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Simulation and Designing of MPPT Based Solar PV System with DC-DC Boost Converter

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ABSTRACT

Solar PV array output power is dependent on irradiation, temperature and voltage across its terminals. Under constant irradiation and temperature condition, at one particular voltage it delivers maximum power and the point corresponding to that particular voltage on P-V or I-V characteristics curve is called Maximum Power Point (MPP) and with the change in irradiation and temperature, MPP also varies. Therefore, a technique used to extract maximum power by varying its terminal voltage is called as Maximum Power Point Tracking (MPPT). This paper presents simulation and designing of 4.98 kW PV array connected to resistive load through DC-DC boost converter with perturb and observe MPPT technique and results are discussed under constant as well as variable irradiation and temperature conditions.

KEYWORDS

Photo-voltaic, DC-DC boost Converter, Maximum power point tracking (MPPT), Perturb and Observe (P&O).

1. INTRODUCTION

As we are well familiar with the fact that there is continuous rise in energy demand and non-renewable sources of energy (Fossil Fuels such as Coal, Oil and Natural gas) are getting depleted day by day. Also, with the usage of non-renewable sources of energy there are environmental related issues such as emission of green-house gases which are responsible for global warming and hazardous waste released from their usage cause Air, Water and Soil pollution. Because of above reasons there is growing attention towards use of Renewable Energy Resources such as Solar, Wind etc.

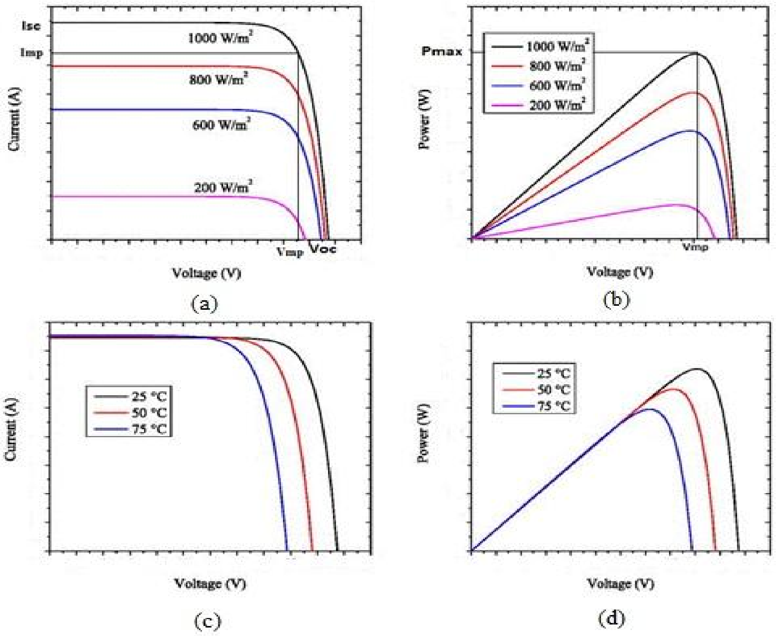

Fig.1. I-V & P-V characteristics of PV Cell at different Irradiations and Temperatures

As solar is the most clean, abundant and easily available renewable energy source [1], therefore, there is large interest for its use globally. Solar PV cell shows non-linear P-V and I-V characteristics as shown in Fig.1. and it can be noticed that at one particular voltage (V_{mp}) PV cell delivers maximum power (P_{max}) and with change in irradiation and temperature P-V (power-voltage) and I-V (current-voltage) characteristics change and hence, voltage at maximum power point (V_{mp}), current at maximum power point (I_{mp}), open circuit voltage (V_{oc}) and short circuit current (I_{sc}) change with change in irradiation and temperature (as shown in Fig. 1.).Therefore, there is need to track maximum power point (MPP) and there are a lot of MPPT techniques that have been reported and most commonly used MPPT techniques are incremental conductance and perturb and observe MPPT [2]. In this paper perturb and observe (P&O) technique is implemented.

a) I-V characteristics of PV Cell at different Irradiations (in W/m^2).

b) P-V characteristics of PV Cell at different Irradiations (in W/m^2).

c) I-V characteristics of PV Cell at different Temperatures (in).

d) P-V characteristics of PV Cell at different Temperatures (in).

Solar PV cell is a P-N junction diode when exposed to sunlight produces 2-3 W at 0.6-0.7 V which is of no practical use. To make it useful for practical purposes these cells are connected in series to get useful voltage and these series connected cells are collectively called as Module. The series and parallel connected PV modules to get required voltage and power are collectively called as PV Array.

Solar module taken for simulation is Solar Power System TP250MBZ and its data sheet is shown in Table 1.

Table 1Tata Power Solar System TP250MBZ Data Sheet.

PV Module Parameters	Values
Maximum Power (W)	249
Cells per module (N_{cell})	60
Open circuit voltage V_{oc} (V)	36.8
Short-circuit current I_{sc} (A)	8.83
Voltage at maximum power point V_{mp} (V)	30
Voltage at maximum power point I_{mp} (A)	8.3
Temperature coefficient of V_{oc} (%/)	-0.33
Temperature coefficient of I_{sc} (%/)	0.063805

Twenty such modules are taken to get maximum power of 4.98 kW (at Irradiation (S) = 1000 W/m^2 and Temperature (T) = 25) are connected as:

Number of parallel strings = 2

Number of series connected modules per string = 10

I-V (Current-Voltage) and P-V (Power-voltage) Characteristics of PV array at different Irradiation and Temperature are shown in Fig. 2. and it can be observed from characteristics that at standard atmospheric condition (S = 1000 W/m^2 and T = 25), V_{mp} is 300 V , I_{mp} is 16.6 A and P_{max} is 4.98 kW of PV array and these parameters vary with variation in irradiation and temperature .

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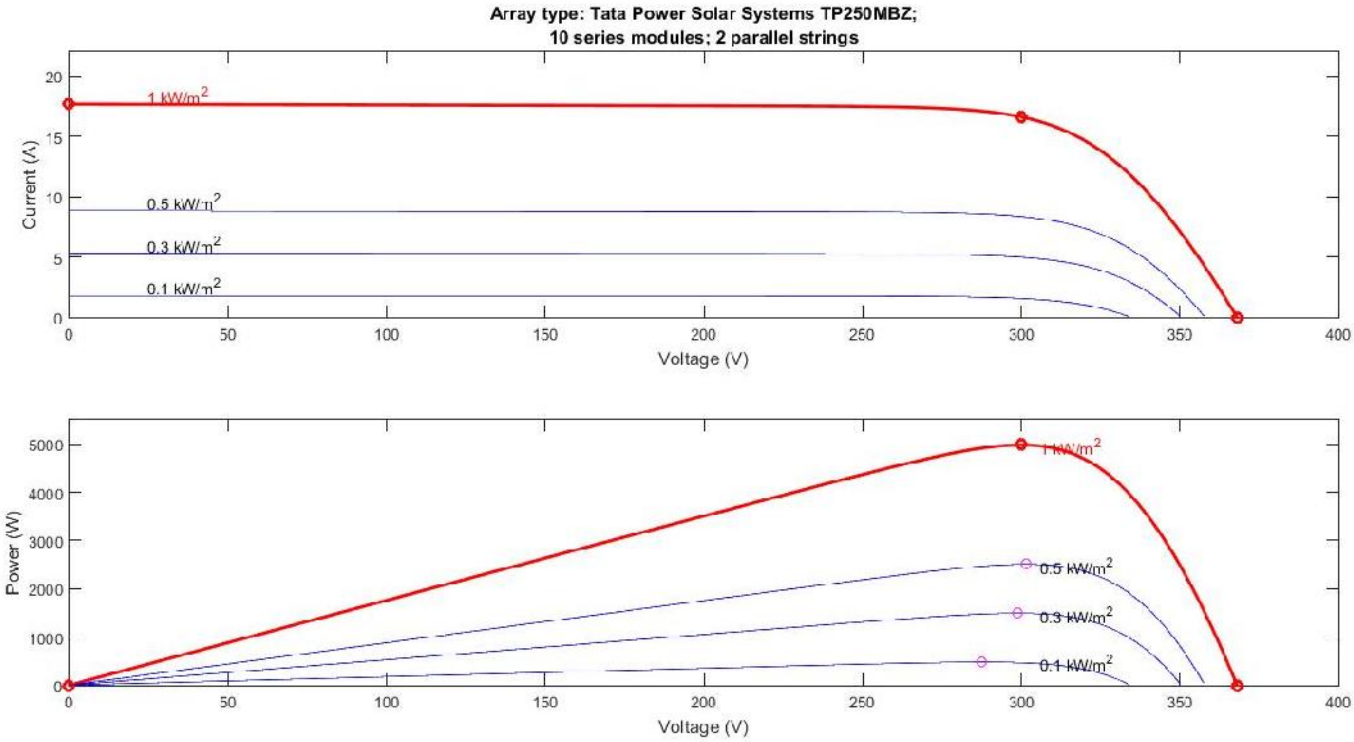

Fig. 2. I-V and P-V Characteristics of PV array at different Irradiations (1000, 500, 300 and 100 W/m^2) and constant Temperature (T=25)

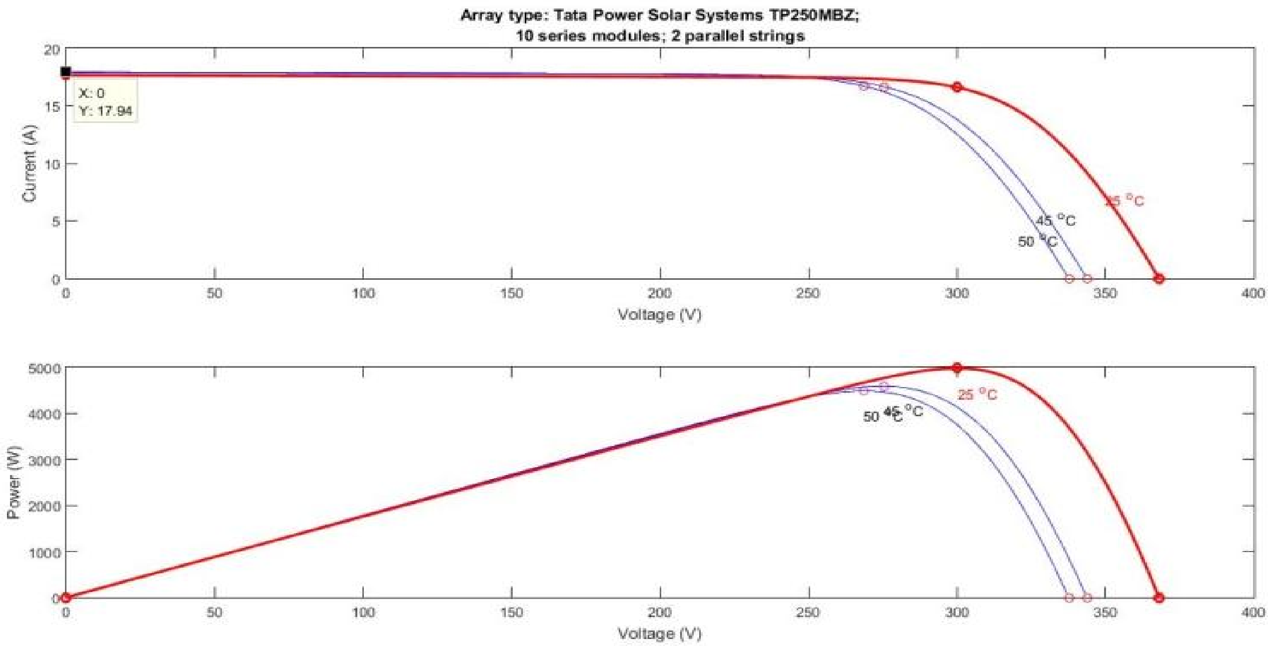

Fig. 3.I-V and P-V Characteristics of PV array at different Temperatures (25 , 45 and 50) and Constant Irradiation (1000 W/m2)

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2. DESIGNING OF DC-DC BOOST CONVERTER FOR MPPT

DC-DC Boost converter (Fig. 4.) is used here to vary input voltage (or PV output voltage) by varying duty cycle. Input capacitor (C_{in}) and output capacitor (C_{out}) keeps the input and output voltage stiff respectively. Inductor (L) reduces the ripple in current. Designing of boost converter for MPPT is explained in this section.[1],[3]

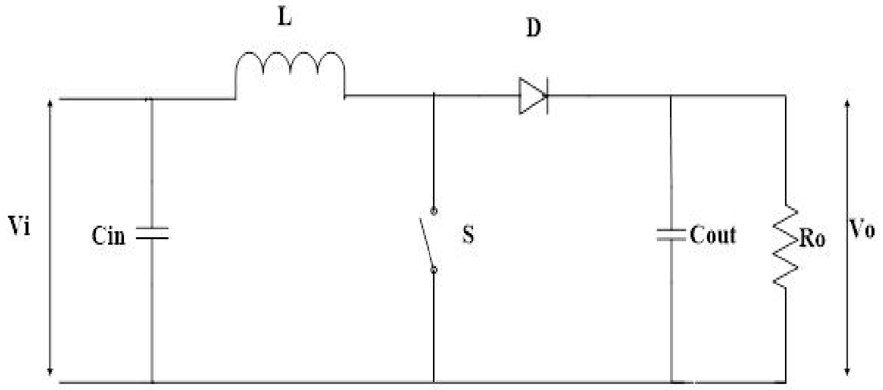

Fig. 4.Circuit Diagram of Boost Converter

Selection of Inductor is done on the basis of estimated Inductor current ripple and can be calculated as

$$L = \frac{V_i \times (V_o - V_i)}{\Delta I_L \times f_s \times V_o} \tag{1}$$

Where, ΔI_L is the estimated inductor current ripple and for 1% of maximum output current it can be calculated as

$$\Delta I_L = 0.1 \times I_{O(m\quad)} \tag{2}$$

Above calculated value of inductor must be more than the critical value of inductor (L_C) otherwise boost converter will not be able to operate in current continuous mode. Critical Inductance can be calculated as

$$L_C = \frac{D \times (1 - D)^2 \times R_o}{2 \times f_s} \tag{3}$$

Selection of output capacitor is done on the basis of output voltage ripple and can be calculated as,

$$C_o = \frac{D}{R_o \times fs \times (\Delta V_o / V_o)} \tag{4}$$

Where, ΔV_o is the desired output voltage ripple and for voltage ripple of 1% of output voltage above equation can be rewritten as,

$$C = \frac{D}{R_o \times fs \times 0.01} \tag{5}$$

D is the duty cycle corresponding to MPP and can be calculated as,

$$D = 1 - \sqrt{\frac{Z_M}{Z_o}} \tag{6}$$

Where, Z_M is the input impedance at Maximum Power Point and can be calculated as,

$$Z_M = \frac{V_m}{I_m} \tag{7}$$

Load impedance must be chosen as,

$$Z_o \geq Z_M \tag{8}$$

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Using above formulas, Boost converter designing parameters are calculated and shown in Table 2.

Table 2. Designing Parameters of Boost Converter.

Design Parameters	Values
Input Voltage at MPP (V_m)	300 V
Input Current at MPP (I_m)	16.6 A
Duty Cycle (D)	0.59
Switching Frequency (f_s)	10 kHz (chosen)
Output Voltage (V_o)	730 V
Inductor (L)	0.28 H
Output Capacitor (C_o)	38.3 µF
Input Capacitor (C_{i1})	10.0 µF
Load Resistance (Z_o or R_0)	115.84 Ω

3. DIRECT DUTY CYCLE PERTURB AND OBSERVE MPPT TECHNIQUE

Here we are using Boost Converter to obtain MPP and as for same we know,

$$D = 1 - V_i/V_o \qquad (9)$$

From above expression it is clear that V_i or V_{pv} (PV output voltage) is inversely proportional to duty cycle (D) and in this method we use this relation to find MPP.

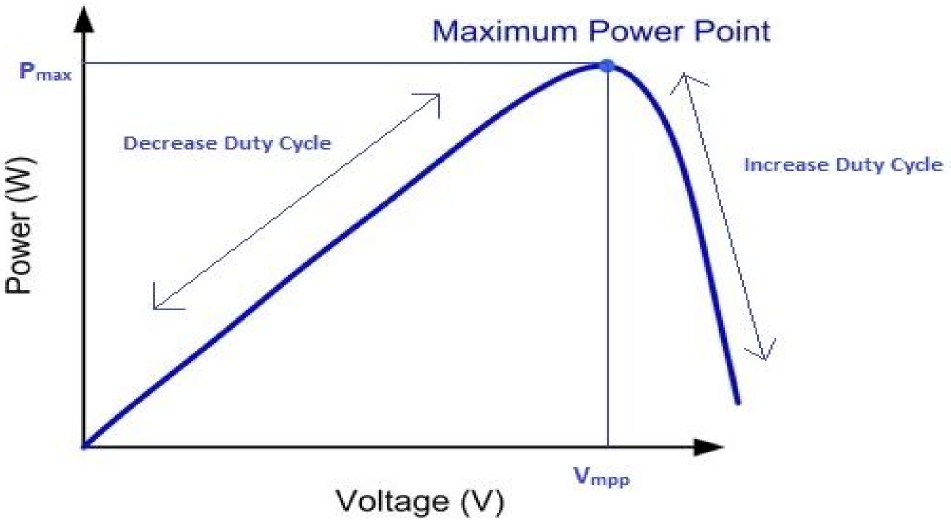

Fig. 5.Graphical representation of Direct Duty Cycle Perturb & Observe method.

Perturbation is done in such a way that, when

$\frac{d}{d} \geq 0$ Then decrease duty cycle and as a result V_i/V_{pv} increases.

$\frac{d}{d} < 0$ Then increase duty cycle and as a result V_i/V_{pv}decreases. [4]

And when MPP is achieved it keeps oscillating around it and settled 3 step operation is achieved [5]. Flowchart of P&O MPPT technique is shown in Fig.6.

In P&O MPPT method output current and voltage of PV array are sensed and they are sampled at specific rate and input voltage response of boost converter with change in duty cycle is of second order [6]. So one of the most important criteria while designing P&O technique is selection of sample time which must be greater than settling time of V_i or V_{pv} but as the sample time increases the overall time of MPPT increases. So, the choosing of sample time must be such that

(1) With every change in duty cycle V_i must reach to its steady state and
(2) Overall time for MPPT is in acceptable range.

Another important criterion while designing MPPT technique is selection of step size. Lesser the step size lesser is the steady state ripple (in P, V or I) but higher is the overall time of MPPT. So, step size is chosen such that steady state ripple and time taken for MPPT are in acceptable range.

So, it is trade-off between tracking time and accuracy and therefore, perturb and observe method (P&O) is not suitable in case of fast changing atmospheric conditions.

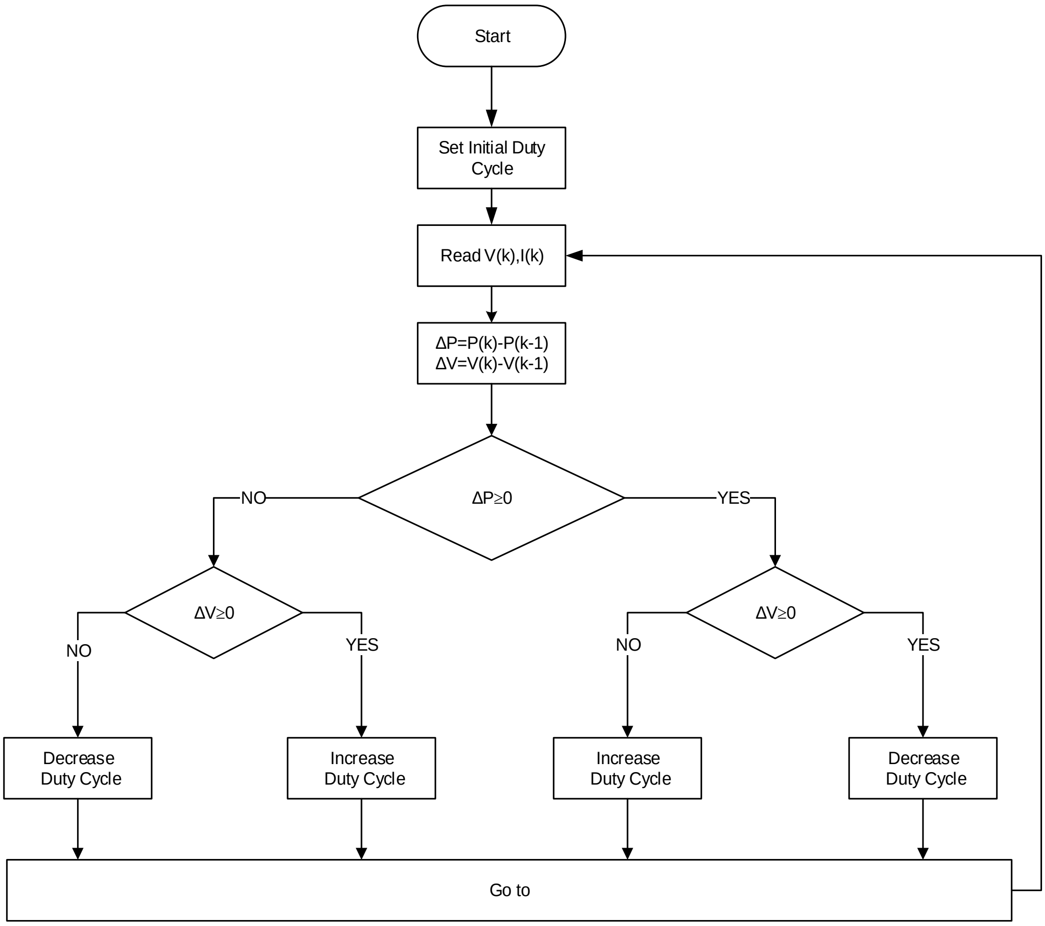

Fig. 6.Flowchart of Direct Duty Cycle Perturb and Observe MPPT Technique. [4]

4. SIMULATION MODEL AND RESULTS

Simulation is performed in MATLAB 2015a/SIMULINK and boost converter circuit parameters are taken as calculated in section 2 and IGBT is used as switch. Simulation models of circuit and P&O MPPT technique are shown in Fig. 7 and Fig. 8 respectively.

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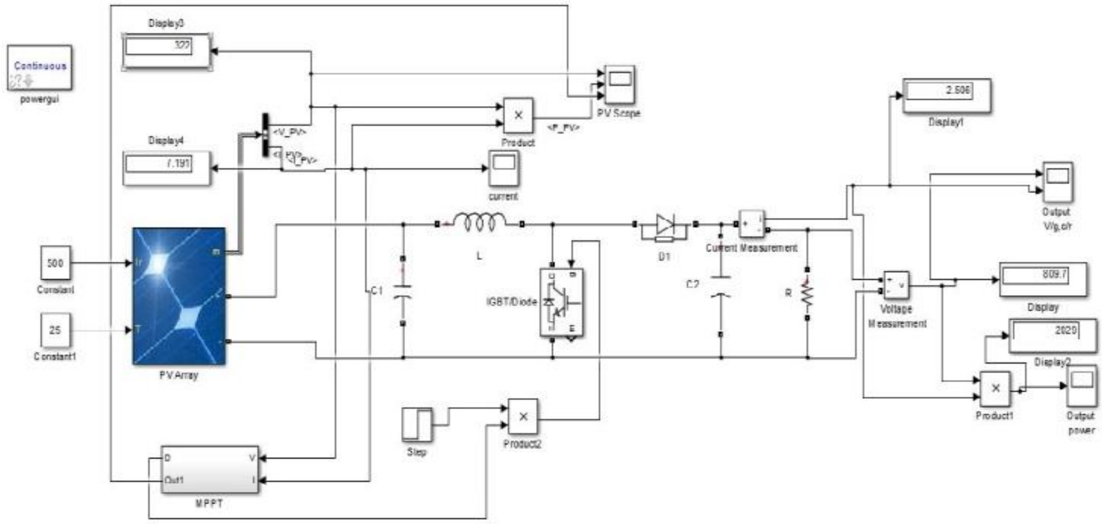

Fig. 7.Simulink model of PV Array connected to Resistive load with MPPT (P&O) (at Irradiation =1000 w/m2 and Temperature =25)

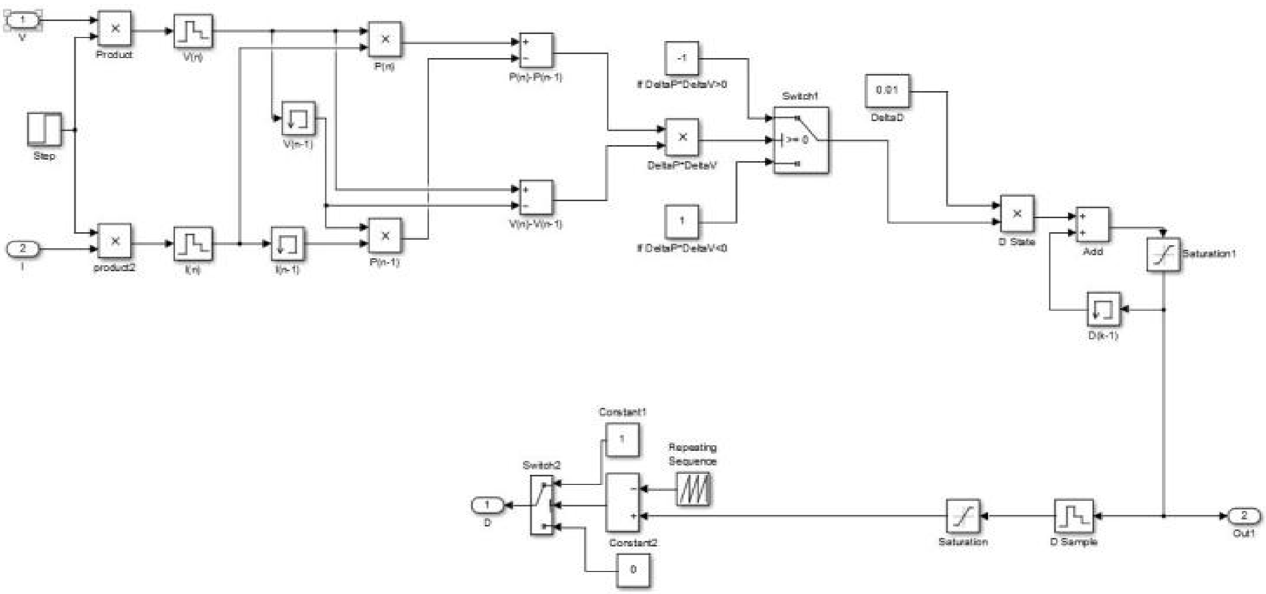

Fig. 8.Simulink Model of P&O MPPT algorithm

Results are taken under constant as well as variable irradiation and temperature conditions and as perturb and observe technique is used all results show 3-step operation under steady state condition.

4.1 SIMULATION RESULTS UNDER CONSTANT IRRADIATION (1000 W/M2) AND TEMPERATURE CONDITION (25).

It can be observed from PV array characteristics (Fig. 2.) that it delivers maximum power of 4.98 kW at 300 V and Current of 16.6 A.

Initially PV is made to operate at duty cycle equals to zero for 0.1 sec. Then MPPT is started and voltage and current are time sampled at 0.1 sec using zero order hold . Initial Duty cycle (for MPPT) and step size (ΔD) are taken as 0.5 and 0.01 respectively.

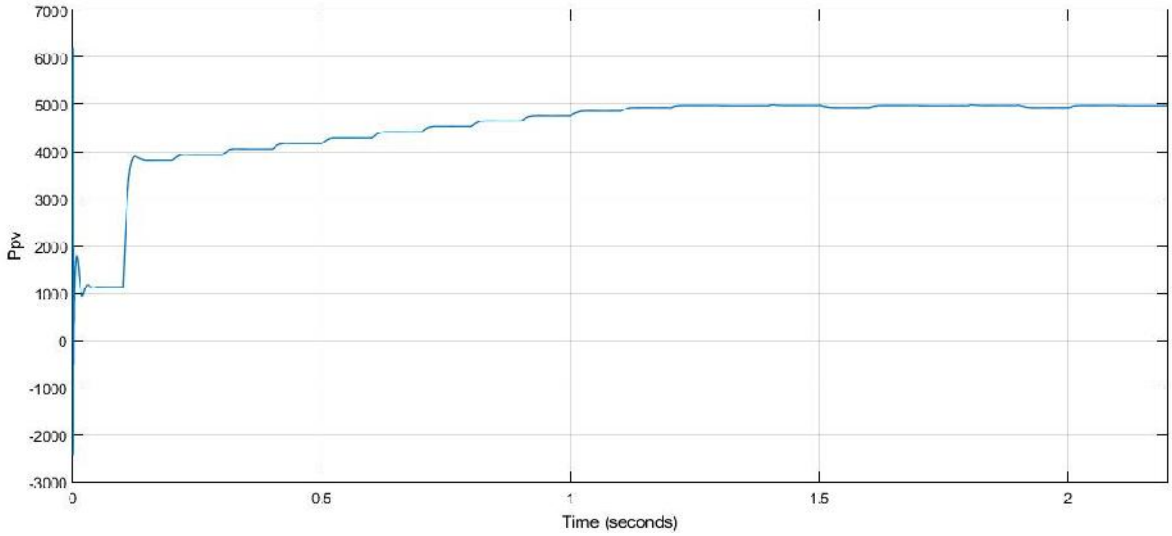

Fig. 9. Waveform of output power of PV (P_{pv} in watts)

Initially at duty cycle = 0, P_{pv} shows second order response as shown in Fig. 9. and settles down at around 1.1 kW and when MPPT is started, it begins to track maximum power and settles down at 4.98 kW and as P&O is used for MPPT it keeps oscillating around MPP.

PV output voltage waveform is shown in Fig. 10. and settles down at 300 V which is $V_{mp}$of PV array taken and it keeps oscillating around V_{mp} in 3 steps.

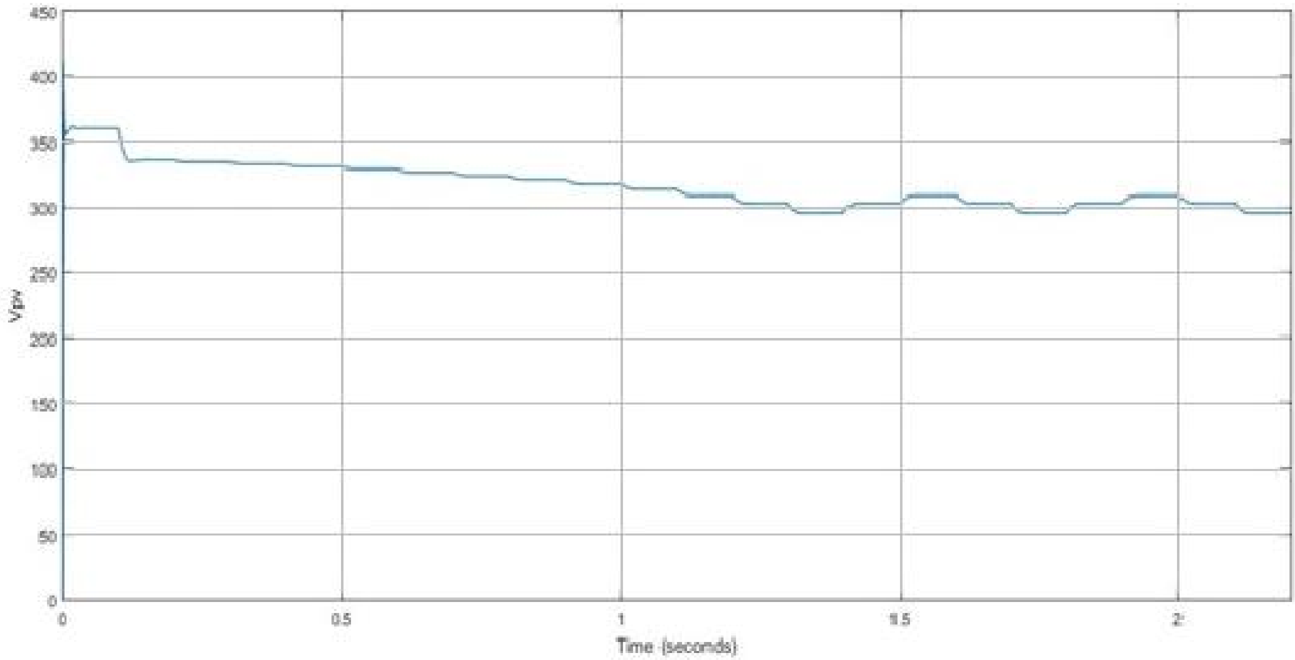

Fig. 10.Waveform of output voltage of PV (V_{pv} in volts)

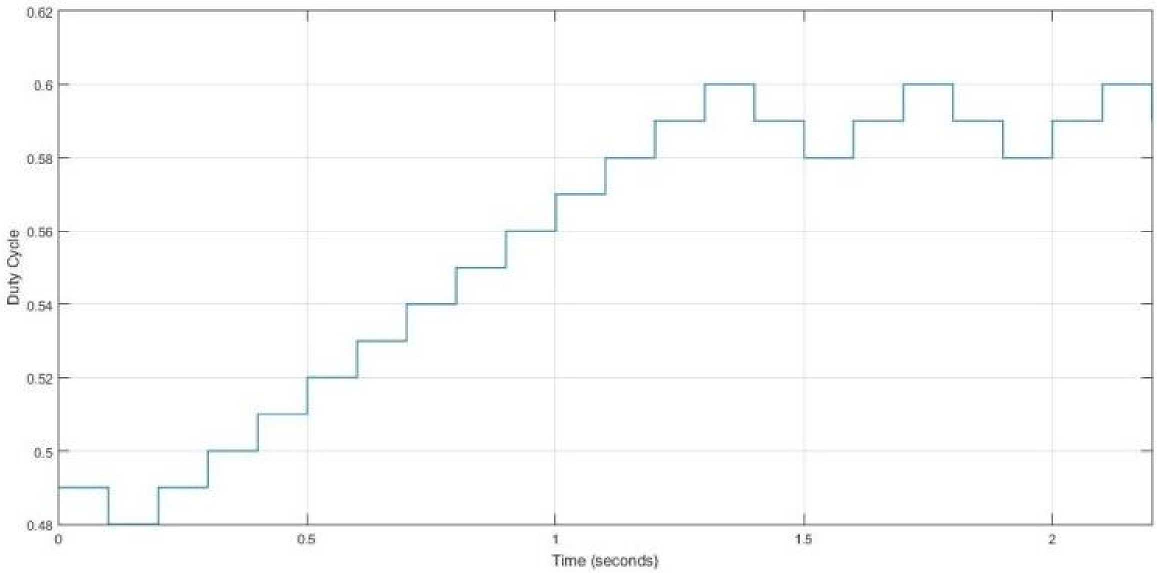

Fig. 11.Waveform of Duty Cycle (Initial Duty Cycle = 0.5)

Fig. 11. shows that Duty cycle settles down at 0.59 which is calculated Duty Cycle at MPP and it keeps oscillating around 0.59 in 3 steps.

PV output current settles down at 16.6A as shown in Fig. 12. which is our PV output current at MPP and it keeps oscillating around 16.6 A in 3 steps.

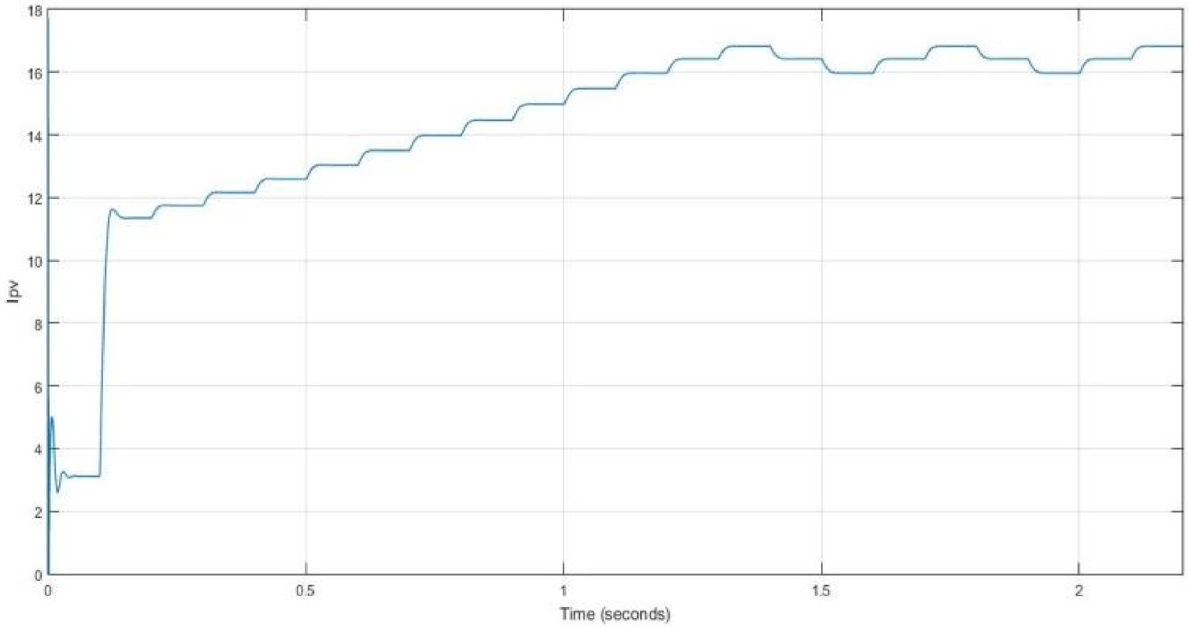

Fig. 12.Waveform of PV output current (I_{pv} in Amperes)

Similarly, Fig. 13, 14 and 15 show output power (P_{out}), voltage (V_{out}) and current (I_{out}) settles down at 4.7 kW, 730 V and 6.43 A respectively and each parameter keeps oscillating around their respective value at MPP in 3 steps.

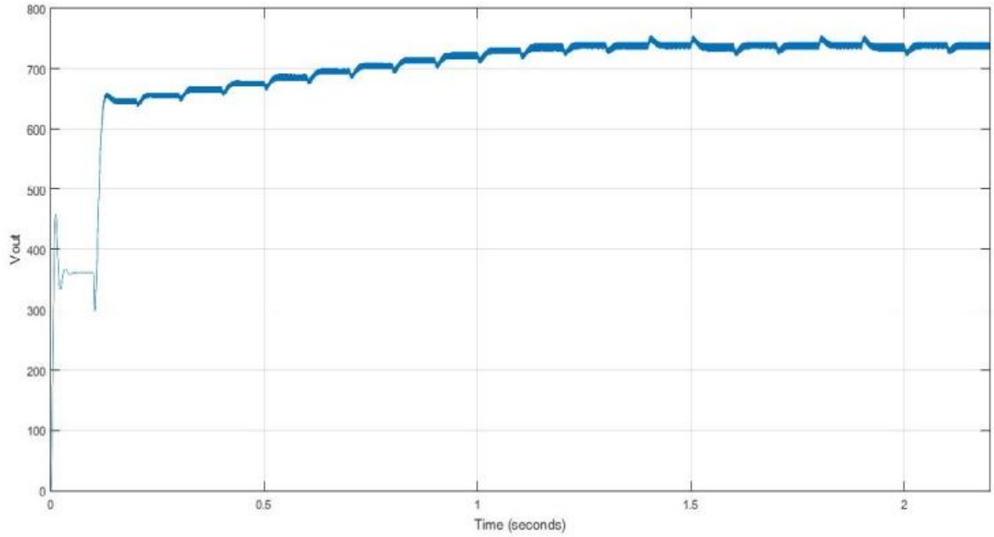

Fig. 13.Waveform of Boost Converter output Voltage (V_{out} in volts)

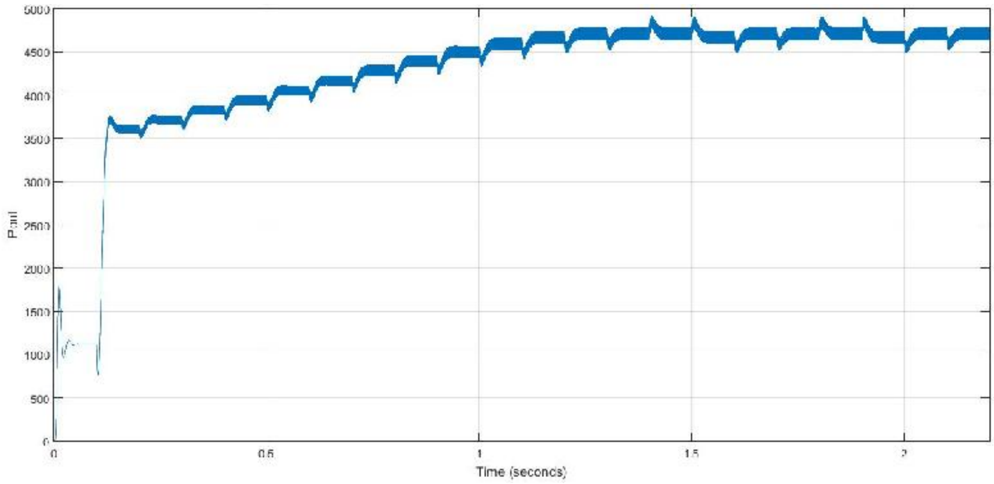

Fig. 14.Waveform of Boost Converter output power (P_{out} in watts)

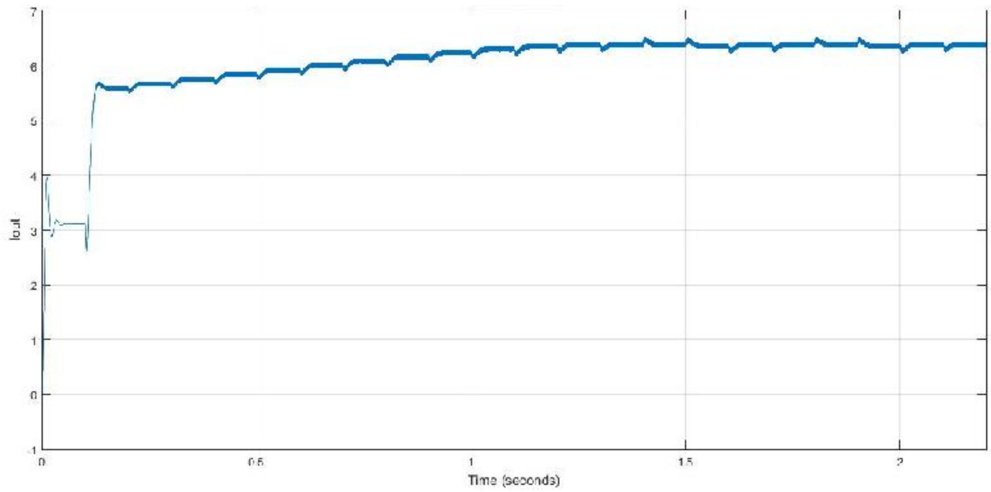

Fig. 15.Waveform of Boost converter output current (I_{out} in Amperes)

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4.2 SIMULATION RESULTS UNDER VARIABLE IRRADIATION AND TEMPERATURE CONDITION.

It can be seen from PV array characteristics (fig. 2. and fig. 3.) that as irradiance and temperature changes P_{max}, V_{mp}, I_{mp}, I_{sc} and V_{oc} changes. MPPT algorithm must track new maximum power point as irradiation and temperature changes and following results verify the correct working of MPPT. Just like in case of constant irradiation and temperature initially boost converter is operated at duty cycle (D) = 0 for 0.1 sec and then MPPT is started. Sample time, initial duty cycle (for MPPT) and step size are taken as 0.1 sec, 0.5 and 0.01 respectively.

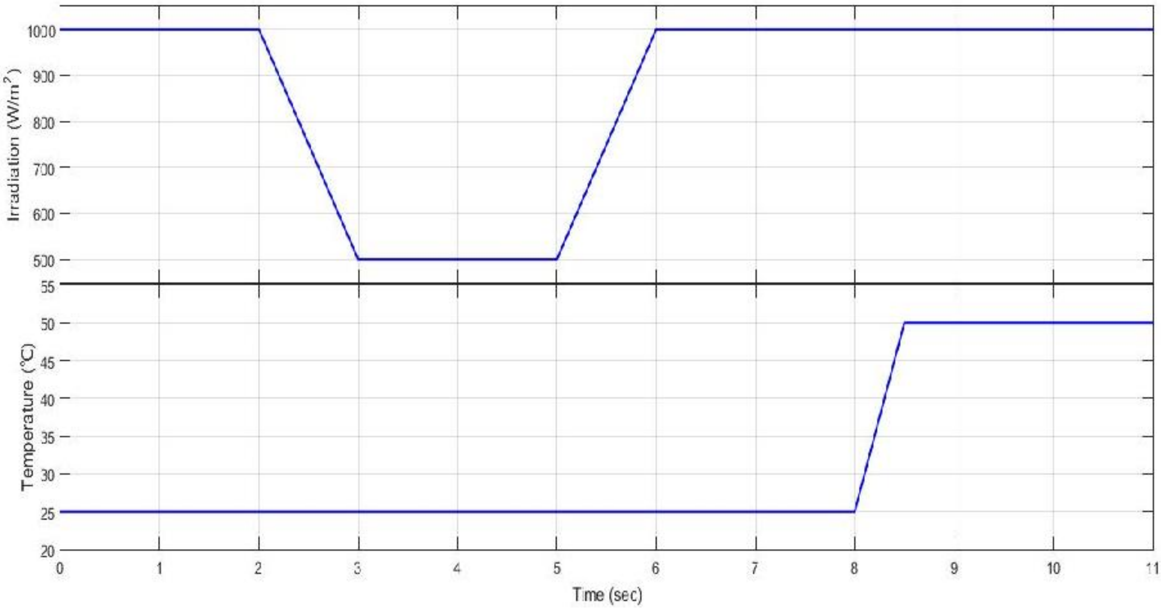

Fig. 16.Waveforms of variable Irradiation (in W/m2) and Temperature (in).

Fig. 16. shows the waveforms of variable irradiation and temperature signals that are applied to PV array as input.

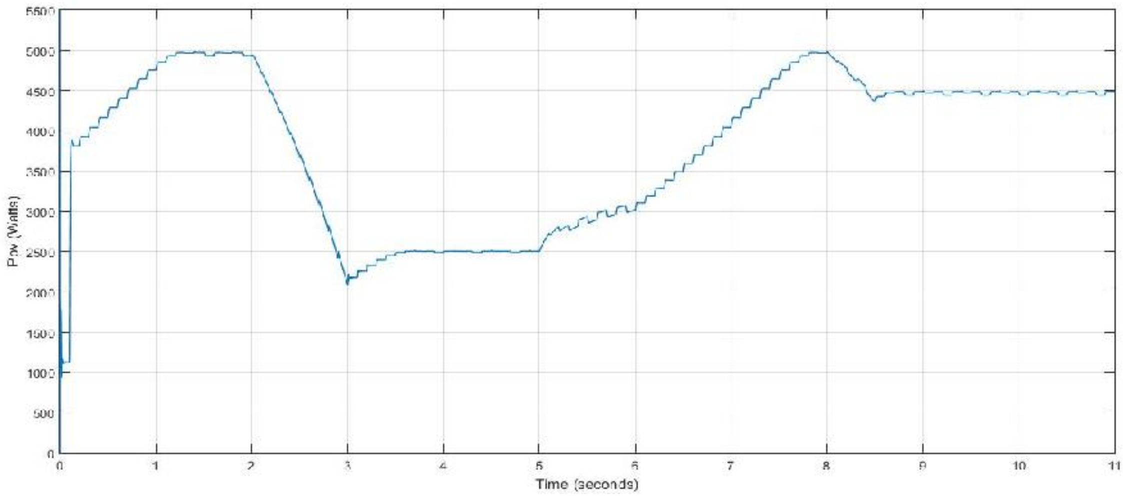

Fig. 17 Waveform of PV output power (P_{pv} in watts) under variable irradiation and temperature condition

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Waveform of PV output power is shown in Fig. 17. and Perturb and Observe MPPT tracks new maximum power as irradiation and temperature changes.

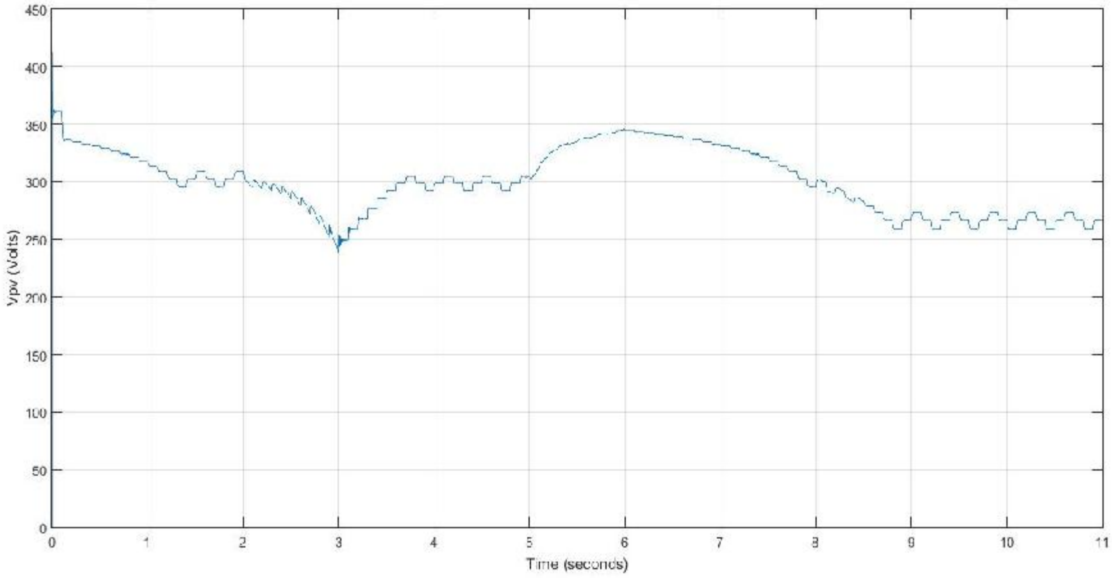

Fig. 18. Waveform of PV output voltage (V_{pv} in Volts)under variable irradiation and temperature condition

Fig. 18. shows waveform of PV output voltage and it tracks to new V_{mp} as irradiation and temperature changes

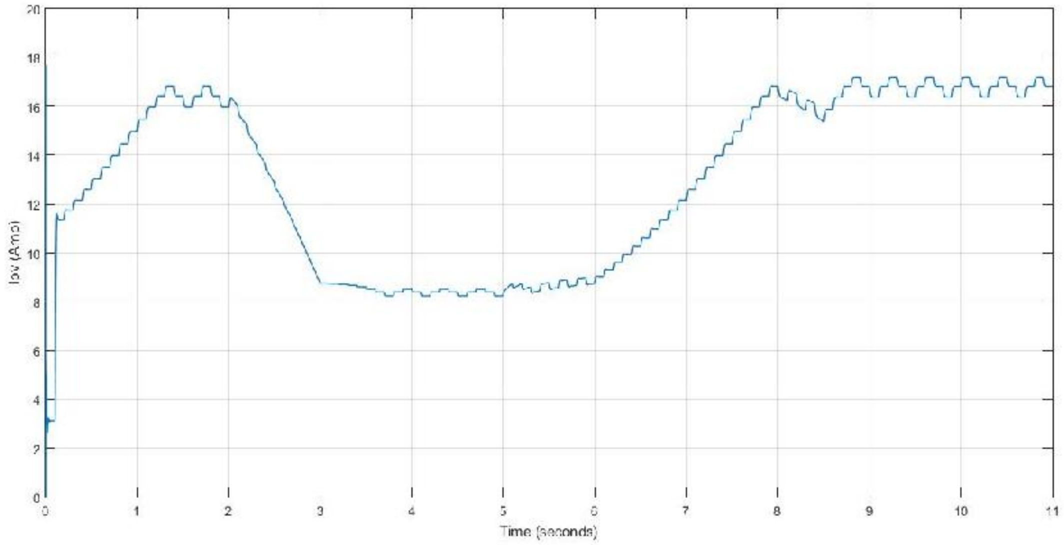

Fig. 19Waveform of PV output current (I_{pv} in Amperes)under variable irradiation and temperature condition

Fig. 19. shows waveform of PV output current and it tracks new I_{mp} as irradiation and temperature varies. It also shows that the variation of I_{mp} is more when irradiation varies and less when temperature varies. (which can be verified by I-V characteristics of PV array (Fig. 2 and 3)).

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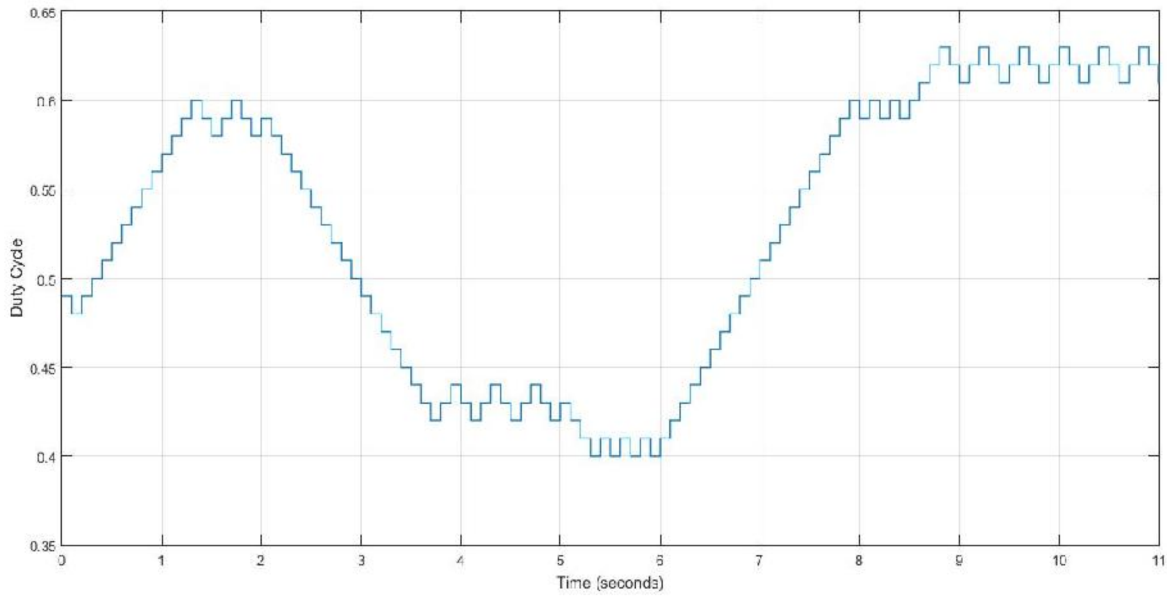

Fig. 20.Waveform of Duty Cycleunder variable irradiation and temperature condition

Fig. 20. shows waveform of duty cycle and it tracks to 0.59 at S=1000W/m^2 and T=25   and tracks to new duty cycle as irradiation and temperature varies.

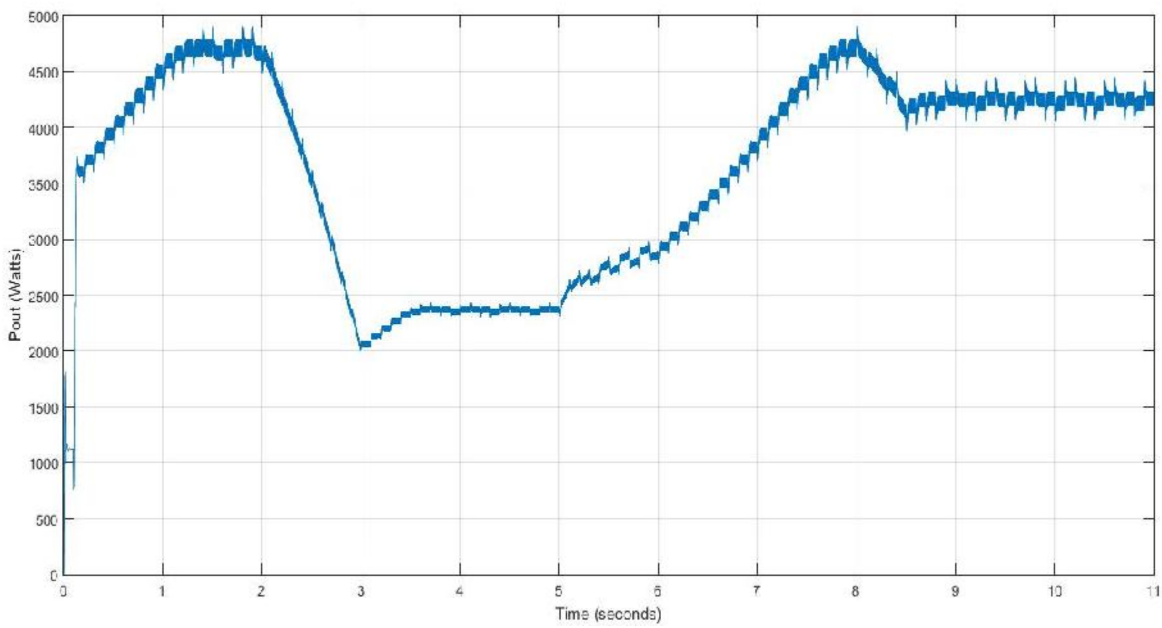

Fig. 21.Waveform of Boost Converter output power (P_{out} in watts)under variable irradiation and temperature condition

Fig. 21. shows waveform of boost converter output power or the power absorbed by resistive load.

Waveform of boost converter output voltage is shown in Fig. 22. and it tracks to calculated output voltage (730 V) at 0.59 duty cycle (at S=1000W/m^2 and T=25   ) and varies as irradiation and temperature varies.

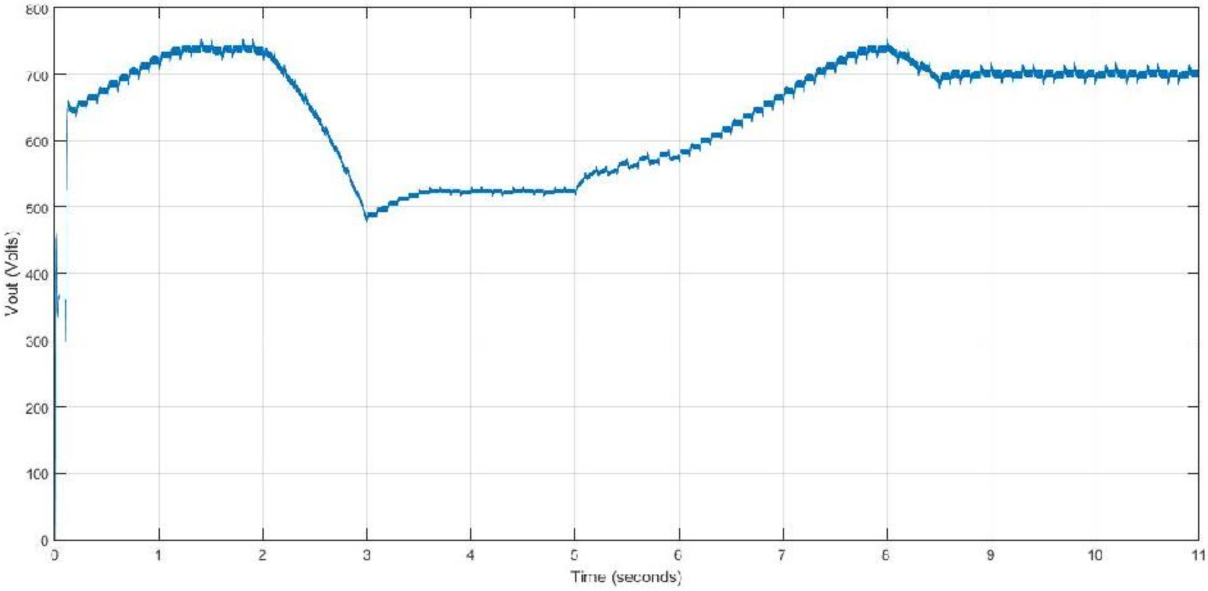

Fig. 22.Waveform of Boost Converter output voltage (V_{out} in volts)under variable irradiation and temperature condition

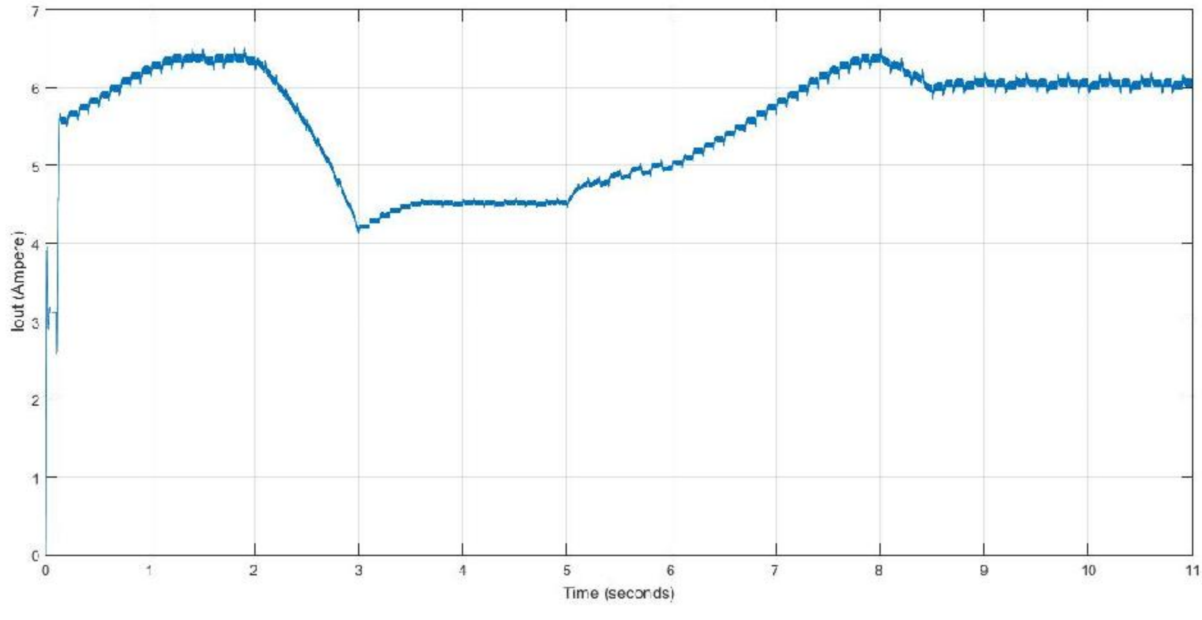

Fig. 23.Waveform of Boost converter output current (I_{out} in Amperes)under variable irradiation and temperature condition

Fig. 23. shows waveform of boost converter output current or the current fed to resistive load.

5. CONCLUSION

In this paper simulation and designing of 4.98kW PV array connected to resistive load through DC-DC boost converter with P&O MPPT is presented andefficiency of overall system is found to be 95%. Results are discussed under constant as well as variable irradiation and temperature conditions and it is found that Perturb and Observe MPPT technique is easy to implement and shows good performance under steady change in atmospheric conditions but is less suitable under fast changing atmospheric conditions.

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