where 'I_o' is the reverse saturation current of the diode; 'q' is the electron charge; 'V_d' is the voltage across the diode; 'k' is Boltzmann constant (1.38 x 10^{-19} J/K) and T is the junction temperature in Kelvin (K).

From above equations

$$I = I_{sc} - I_o (V_d/kT - 1) \quad (2)$$

MAXIMUM POWER POINT TRACKING TECHNIQUES

The maximum efficiency of a solar panel can only be upto 30-40%.So a charge controller is required to get the maximum power. In this paper a controller based on MPPT technique is studied. Now, for harvesting maximum power from solar panel we take a que from Maximum Power Transfer theorem as per which "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:

i. Perturb and Observe (hill climbing method)
ii. Incremental Conductance method
iii. Fractional short circuit current
iv. Fractional open circuit voltage
v. Neural networks
vi. Fuzzy logic

The choice of the algorithm depends on the time complexity the algorithm takes to track the MPP, implementation cost and the ease of implementation. [7]

Perturb & Observe

Perturb & Observe (P&O) is one of the simplest method to implement. We use only voltage sensor to measure the PV array voltage. So it is less costly as compared to other methods and hence more economical and easy to implement. Although the time complexity of this method is very less but it doesn't stop on reaching close to the MPP and continues to perturb on both the directions. We can overcome this limitation by setting an appropriate error limit or can use a wait function, however this increases the time complexity of the algorithm. One more limitation of this method is that it 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 overcome this problem we can use incremental conductance method. [2, 6, 7]

Incremental Conductance

In Incremental conductance method, two sensors (a voltage and a current)are used to sense the output voltage and current of the PV array. The slope of the PV curve at MPP is 0. So,

$$\left(\frac{dP}{dV}\right)_{MPP} = \frac{d(VI)}{dV}$$

$$\left(\frac{dP}{dV}\right)_{MPP} = \frac{-I}{V} \qquad (3)$$

Where,

$\left(\frac{dP}{dV}\right)_{MPP}$: - instantaneous conductance of solar panel

When the condition represented by eq. (3) is satisfied the solar panel is said to be operating at MPP. Also, since the output sensors are only for voltage & current, hence the error due to the variation in irradiance is removed. But when it comes to realising the algorithm physically, the hardware cost & complexity of design becomes a problem. This trend will continue to increase as we go down in this list. Hence the systems designed for these algorithms are superior class facilities or power plants. [7]

Fractional open circuit voltage

Even under continuously changing irradiance and temperature , V_{MPP} and V_{OC} of the PV array are nearly linearly related .This property is used in the fractional V_{OC} method.

$$V_{MPP} = k_1 V_{oc} \qquad (4)$$

'k_1' being the constant of proportionality. The value of k_1 depends upon the characteristics of the PV array being used So its value is calculated in advance by approximating V_{MPP} and V_{OC} for the PV array at different irradiance level and temperature .The value of k_1 is in between 0.71 and 0.78. By knowing the value of $k_{1,}$and measuring V_{OC} by shutting down the power converter momentarily, V_{MPP} can be calculated using the relation given in (4). However shutting down the power causes power loss, which is one of the disadvantage of thus technique

Fractional short circuit current

Fractional I_{SC} is similar to Fractional V_{OC} method.In this method ,the linear relation between I_{MPP} and I_{SC} for different irradiance and temperature is used.

$$I_{MPP} = k_2 \, Isc \qquad (5)$$

k_2 being the constant of proportionnality. In this case too, the value of k_2 has to be for the PV array in use. The value of k_2 leis between 0.78 and 0.92.It is problematic to measure the value of I_{SC} during operation. So an additional switch along with a current sensor is employed to short the converter and measure I_{SC} .[7]

Fuzzy Logic Control

The use of Fuzzy logic for MPPT has gained popularity over the last decade because here we have the liberty of using imprecise inputs,no requirement of accurate mathematical model and handlng non linearity. [7]

Neural Network

Along with Fuzzy logic controller ,the neural networks have also gained popularity in the recent years. Neural networks usually works with three layers: input, hidden, and output layers.

Each layer has different number nodes and are user-dependent .Relevant PV array parameters like V_{OC} and I_{SC}, irradiance level and temperature are given as input to the controller and a reference signal (duty cycle) is obtained at the output .This duty cycle is then used for impedance matching and hence maximum power is transferred. [7]

PERTURB & OBSERVE ALGORITHM

Under the perturb and observe algorithm follows the process wherein the working voltage or module voltage is varied in small step , which in turn results in adjustment of power, if resultant variance of power is positive, then we are heading towards maximum power point, and we keep on incrementing the voltage in the same direction, where as if the resultant variance of power is negative, indicating that we are heading away from the maximum power point therefore we need to decrement the supplied voltage.

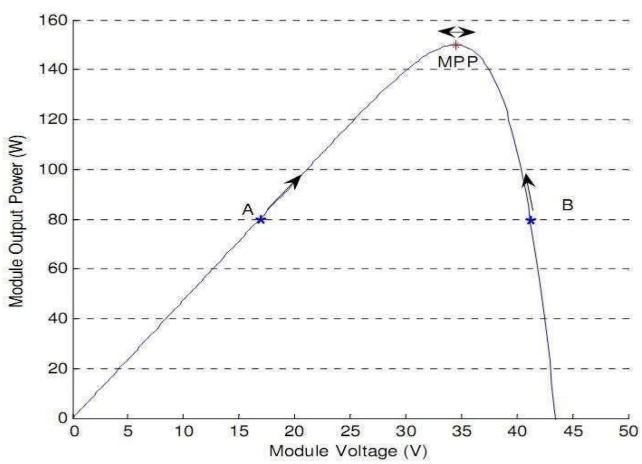

Fig. 2 Solar panel characteristics showing MPP and operating points A and B

Fig 5 is a graph plotted between power and the operating voltage of the solar panel at the given intensity of light .The maximum power point is marked as MPP, which is the maximum output generated by PV module. Here points A and B are two operating points, A is situated on the left side of MPP and B is situated on the right side of MPP. Therefore in case of A , as we increase the voltage taking us further toward MPP resulting in positive change in power but on the other hand as we increase voltage beyond MPP the change is power is negative depicting that we ought to steer the perturbation in the opposite direction to achieve MPP in case of B.

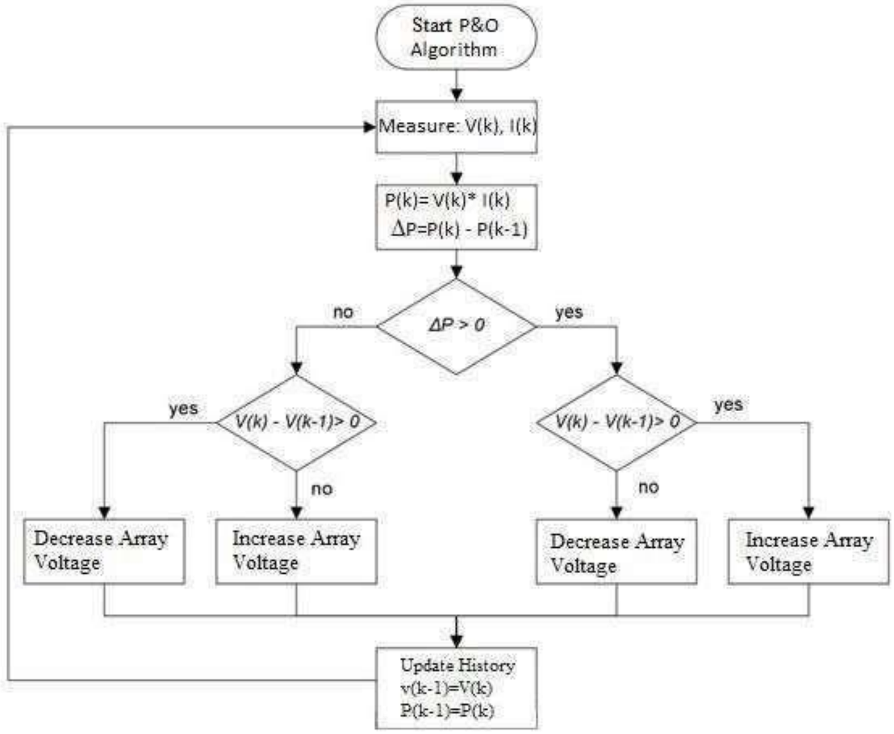

Fig. 3 Flowchart of Perturb & Observe algorithm

Limitations of Perturb & Observe algorithm

Given the certain circumstances, where the intensity of light changes speedily, the maximum power point shift onto right side of curve. This algorithm deciphers this change as perturbation and the next iteration changes the direction of disturbance and henceforth goes away from MPP as shown in fig. also, in this algorithm requires only one sensor or detector (voltage sensor) which detects the PV module operating voltage. The time complexity and the price of enforcing this algorithm is very less. On the other hand complexity may be less but as we approach towards MPP or very close to MPP, it does not halt at MPP and keeps on vibrating very close to MPP. To overcome this error, as soon as algorithm approaches MPP, we employ two main methods:

1. Use wait function which develops the time complexity.
2. Develop an error function which sets is its limit.

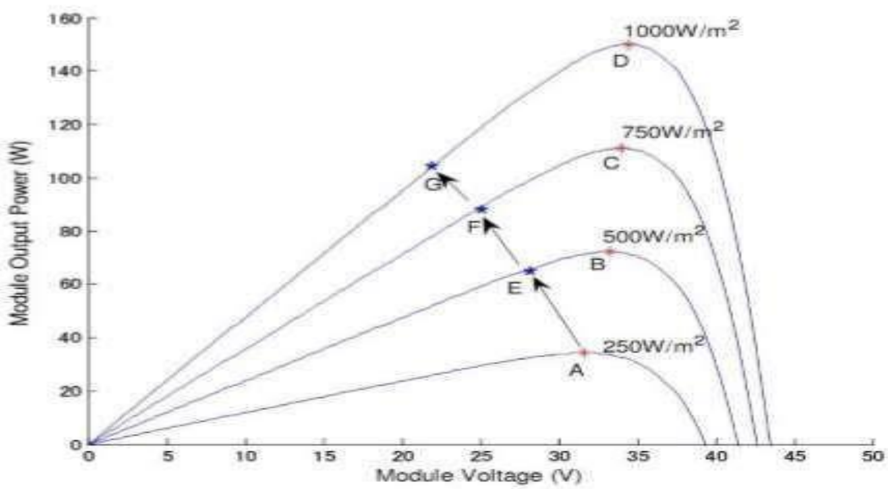

Fig. 4 Curve showing wrong tracking of MPP by P&O algorithm under rapidly varying irradiance

BOOST CONVERTER ASSISTED MPPT

In order to change the input resistance of the panel to match the load resistance (by varying the duty cycle), a DC to DC converter is required. It has been studied that the efficiency of the DC to DC converter is maximum for a buck converter, then for a buck-boost converter and minimum for a boost converter. To widen the scope of MPPT into practical or real world usage we employ boost converter which helps in better utilization of solar panel. Boost converter shifts the initial low voltage output to a higher point. One main highlighting point is that there are no switching losses in case of Boost Converter. Fig. 8 given below is the circuit implementation of MPPT using boost converter.

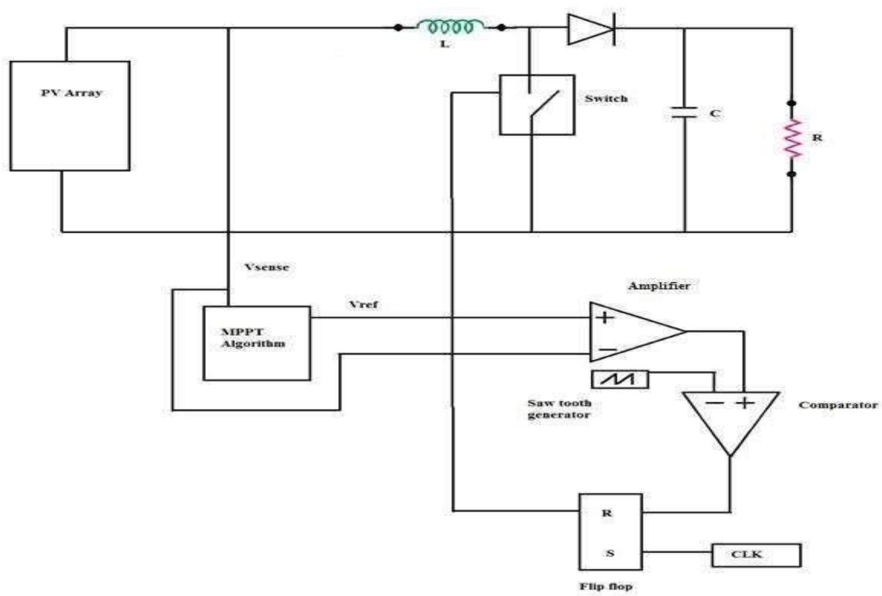

Fig. 5 Circuit implementation for MPPT system

MODELLING OF STANDALONE PV SYSTEM

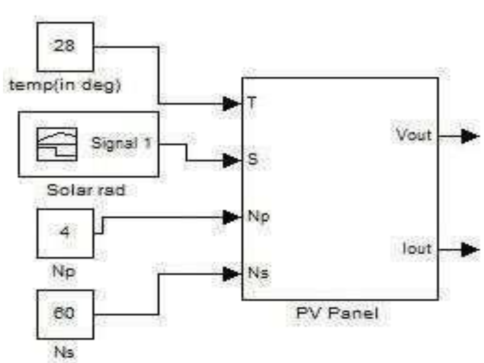

Fig. 6 Masked block diagram of the modelled solar PV panel

Solar panel

Modelling of whole system has been done on MATLAB™ 2013a and Simulink™. Solar panel block diagram has been depicted in fig. shown below. The various inputs of PV module are listed below:

1. Solar irradiation
2. Number of solar cells in series
3. Given temperature
4. No. of rows of solar cells

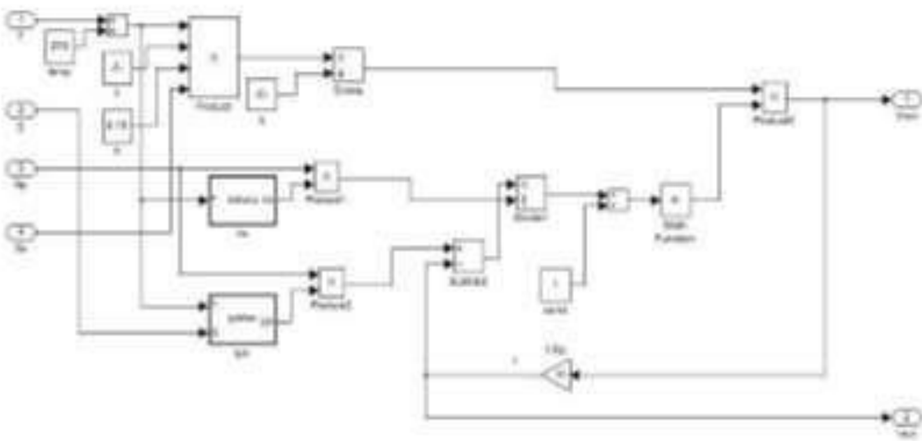

Fig. 7 Block diagram (unmasked) of modelled solar PV panel (unmasked)

The simulations are conducted at a temperature of around 28 °C with 60 solar cells connected in series placed along 4 parallel rows. Irradiance of various intensity level is taken to imitate the real world conditions and exhibit the role of MPPT. The intensity of irradiance vary from 60 watt per sq. cm to 85 watt per sq. cm which is close enough to the distribution of per day insolation on earth surface. The process is carried out for 0.12 seconds during which level of intensity changes every .03 seconds.

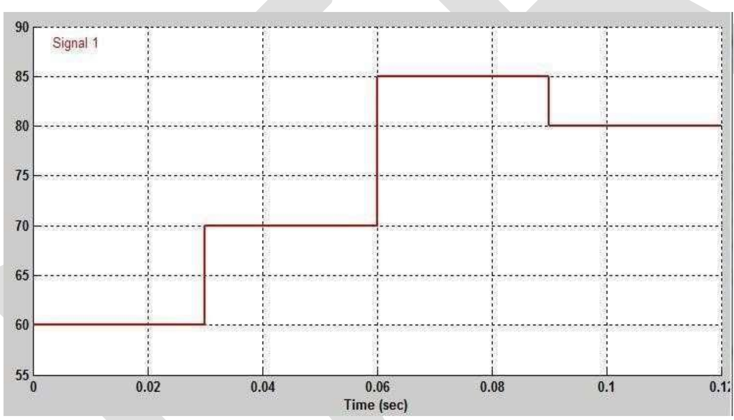

Fig. 8 Irradiation signal (Watt/ cm^2 vs time)

MPPT INTERFACING

The modelled panel is interfaced to the other parts using inverters of two types

i. Current source inverter

ii. Voltage source inverter

Also a boost converter is employed using *Simpower* system module in the MATLAB. Block diagram in Fig. 12 represents the case of deviating output voltage. This simulation is carried out to showcase the divergence between the power outputs during the two cases viz. while using MPPT & without using MPPT & analysing the power in both instances. The model contains a switch which is operated manually. The PV Module by passes the MPPT algorithm when the switch is moved to left and the required power output is obtained. Similarity when switch is moved towards right, it uses MPPT algorithm to harness maximum power.

Boost Converter

Boost converter used in our situation is employed for numerous real life applications such as pumping water, running DC motors , battery charging . The resistive load employed is about 300 ohm and inductor of .763 mH and capacitance of .61uF for ripple less current.

PI Controller

The purpose of a MPPT system is to match the operating voltage of PV module with the reference voltage V_{ref} at which maximum power output is obtained. This system employs a PI controller which is the external control loop responsible for controlling the voltage at input. The sampling process is done at a rate of 1 to 10 samples per second. The pulse width modulation is performed in the PWM block at a considerably faster switching frequency of 100 KHz. The values of K_p & K_i are given in Table 1 . The higher relative value of K_i is so as to ensure that the system stabilizes at a faster rate. The main aim of the controller is to reduce the difference between the reference and measured voltage by adjusting the duty cycle through switching. In this case the switch is physically realised by a gate voltage controlled MOSFET by varying duty cycle.

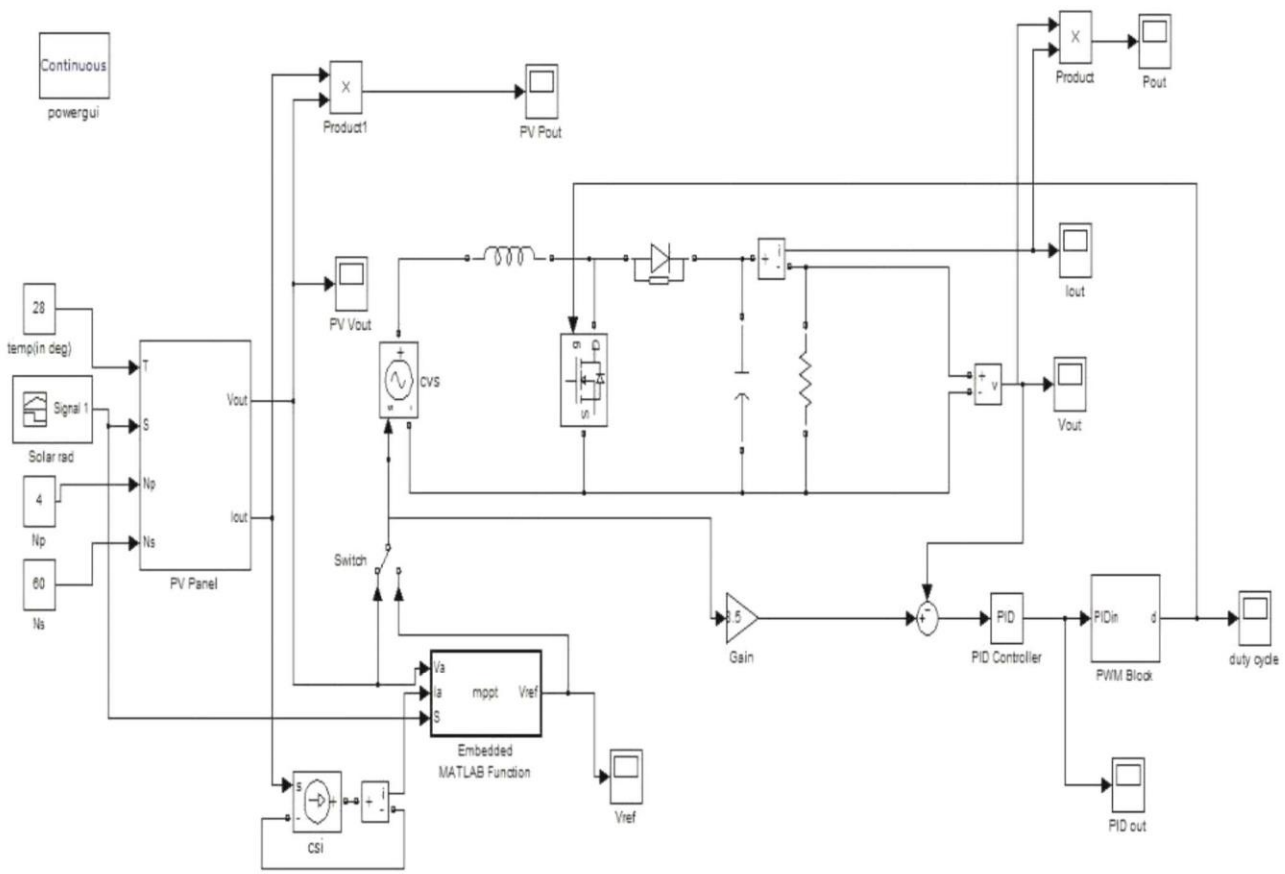

Fig. 9 SIMULINK Model of MPPT system using P&O algorithm

Parameter	Value taken for simulation
Solar Module Temperature (T)	28°C
No of rows of solar cells in parallel (N_P)	4
No. of cells in series	60
Resistance of load (R)	300 Ω

Capacitance of boost converter (C)	0.611 µF
Inductance of boost converter (L)	0.763 mH
Switching frequency of PWM	100 KHz
Proportional gain of PI controller (K_P)	0.006
Integral gain of PI controller (K_I)	7

Table 10 : Different parameters of the standalone PV System

RESULT FIGURES

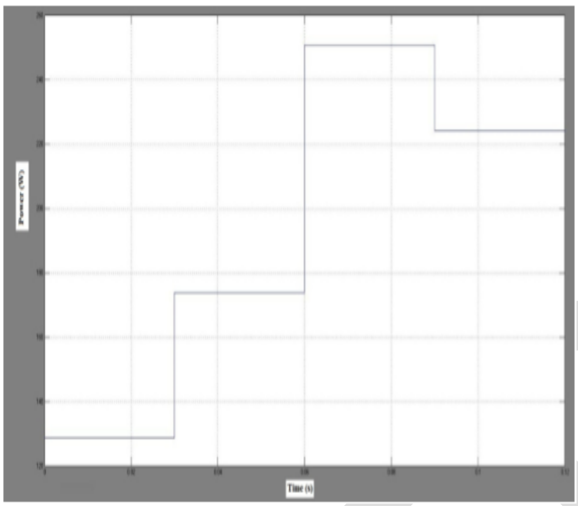

Fig. 11 Plot of Power obtained at panel side vs time (without MPPT)

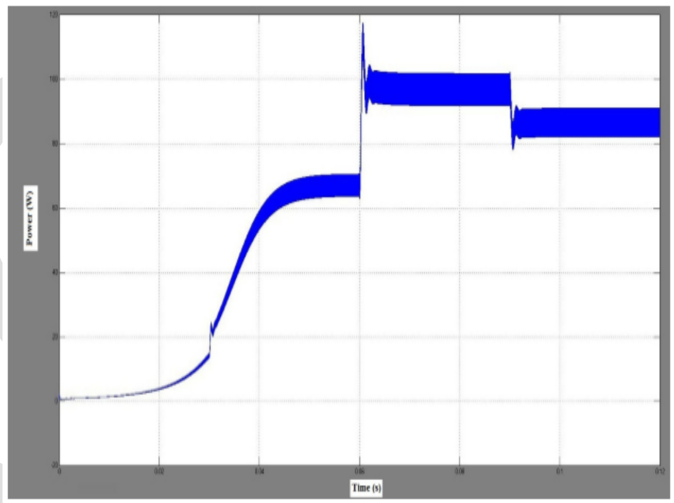

Fig. 12 Plot of Power obtained at load side vs time (without MPPT)

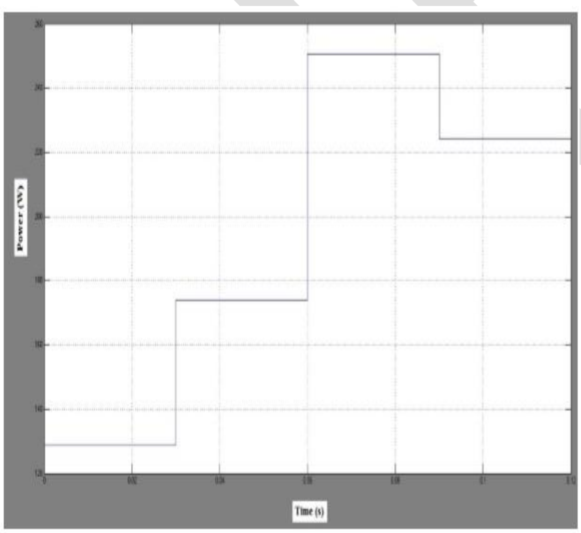

Fig. 13 Plot of Power obtained at panel side vs time (using MPPT)

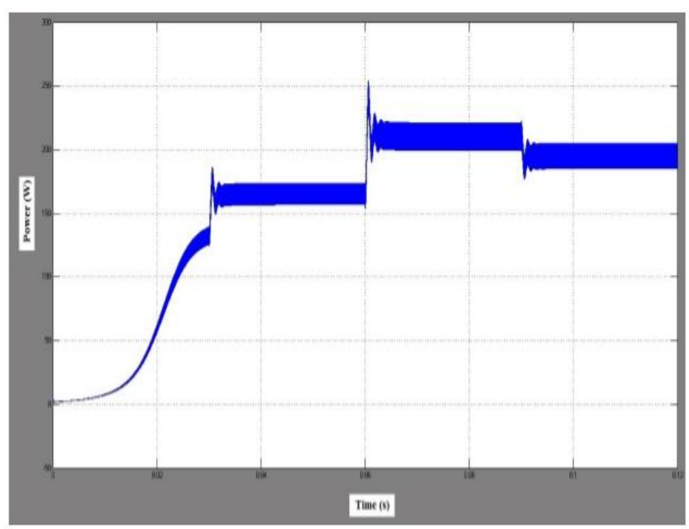

Fig. 14 Plot of Power obtained at load side vs time (using MPPT)

CONCLUSION

As seen in the result figures the simulations were carried out in two stages viz. “no MPPT mode” & “MPPT mode”. The respective results obtained for each were as follows:

With the MPPT algorithm block bypassed (under irradiation condition of 85 W/cm$^{2)}$, the power obtained across load was 95 W. In the MPPT mode V_{ref} (calculated by the P&O algorithm) was fed to the PI controller under the same irradiation conditions. The power obtained in this case was around 215 W. Thus it can be seen that under this (P&O) algorithm the efficiency of panel was increased by around 126 %.

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