Comparative Study and Simulation of Different Maximum Power Point Tracking (MPPT) Techniques in a Solar Power Generation

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Abstract— This paper presents the comparative analysis between Perturb & Observe (P&O), Incremental Conductance (INC), Constant Current and Constant Voltage algorithms for extracting the maximum power from Photovoltaic Array(PV Array). Maximum power point trackers (MPPT) play an important role in photovoltaic(PV) power systems because they extract the maximum power output from a PV system for a given set of conditions, and therefore different Maximum Power Point Tracking (MPPT) algorithms are used in Photovoltaic Array to maximize the output power i.e. maximize the array efficiency. DC-DC converters and MPPT systems together are used to avoid the energy losses. In this paper the MPPT algorithms are implemented using Boost converter. In this paper Mathematical Model of PV Panel simulated in Matlab is used. Parameters of 60W Solarex MSX60 PV panel is chosen for evaluating the developed PV model. The dynamics of Photovoltaic Array is simulated at different solar irradiance(G) and cell temperature(T_{op}). To demonstrate the effectiveness of the proposed system, simulations are performed with Matlab Simulink.

Keywords- *Photovoltaic Array, Solarex MSX60, MPPT, Boost Converter, MATLAB R2013a Software.*

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I. INTRODUCTION

Now a days as the world population is increasing rapidly, therefore demand of electrical energy is also increases accordingly and the available energy sources are not sufficient to meet these demand. So renewable energy sources are the best alternatives for that problem. In that Solar energy is best option, because (1) it is abundantly available, (2) it is a clean source of energy, (3) its conversion to electricity is easy i.e. by using PV Array. PV Module works on the principle of photovoltaic effect and it is also advantageous because it has no moving parts, that's why its maintenance cost is minimum and do not produce any noise. The changing environmental conditions i.e. solar irradiance and temperature directly affect the output characteristics of the PV Array(IV and PV characteristics). So it is necessary to operate the PV module at its maximum efficiency and MPPT provides the best solution for this. MPPT track the environmental changes and generate the duty cycle accordingly. Here DC-DC converter provide the interface between PV Array and Load as shown in Figure (1). As boost converter used to step up the input voltage but here it is also reduces the power loss. Many MPPT techniques have been developed and implemented. The methods vary in complexity, sensors required, convergence speed, cost, range of effectiveness, implementation hardware, popularity, and in other respects.

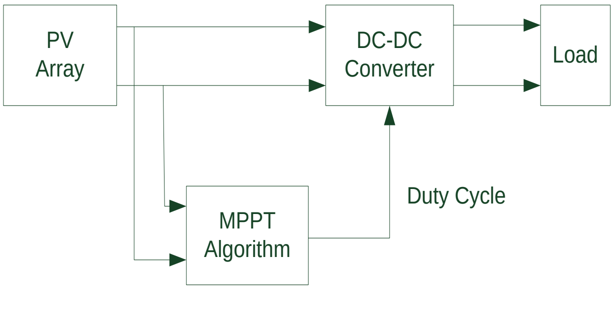

Figure 1- Block Diagram of Tracking System

Figure (1) shows the block diagram of tracking system which is composed of PV array, DC-DC converter, MPP tracker and load. Voltage and current generated by PV array are input to the MPPT algorithm and duty cycle is the output to converter.

II. MODELING OF PV ARRAY

A simple solar cell consist of solid state p-n junction fabricated from a semiconductor material (usually silicon). When solar cell is placed in the sun radiation, it converts the solar energy into electrical energy by photovoltaic effect. Therefore it generates the photovoltaic current (Iph) which is directly proportional to solar irradiation (G). Figure (2) shows the standard equivalent circuit of the PV cell.

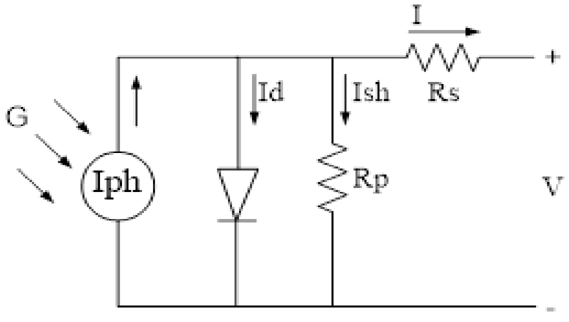

Figure 2: Equivalent circuit of PV cell

Following equations describes the mathematical model of the PV cell,

$$I = Iph - Id - Ish \tag{1}$$

$$Vt = kTop/q \tag{2}$$

$$Ish = (V + IRs)/Rp \tag{3}$$

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$$Id = IsNp\left[exp\left\{\frac{\frac{V}{Ns}+\frac{IRs}{Np}}{nVtC}\right\}-1\right] \quad (4)$$

$$Iph = G\{KI(Top - Tref) + Isc\} \quad (5)$$

$$Irs = Isc/[exp(qVoc/NsknTop) - 1] \quad (6)$$

$$Is = [(Top/Tref)^3 Irs]\left\{e^{\frac{q^2Eg\left(\frac{1}{Tref}-\frac{1}{Top}\right)}{nk}}-1\right\} \quad (7)$$

Where,

V is output voltage of a PV module (V).
Vt is the thermal voltage (V).
I is output current of a PV module (A).
Tref is the reference temperature = 298 K.
Top is the module operating temperature in Kelvin.
Iph is the light generated current in a PV module (A).
Irs is the reverse saturation current at Top (A).
Is is the reverse saturation current (A).
n is an ideality factor = 1.36.
k is Boltzman constant = 1.3805 × 10-23 J/K
q is Electron charge = 1.6 × 10-19 C.
Rs is the series resistance of a PV module.
Rp is the shunt resistance of a PV module.
Isc is the PV module short-circuit current at 25 ^{o}C.
Ish is the shunt current (A).
Eg is the band gap for silicon = 1.1 eV.
G is the solar irradiation (W/m^2).
Ns is the number of cells in series.
Np is the number of cells in parallel.

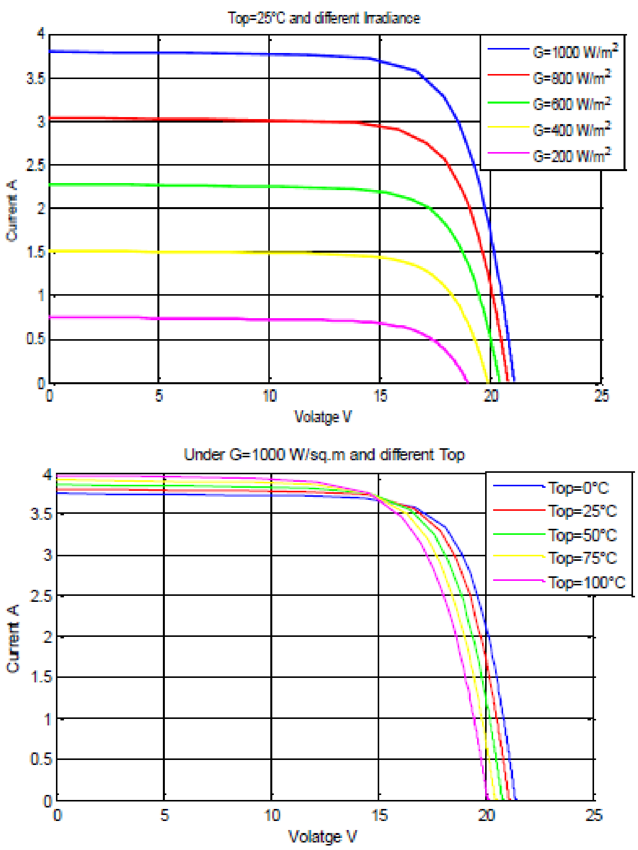

Figure 3: I-V characteristics at different G and Top

After simulating the mathematical model of PV Array in Matlab, above results are obtained. Figure (3) shows the I-V characteristics of PV Array at different irradiance with temperature constant at 25^{o}C and at different temperature with irradiance constant at 1000 W/m^2 .

III. MAXIMUM POWER POINT ALGORITHM

To operate the PV Panel at its maximum output power for changing environmental conditions MPPT is used. MPPT adjusts the duty cycle of the Boost converter to obtain the PV Array at its Maximum Power Point (MPP). In this paper, four different MPPT Algorithms are explained briefly and compare on different basis.

A. *Perturb and Observe Method*

P&O Algorithm is the most popularly used algorithm, as its implementation is easy and it is also cost effective. It generates the proper duty cycle for Boost converter by perturbation in panel operating voltage (ΔV). The main principle of P&O algorithm is decreasing the voltage on the right hand side and increasing the voltage on the left hand side to obtain the MPP on the PV curve.

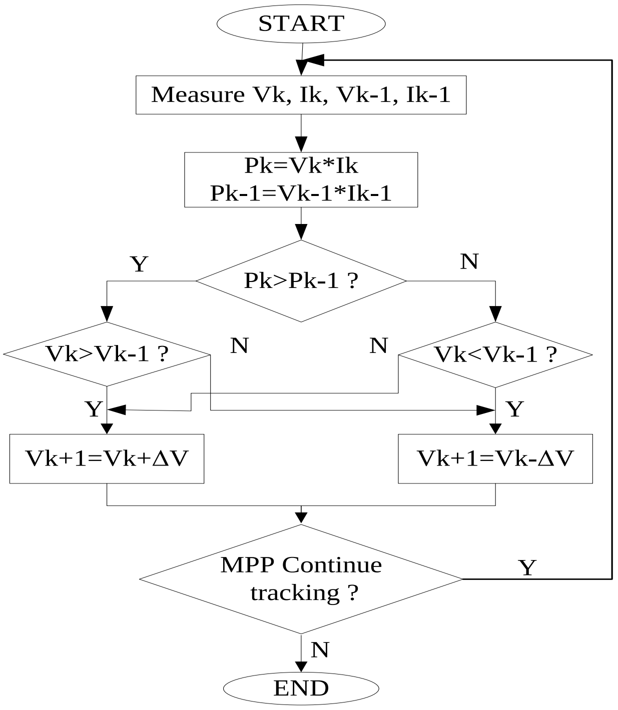

Figure 4: P&O Algorithm

Figure (4) shows the P&O Algorithm. Let’s say that, after performing an increase in the panel operating voltage, the algorithm compares the current power reading with the previous one. If the power has increased, it keeps the same direction (increase voltage), otherwise it changes direction (decrease voltage). This process is repeated at each MPP tracking step until the MPP is reached. After reaching the MPP, the algorithm naturally oscillates around the correct value.

B. Increamental Conductance Method

The method is based on the principle that the slope of the PV array power curve is zero at the maximum power point.

(dP/dV) = 0. Since (P = VI), it yields:

dI/dV = - I/V , at MPP

dI/dV > - I/V , left of MPP

dI/dV < - I/V , right of MPP

The MPP can be tracked by comparing the instantaneous conductance (I/V) to the incremental conductance (dI/dV). The algorithm increments or decrement the array reference voltage until the condition of equation (4.a) is satisfied [9]. Once the Maximum power is reached, the operation of the PV array is maintained at this point. This method requires high sampling rates and fast calculations of the power slope.

The main principle behind this method is to compare the incremental conductance (dI/dV) to the instantaneous conductance (I/V). Depending on the above three cases which one is satisfied, accordingly the panel operating voltage is either increased, or decreased until the MPP is reached. Since one of the demerit of P&O algorithm is, it naturally oscillates around the MPP, which has been overcame in incremental conductance method and stops modifying the operating voltage when the correct value is reached. A change in the panel current will restart the MPP tracking. Figure (5) shows the flowchart for INC algorithm.

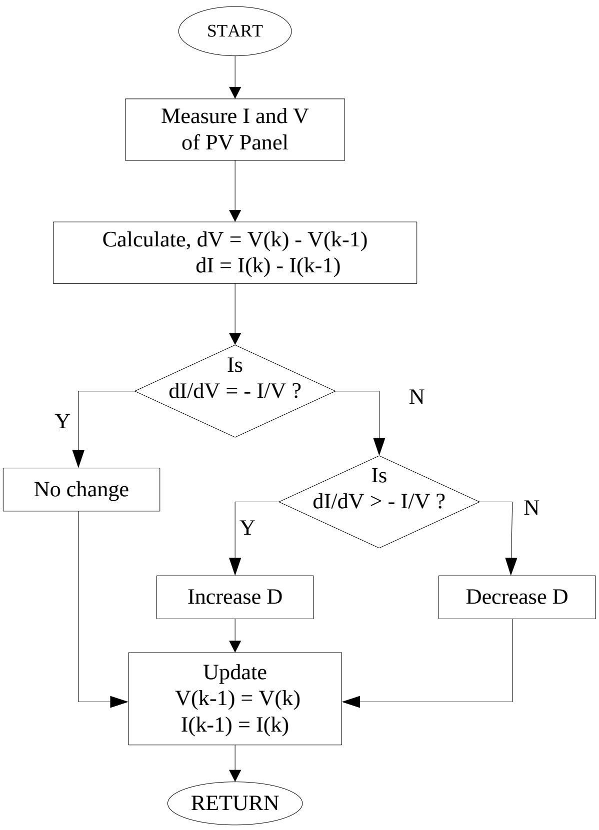

Figure 5: INC Algorithm

C. Fractional Short Circuit Current Method

This current base maximum power point tracker is used to obtain the MPP at different irradiance level (G). The MPP current (I_{MPP}) is directly proportional to Short circuit current (I_{SC}).

$$I_{MPP} = Ki * I_{SC} \qquad (8)$$

Where, I_{MPP} is Maximum power point current, I_{SC} is Short Circuit current, Ki is Current factor.

It is always less than 1. It varies between 0.78 and 0.92 depends upon the characteristics of solar panel. For all operating points and atmospheric conditions the short circuit current is continuously control the buck converter and calculates the maximum power point of the solar panel which depends upon the photovoltaic array current. For short circuit current the photovoltaic array voltage is zero, then short circuit current can be written as,

$$Isc = Iph - Irs * \{\exp\left(\frac{qIRs}{nkTop}\right) - 1\} \qquad (9)$$

D. Fractional Open Circuit Voltage Method

The method is based on the observation that, the ratio between array voltage at maximum power V_{MPP} to its open circuit voltage V_{OC} is nearly constant.

$$V_{MPP} = Kv * V_{OC} \qquad (10)$$

Where, V_{MPP} is Maximum power point Voltage, V_{OC} is Short Circuit current, Kv is Voltage factor.

This factor Kv has been reported to be between 0.71 and 0.78. Once the constant Kv is known, V_{MPP} is computed by periodic measurement of V_{OC}. Although the implementation of this method is simple and cheap, its tracking efficiency is relatively low due to the utilization of inaccurate values of the constant Kv in the computation of V_{MPP}. For open circuit voltage the photovoltaic array current is almost zero, then open circuit voltage can be written as,

$$Voc = nVt * \ln\left\{\frac{Iph}{Is} + 1\right\} \qquad (11)$$

IV. MATLAB MODELLING AND SIMULATION

Now the complete Tracking system is simulated in Matlab. It consist of mathematical model of PV Panel, Simulink model of MPPT and Boost Converter with resistive load. Figure (6) shows the Matlab model of the System.

The system is simulated for different environmental conditions i.e. at different irradiance level and at different temperature level. Now we compare the results obtained for the different MPPT Algorithm at various conditions. We also compare these algorithms on basis of its implementation complexity and cost.

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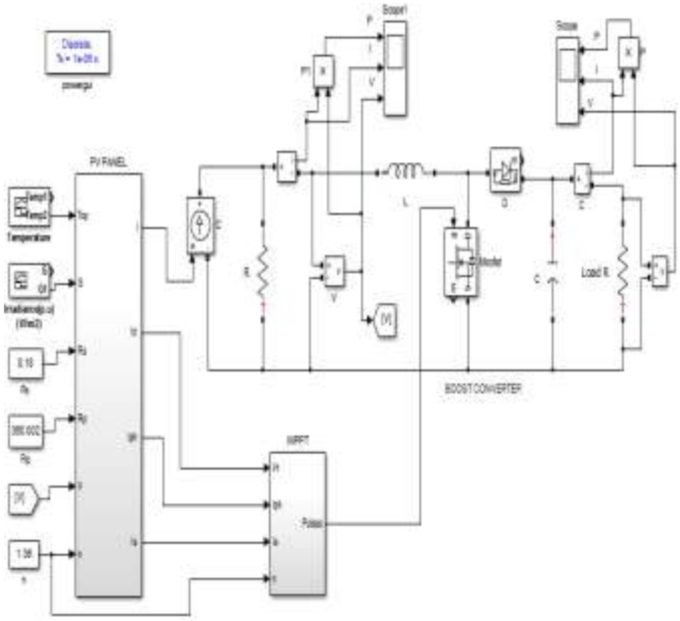

Figure 6: Matlab Model of Tracking System

V. SIMULATION RESULTS AND COMPARISON

After simulating the above discuss Algorithms, we get the following results

A. Perturb and Observe Method

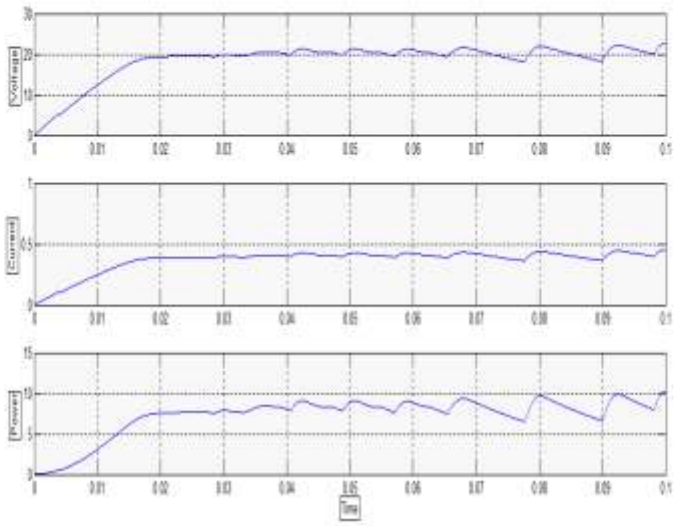

Figure 7: Output Voltage, Current and Power waveform at different G and constant Top=25^{o}C.

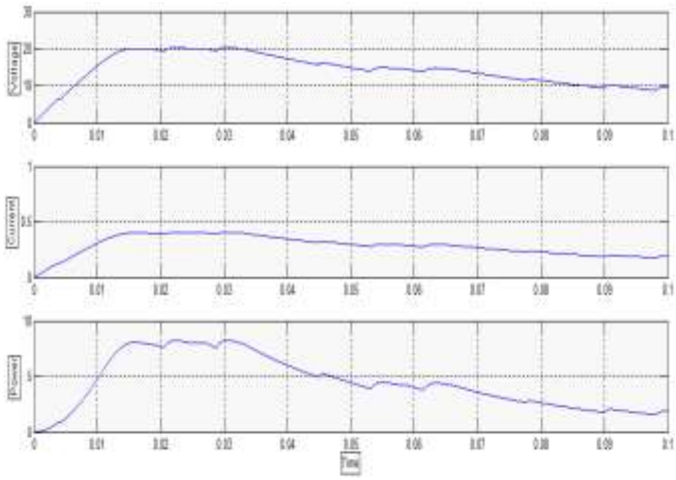

Figure 8: Output Voltage, Current and Power waveform at different Top and constant G=1000 W/m^2.

B. Increamental Conductance Method

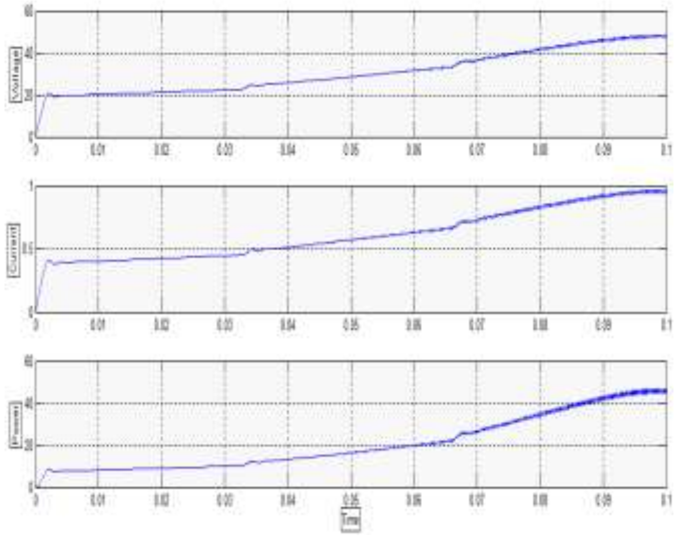

Figure 9: Output Voltage, Current and Power waveform at different G and constant Top=25^{o}C.

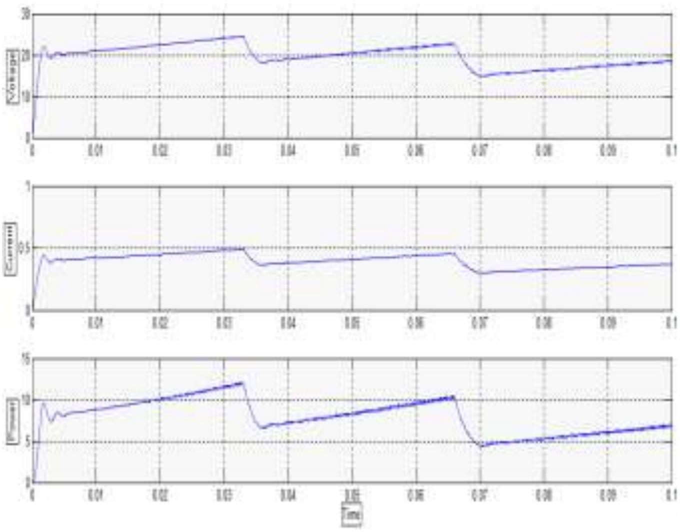

Figure 10: Output Voltage, Current and Power waveform at different Top and constant G=1000 W/m^2.

C. *Fractional Open Circuit Method*

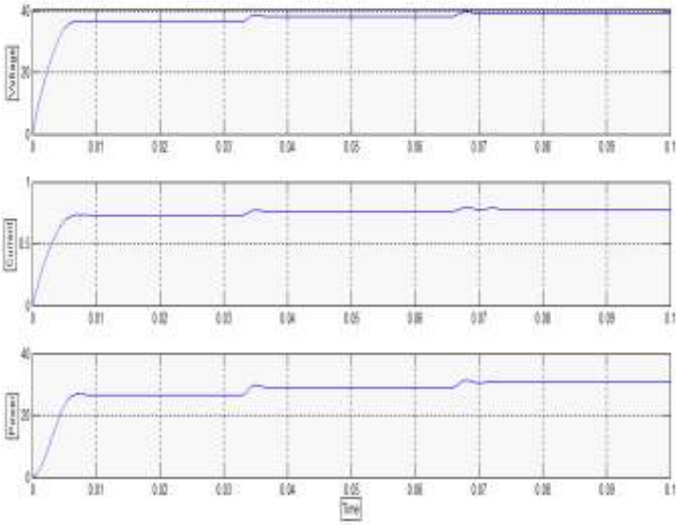

Figure 11: Output Voltage, Current and Power waveform at different G and constant Top=25^{o}C.

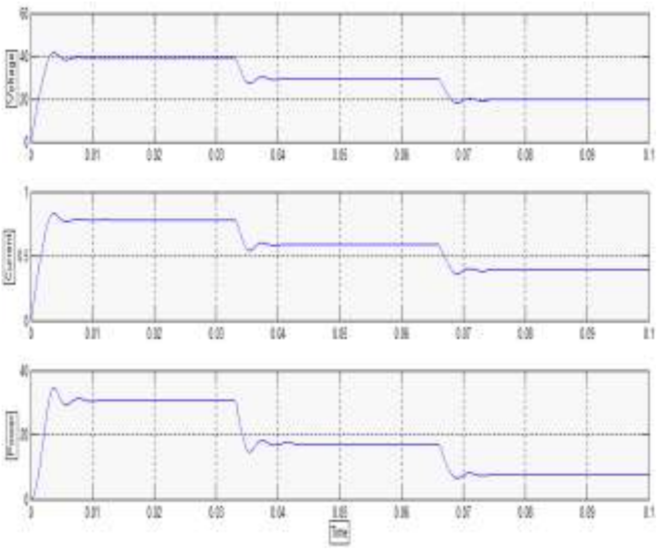

Figure 12: Output Voltage, Current and Power waveform at different Top and constant G=1000 W/m^2.

D. *Fractional Short Circuit Method*

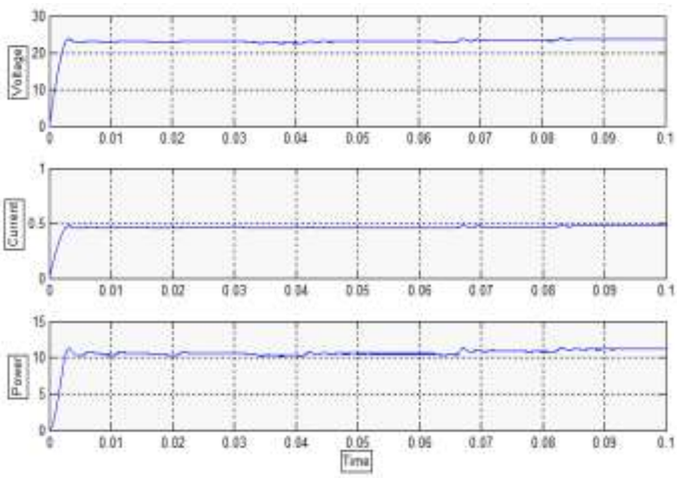

Figure 13: Output Voltage, Current and Power waveform at different G and constant Top=25^{o}C.

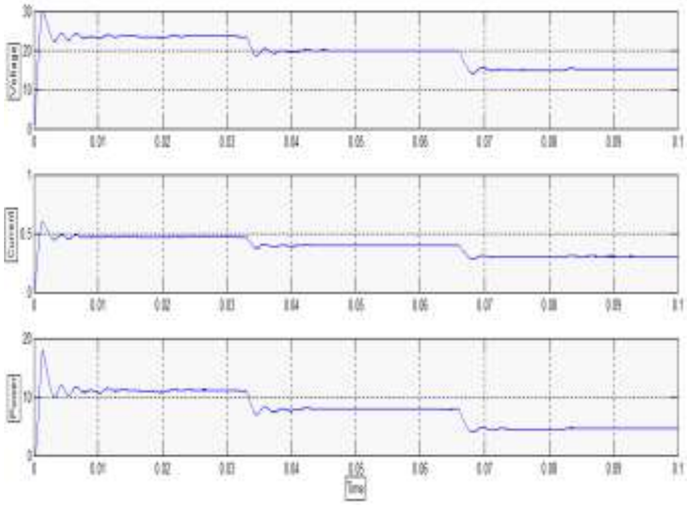

Figure 14: Output Voltage, Current and Power waveform at different Top and constant G=1000 W/m^2.

TABLE I. COMPARISION OF DIFFERENT MPPT TECHNIQUES

MPPT Techniques	Parameters		
	Convergence Speed	***Implementation Complexity***	***Sensed Parameters***
P&O Method	Varies	Low	Voltage
INC Method	Varies	Medium	Voltage, Current
Fractional Isc Method	Medium	Medium	Current
Fractional Voc Method	Medium	Low	Voltage

E. *Cost comparison*

To complete our analysis a simple discussion about the cost of the MPPT technique is presented. Some applications need accurate MPPT and cost is not an issue, such as, solar vehicles, industry, large-scale residential. But some systems like small residential applications, water pumping for irrigation, etc., need a simple and cheap MPPT technique. Expensive applications generally use advanced and complex circuitry because accuracy and fast response are main priorities there.

The number of sensors required to implement the MPPT technique also affects the final costs. Most of the time, it is easier and more reliable to measure voltage than current and the current sensors are usually more expensive and bulky. The irradiance or temperature sensors are very expensive and uncommon. So Fractional short circuit current, Fractional open circuit voltage are the cheapest methods because it require only one sensor and does not require microcontroller for its implementation. Whereas P&O is costly than these two. INC is the most costlier method to implement because it require two sensors and it has more complex circuitry.

VI. CONCLUSION

In this paper, four MPPT Algorithms are implemented using Boost converter. The models are simulated using

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MATLAB/SIMULINK. It is shown that PV system output power increases with rise in solar irradiance and fall in cell temperature. Therefore, solar cell performance better in winter season than summer. Implementation of Fractional open circuit voltage, Fractional short circuit current are easy but its efficiency is poor whereas P&O and INC MPPT has better efficiency. INC MPPT gives more accurate value of power but its implementation is sometimes more complex. Hence MPPT implementation has the great future in renewable power generation.

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