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Design and Simulation of DC-DC Converter Connected to a Photovoltaic Array with MPPT Controller

K.V.V.Bapi Raju[1], Vinod Vara[2] P.S.V.Subrahmanyam[3]

[1]Assosciate Professor, Dept. of Electrical & Electronics Engg., Srinivasa Inst.of Engg & Tech, Cheyyeru, E.G. Dist A.P, India

[2]Assistant Professor, Dept. of Electrical & Electronics Engg., Srinivasa Inst. of Engg & Tech, Cheyyeru, E.G. Dist A.P, India

[3]Assistant Professor, Dept. of Electrical & Electronics Engg., Srinivasa Inst. of Engg & Tech, Cheyyeru, E.G. Dist A.P, India

ABSTRACT: In this paper deals with modeling of PV cell including the effects of temperature and irradiation. The DC-DC boost converter is used for boosting low voltage of the PV cell to high dc voltage. The renewable energy is important of power generation system due to decrease of fossils fuel. Energy production from photovoltaic is widely accepted as it is clean, available in abundance and free of cost. Although solar energy is available throughout the day its insolation varies from morning to evening and with varying climatic condition. The solar PV panel is low it becomes mandatory to remove maximum power from the PV panel at any given period of time. To track maximum power point perturb and observe (P and O) algorithm is used which periodically perturbs the array voltage or current and compare PV output power with that of previous perturbation cycle which controls duty cycle of DC-DC boost converter. A maximum power point tracker is used for extracting the maximumpower from the solar PV array and transferring that power to load.Simulation results are presented in by using MATLAB/Simulink.

KEYWORDS: Maximum power point tracking (MPPT), PV array, DC-DC Converter, P&O algorithm.

1. INTRODUCTION

The renewable energy sources (solar, wind, biomass etc) are main part of power generation. Electricity can be createdworking these sources in parallel with the grid. The photovoltaic(PV) system which perfectly suitable for distribution generation is gaining importance today, since it offers many advantages such as needs less maintenance, noise free, pollution free and is more environmental friendly.[1] The photovoltaic system produces DC energy when solar insolation falls on photovoltaic array. The energy available at the terminal of a photovoltaic array can feed small loads such as lightning system, DC motors, but some application requires DC-DC converter, to process the energy from photovoltaic device. These converter are used to control the voltage and current at the load, to control power flow in the system and mostly to track maximum power point [2] the amount of energy produced by photovoltaic array varies with change in ecologicalcondition such as temperature and insolation which minimize the overall conversion efficiency of photovoltaic module. The controlling maximum power point tracker (MPPT) at maximum power point (MPP) is important in PV system. The amount of power generated by PV array depends on operating voltage of the array. Its I-V & P-V characteristics identify the unique operating point called MPP at which PV should operates and maximum power can be sent to load operating at its highest efficiency. To improve the performance of PV many methods are available [4]-[7] which vary in many aspects such as simplicity, convergence speed, hardware implementation, sensors

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required & cost. The open circuit voltage method is based on observation that the voltage of the maximum power point is always close to a fixed percentage of the open circuit voltage. The main drawback in this method is energy produced by PV system is less, additional power components is required, static switch is needed which increases the cost of the algorithm.

These disadvantages can be overcome by perturb and observe (P&O) technique. It operates by periodically incrementing or decrementing the array terminal voltage or current and comparing the PV output power with that of previous perturbation cycle. The advantage of P &O technique is easy to implement, control is simple and cost is less compared to other MPPT algorithm techniques. The work presented here is about the modeling, simulation of PV array connected to DC load. The boost converter duty cycle is controlled by using P&O algorithm techniques. First section deals with modeling of PV array along with MPPT algorithm, followed by design of DC-DC converter, Simulink model and results obtained are discussed in subsequent section.

II.SYSTEM CONFIGURATION

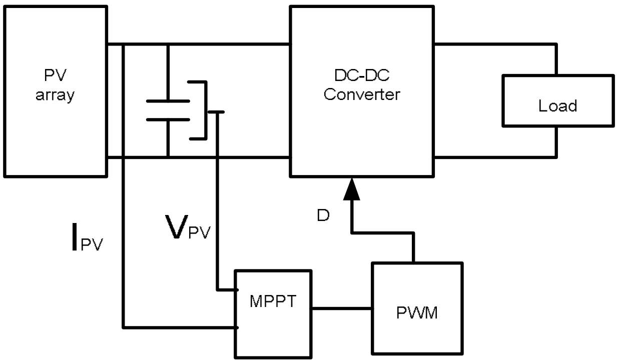

Fig.1 Schematic of the system

The above schematic as shown in Fig.1 present the configuration used in this paper. The PV array contain 5 modules of 250 Wp which is connected in series. The MPPT algorithm is used for extracting the maximum power from solar PV array and extracted power is supplied to load. The DC/DC converter used acts as an interface between PV array and load and serves the purpose of transferring maximum power from PV to load. By changing the duty cycle of the pulse width modulated (PWM) control signal of DC/DC converter, the load impedance seen by source varies and matches the peak power point with that of source, so as to transfer the maximum power. [1]-[2].

III. MATHEMATICAL MODELING OF PHOTOVOLTAIC ARRAY

A. Ideal photovoltaic cell

Solar PV is made of photovoltaic cells. Cells are grouped to from panels or modules and panels are grouped to from large PV array. The basic equation which mathematically describes the ideal PV cell is given by Eq. (1) [2]

$$I = I_{pv,cell} - I_{o,cell}\left[\frac{exp\left(^{qV}/_{AkT}\right)}{I_d} - 1\right] \quad (1)$$

Where:

Ipv, cell is the current generated by the incident light, Io cell is the reverse saturation current of the diode, q is the electro charge valued at 1.602x10-19 C, k is Boltzmann's constant valued at 1.381x10-23 J/K, T is the junction temperature in Kelvin, A is diode identity constant, V is the voltage across PV cell & I is the output current of the ideal PV model.

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B. Modelling of photovoltaic array

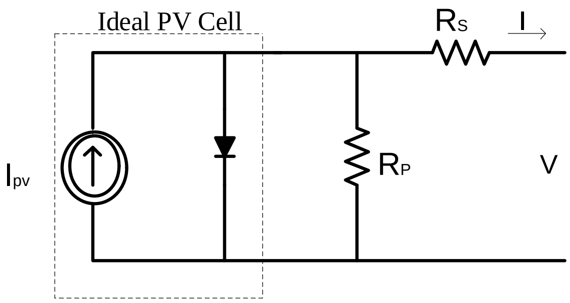

Fig.2 Equivalent circuit of practical PV cell.

The basic PV equation does not represent the I-V characteristics as a practical PV module consists of several PV cells which require the additional parameters which is series resistance and parallel resistance (Rs&Rp) as shown in Fig.2. The modeling of PV module is based on mathematical equations of the solar cell which is given by Eq.2. [2].

$$I = I_{pv} - I_o\left(exp\left\{\left(\frac{q(V+I*R_S)}{N_S*AkT}\right)-1\right\}\right) - \frac{V+I*R_S}{R_p} \quad (2)$$

The light generated current (Ipv) depends linearly on solar radiation and is influenced by temperature is given by Eq. (3)

$$I_{pv}=\left[I_{sc} + K_i\left(T - T_{ref}\right) * \frac{G}{Gn}\right] \quad (3)$$

Module reverse saturation current (Irs) at nominal condition and reference temperature is given by Eq.(4)

$$I_{rs} = \frac{I_{sc(n)}}{\left[exp\left(\frac{q*V_{oc}}{N_S*AkT_r}\right)-1\right]} \quad (4)$$

Module saturation current (I0) is given by Eq. (5).

$$I_o = I_{rs}\left[\frac{T}{T_{ref}}\right]^3 * exp\left[\frac{qE_g}{Ak}\left(\frac{1}{T_{ref}} - \frac{1}{T}\right)\right] \quad (5)$$

Basic output current of PV module of single diode is given by Eq.(6).

$$I = N_p * I_{pv} - I_o * N_p\left[exp\left(\frac{q(V+I*R)}{N_S*AkT}\right) - 1\right] \quad (6)$$

Where Ns and Np is number of solar cells connected in series and parallel.

IV.BOOST CONVERTER OPERATION

The diagrammatic representation of the boost converter is shown in below figure 3. As The basic principle of a Boost converter consists of 2 distinct states.

- In the On-state, the switch Q is closed, resulting in an increase in the inductor current.
- In the Off-state, the switch is open and the only path offered to inductor current is through the fly back diode D, the capacitor C and the load R. This result in transferring the energy accumulated during the On-state into the capacitor.

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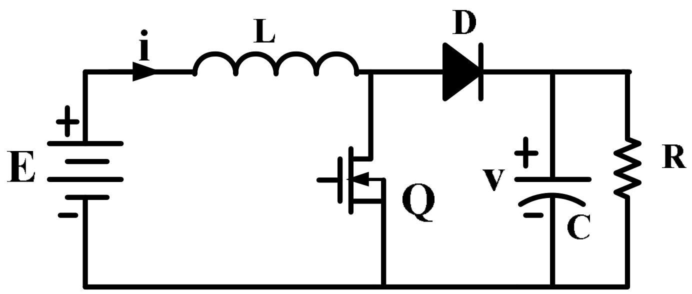

Fig. 3. Boost DC-DC Converter.

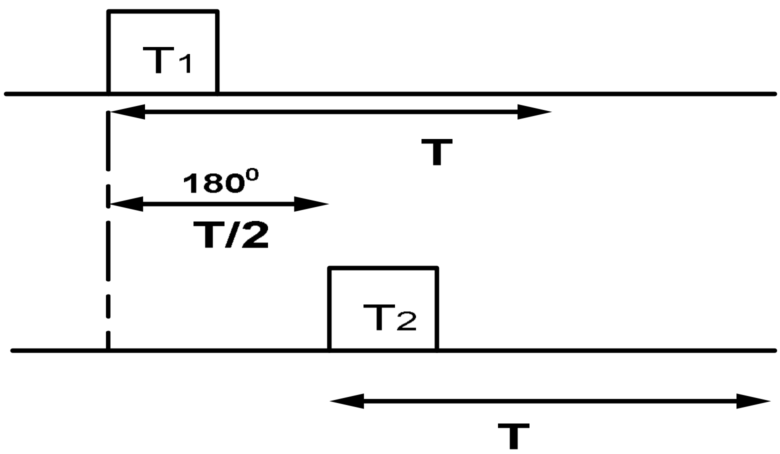

Fig.4.Timing diagram of Control Signal

The modes of operation of this converter are describes as follows. To simplify the calculation, it is assumed that the inductance value of inductor are L1, where L1=L, and the duty cycle denoted as D

Mode I: During the On-state, the switch S is closed, which makes the input voltage (V_i) appear across the inductor, which causes a change in current (I_L) flowing through the inductor during a time period (t) by the formula:

$$\frac{\Delta I_L}{\Delta t} = \frac{V_i}{L} \quad (7)$$

Mode II: During the Off-state, the switch S is open, so the inductor current flows through the load. If we consider zero voltage drop in the diode, and a capacitor large enough for its voltage to remain constant, the evolution of I_L is:

$$V_i - V_0 = L\frac{dI_L}{dt} \quad (8)$$

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V.DESIGNING OF BOOST CONVERTER

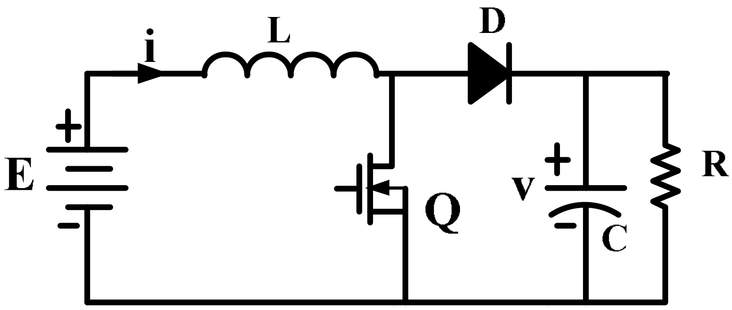
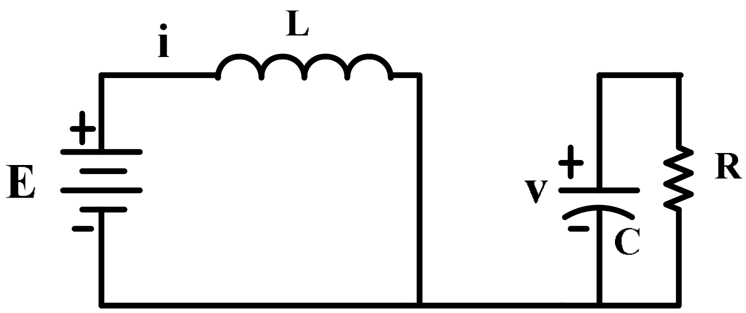


Fig.5. boost converter

Mode1: T1 ON

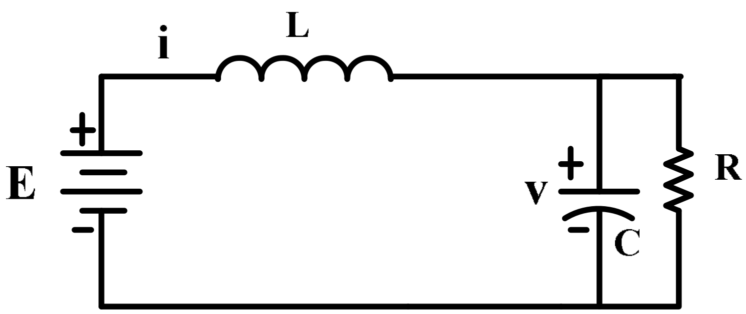


Assume $\Delta I = I_2 - I_1$

$$V_{in} = L_1 \frac{\Delta I}{t_1}$$

$$t_1 = \frac{L \times \Delta I}{V_{in}} \quad (9)$$

Mode 2: DuringT1 off



For inductor L_1

$$V_{in} - V_0 = -L_1 \frac{dI}{dt}$$

$$t_2 = \frac{\Delta I L_1}{V_0 - V_{in}} \quad (10)$$

Substitute t_1=DTs and t_2=(1-D)T_s

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$$\Delta I = \frac{V_{in} \times t_1}{L}$$

$$\Delta I = \frac{V_0 - V_{in} \times t_2}{L}$$

$$\frac{V_{in} \times DT_s}{L} = \frac{(V_0 - V_{in})}{L}(1-D)T_s$$

$$\frac{V_0}{V_{in}} = \frac{1}{1-D} \qquad (11)$$

Total time period

$$T = t_1 + t_2 = \frac{\Delta IL}{V_{in}} + \frac{\Delta IL}{V_0 - V_{in}}$$

$$T = \frac{\Delta IL V_0}{V_{in}(V_0 - V_{in})} \qquad (12)$$

Peak to peak ripple current

$$T = \frac{1}{f}$$

$$\Delta I = \frac{V_{in}(V_0 - V_{in})}{fLV_0} \qquad (13)$$

$$\frac{\Delta I = V_{in} D}{fL} \qquad (14)$$

For output capacitor

$$\Delta V_c = V_c - V_c(t=0) = \frac{1}{c}\int_0^{t_1} I_c\, dt$$

$$= \frac{It_1}{c}$$

Substitute $t_1 = \frac{(V_0 - V_{in}}{V_0 \times f}$

$$\Delta V_c = \frac{I_0 K}{fc} \qquad (15)$$

Condition for CCM operation. Take worst case ripple $\Delta I = 2I_L$

$$\Delta I = \frac{V_s K}{fL} = 2I_L = 2I_0 = 2 \times \frac{V_0}{R}$$

$$= \frac{2 \times V_{in}}{(1-K)R}$$

$$L_{critical} = \frac{K(1-K)R}{2f} \qquad (16)$$

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Take worst case ripple for capacitor

$$\Delta V_c = 2V_0$$

$$2V_0 = \frac{I_0 K}{fc} = 2I_0 R$$

$$C_{critical} = \frac{K}{2fR} \quad (17)$$

VI. MAXIMUM POWER POINT TRACKING

Maximum power point tracking has been shown to increase the efficiency of the system by nearly 30% over charge controllers that do not development MPPT. [8,9] charge In addition, as the battery charges the voltage will change as it passes through several charging states which would create further inefficiencies in the absence of a charge controller. In the charge this paper, the charge controller should be able to monitor voltages from both the photovoltaic array and the battery in order to determine these charging states and maintain maximum efficiency.To show a possiblesituation, consider if the goal of the system is to charge a 12 V battery but the maximum power point occurred at a panelvoltage of 15 V.

If the PV panel were connected direct to the battery, it would pull the panel voltage down to 12, which the graph would clearly show is inefficient and operating below the maximum power point. Rather than allow this energy to bewasted, the charge controller allows the panel to continue to operate at the MPP but uses DC-to-DC converters to compensate for the difference in voltage needed. This prevents significant losses and allows the system to take advantage of the valuable power that is produced in the solar array there are several common methods that are used to implement maximum power point tracking.

A. EFFECTS OF SOLAR IRRADIANCE ON MPPT

There are two key parameters frequently used to characterize a PV cell. Shorting together the terminals of the cell, the photon generated current will follow out of the cell as a short-circuit current (Isc). When there is no connection to the PV cell (open-circuit), the photon generated current is shunted internally by the intrinsic p-n junction diode. This gives the open circuit voltage (Voc). The PV module or cell manufacturers usually provide the values of these parameters in their datasheet In a PV cell current is generated by photons and output is constant under constant temperature and constant incident radiation of light. Varying the irradiation we can get different output levels. .

The current voltage relationship of a PV cell is given below,

$$\mathrm{I} = Isc - [e^{qv}_{kt} - 1]$$

To a very good approximation, the photon generated current, which is equal to is directly proportional to the irradiance (G), the intensity of illumination, to PV cell. If Isc (Go) is the photo current at irradiance Go=1000W/m2 at the air mass AM = 1.5, then the photon generated current at any other irradiance, G (W/m2), is given by,

$$\mathrm{Isc(G)} = \left(\frac{G}{G0}\right) Isc(G0)$$

So, the equation for varying irradiance,

$$\mathrm{I} = \left(\frac{G}{G0}\right) Isc - Is[e^{\frac{qv}{nkt}} - 1]$$

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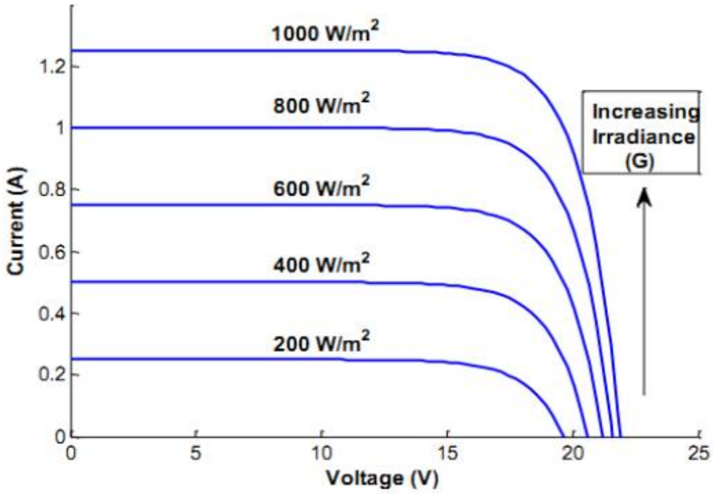

Fig.6.I-V curve with different irradiance.

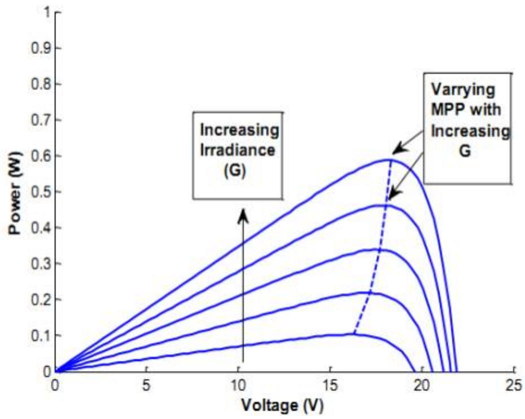

Fig.7.P-V curves with different irradiance.

The PV cell output is both limited by the cell current and the cell voltage, and it can only produce a power with any combinations of current and voltage on the I-V curve. As in Figure.7.The P-V curve shifts with different irradiance sothe MPP also shifts. Now, as the I-V curve of a PV cell changes with different irradiance so it reveals that theamount of power produced by the PV module varies greatly depending on its irradiance. It is important to operate the system at the MPP of PV module in order to exploit the maximum power from the module.

B. MPPT CONTROL SCHEME

Photovoltaic (PV) energy is the most important energy resource since it is clean, pollution free, and inexhaustible. In recent years, a large number of techniques have been proposed for tracking the maximum power point (MPP). Maximum power point tracking (MPPT) is used in photovoltaic (PV) systems to maximize the photovoltaic array output power, irrespective of the temperature and radiation conditions and of the load electrical characteristics the PV array output power is used to directly control the dc/dc converter, thus reducing the complexity of the system. The method is based on use of a Incremental conductance of the PV to determine an optimum operating current for the maximum output power. In perturb and observe method the array terminal voltage is always adjusted according to the MPP voltage it is based on the incremental and instantaneous conductance of the PV module

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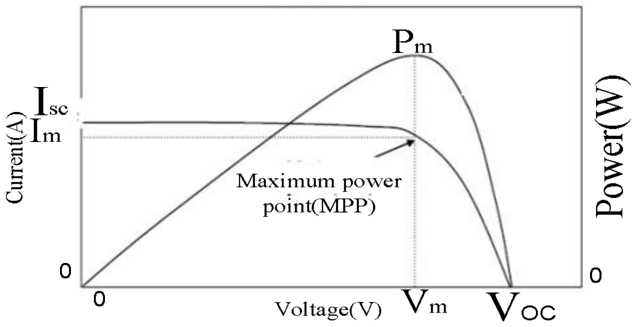

Fig.8.MPPT Control.

Fig shows that the slope of the P-V array power curve is zero at The MPP, increasing on the left of the MPP and decreasing on the Right hand side of the MPP. The basic equations of this method are as follows.
At MPP

$$dp/dv > 0$$

Left of MPP,

$$dp/dv < 0$$

Right of MPP,

$$dp/dv > 0$$

Right of MPP Where I and V are P-V array output current and voltage respectively. The left hand side of equations represents P&O algorithm of P-V module and the right hand side represents the instantaneous conductance. When the ratio of change in output conductance is equal to the negative output conductance, the solar array will operate at the maximum power point. Flow chart for perturb & observe

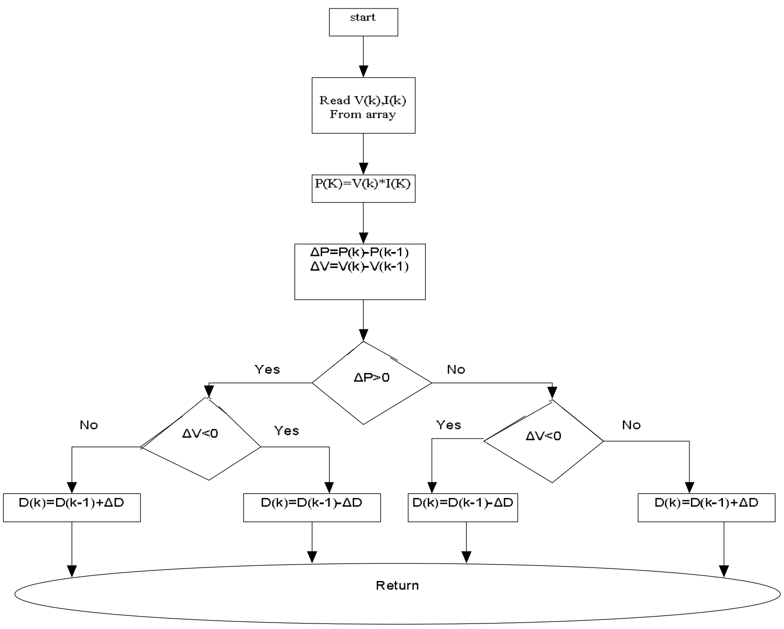

Fig.9. Perturb & Observe Algorithm

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VII.MATLAB/SIMULATION RESULTS

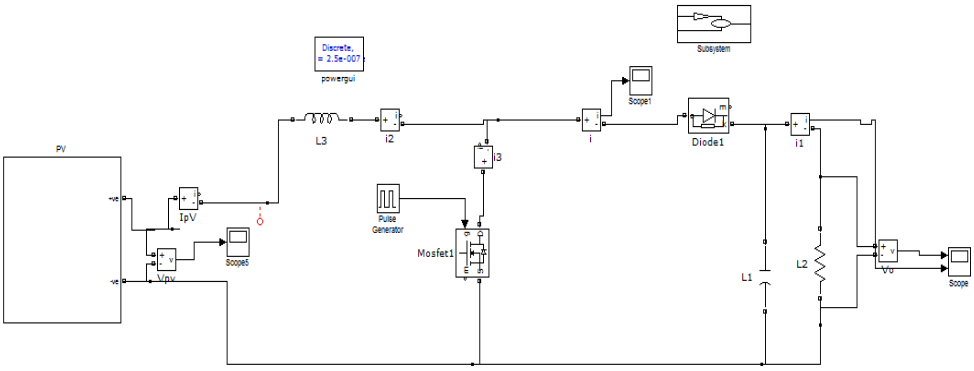

Fig.10.Matlab/simulation model of without MPPT controller.

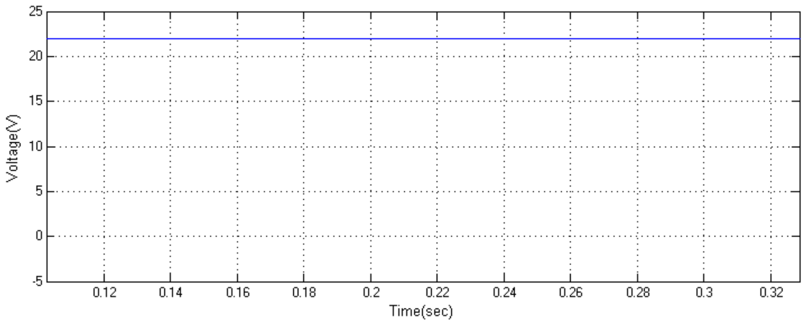

Fig.11.PV output Voltage.

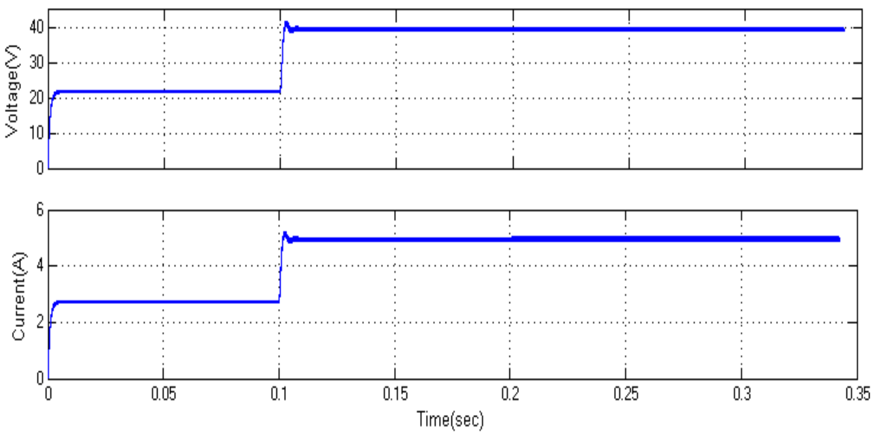

Fig.12.Output voltage and current waveform of the boost converter without MPPT controller.

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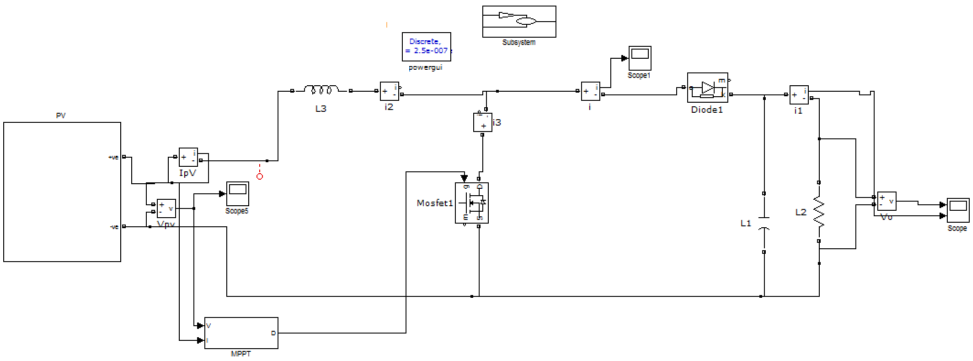

Fig.13.Matlab/simulation model of with MPPT controller.

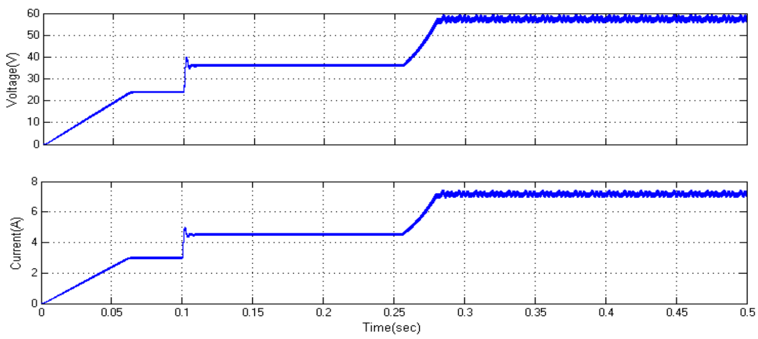

Fig.14.Output voltage and current waveform of the boost converter with MPPT controller.

The PV array model with MPPT control is tested at different temperature and insolation condition. Itis observed that the output voltage generated by PV is 23 V and current is 5 A. Also the boosted output voltage is close to 60 V with slight oscillation as P& O algorithm is used. The boost converter duty cycle obtained is 0.45, which is less than 50 %.

Table.1. Simulation Model Parameters

Input voltage	22V
Inductors	1.26mH
Capacitor	100μF
Resistance	8Ω

VIII.CONCLUSION

The modeling, simulation & design of this system is done in Matlab /Simulink. The model is first tested without MPPT; it is observed that boosted output voltage is less, as the PV array does not operate at MPP. Hence to improve the utilization of PV array the P&O MPPT algorithm is used. The algorithm is tested varying the temperature & insolation input condition of PV array. The result obtained shows that at different insolation & temperature condition, the MPPT algorithm always operates at MPP with slight oscillation, also the duty cycle of converter is controlled appropriately & obtained boosted output voltage is approximately value which is desired. The presented PV array modeled will help to validated different MPPT algorithm. This system can be interfaced with grid by using different inverter control technique taking into account the different power quality issues.

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