Comparative Analysis of MPPT Techniques for Boost Converter Control in Solar Photovoltaic System

Naveen Kumar*, [1] and Ashok Kumar Pandey*

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Abstract – *These days, it's rather usual to employ MPPT (Maximum power Point Tracking) approaches to get the most electricity possible out of a solar panel. The paper presents four techniques employing MPPT, i.e. P&O (Perturb & Observe), InC (Incremental Conductance), Hill Climb and Modified P&O technique. The boost converter along with all four MPPT techniques are described and simulated for comparative analysis based on output power of PV panel, ripples, settling time, overshoot and undershoot. The simulation results conclude that among all the for MPPT techniques discussed the Hill Climb technique reduces the ripples and overshoots but can't extract maximum power so the best is Modified P&O technique because it utilizes the solar panel to get maximum power with less ripples.*

Keywords – MPP (Maximum Power Point), InC, HC, P&O, Modified P&O.

1. INTRODUCTION

Renewable energy sources are gaining popularity due to their vast availability and pure nature, as traditional generating stations put a strain on fossil fuel reserves. Photovoltaic solar energy (PV) is the most widely used renewable energy source, with ongoing research aimed at making it the primary source of electricity for the grid [1]. PV cells are parts that use a mechanism known as the "photovoltaic effect" to directly transform solar energy into electricity. In the photovoltaic sector, the output properties of PV cells have taken on significant importance. In order to optimize the energy output and maximize its effectiveness, photovoltaic cells must always operate at their maximum power point (MPP) [2].

The efficiency of variable sources of energy, like photovoltaic (PV) systems, turbines for wind power, and optical electricity transmission, is increased by the use of maximum power tracking (MPPT) techniques. Based on their tracking algorithms, MPPT approaches may be divided into three groups: optimization, intelligent, and classical [3]. Several widely used MPPT approaches are P&O (Perturb & Observe), InC (Incremental Conductance), HC (Hill Climb) and Modified P&O Technique.

This paper presents the comparison among the four types of MPPT Technique discussed above for boost converter control in solar photovoltaic (PV) system. The comparison will be done on the basis of power output of PV solar panel, ripples content in it, overshoot, undershoot, slew rate and settling time. The simulation study was performed to find the best among all these MPPT techniques.

*Madan Mohan Malaviya University of Technology, Gorakhpur, 203010, India

[1]Corresponding author;
Tel: + 91 8860503650.
E-mail: nk26081998@gmail.com.

2. SOLAR CELL (PV) MODEL

In essence, A P-N junction semiconductor, the PV generator generates power by directly converting solar radiation into electrical current. In Fig. 1, an equivalent circuit is displayed.

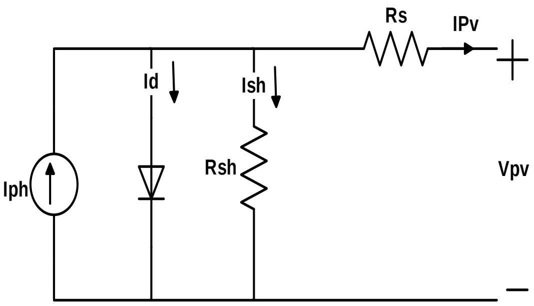


Figure 1. Solar cell model.

A solar cell's voltage–current characteristic equation is given as follows: Photo-current module I_{ph}:

$$I_{ph} = [I_{SC} + K_i(T - 298) * I_r/1000 \quad (1)$$

I_{ph} in this case: photovoltaic-current (A); T is operation temperature (K); I_{sc} is the current (short circuit) (A); K_i is the cell's current (short circuit) at 1000 W/m2 and 25 °C; Sunlight irradiation, or I_r (W/m2). Current I_{rs} for module reverse saturation:

$$I_{rs} = I_{SC}/[\exp(qV_{OC}/N_S knT) - 1] \quad (2)$$

Here, k is Boltzmann's constant; N_s is the number of cells linked in series; n (ideality factor of the diode); and q (electron charge), which is 1.6×10^{-19}C and V_{oc} is open circuit voltage.

The module saturation current is influenced by the cell temperature, which is defined by I_0:

$$I_0 = I_{rs}\, [T/T_r]^3 \exp\left[\frac{q*E_{go}}{nk}\left(\frac{1}{T} - \frac{1}{T_r}\right)\right] \quad (3)$$

Where, T_r stands for temperature (nominal) (298.15 K), E_{g0} for semiconductor for energy gap (band) (1.1 eV), and the P V (Photovoltaic) module's output current is:

$$I = N_P * I_{ph} - N_P * I_0 * \left[exp\left(\frac{V/N_S + I*R_S/N_P}{n*V_t}\right) - 1\right] \quad - I_{sh} \qquad (4)$$

With

$$V_t = \frac{k*T}{q} \qquad (5)$$

And

$$I_{sh} = \frac{V*N_P/N_S + I*R_S}{R_{sh}} \qquad (6)$$

Where: N_p: the quantity of PV modules (parallel connected); V_t (diode thermal voltage) (V); R_s (series) and R_{sh} (shunt) are the resistances (Ω).

3. SOLAR CELL CHARACTERISTICS

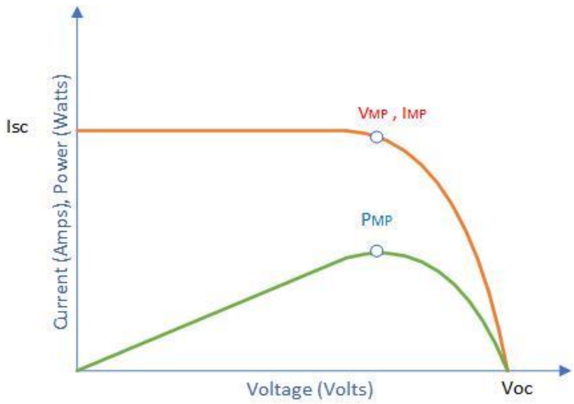


Figure 2. P-V and I-V graph for solar cell model.

Solar photovoltaic cells, sometimes referred to as photovoltaic (PV) solar cells, characteristics is shown which suggests whether they are appropriate for a certain application.

4. MAXIMUM POWER TRACKING APPROACHES

4.1 The Perturb & Observe (P&O) MPPT Approach

The P&O approach is based on varying the duty cycle (step size of perturbation) of a power converter to perturb the array's output PV voltage, and after that monitoring variations in the array's power output. If ΔPo is positive, we are approaching the maximum panel power and the perturbation needs to be done in the same direction. On the other hand, the perturbation needs to be done in the opposite sequence if the output power drops. When the **ΔP** is zero, the MPP is attained. Fig. 3 displays the flowchart of the traditional P&O method, where k stands for the interval. The steady-state oscillations will have a big amplitude. Additionally, tracking is slower and a slight oscillation will still be seen if the step size is tiny. The principal flaw in the P&O algorithm is its constant oscillation around the MPP. Sadly, this obstacle is audacious as it results in energy losses [4].

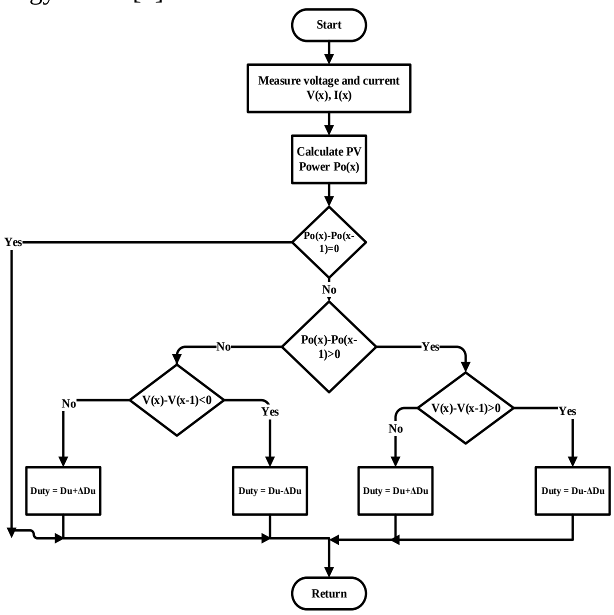


Figure 3. P&O Algorithm (Flowchart).

4.2 Modified Perturb & Observe (P&O) MPPT Method

Excellent precision as well as quick dynamic response in the steady state are two performance requirements that the standard P&O algorithm is unable to meet simultaneously. This is because, in the steady state, if the step-size is chosen big enough to provide a quick dynamic reaction, there will be a rise in oscillations at the maximum-power operational point., leading to decreased power output. The goal of the new approach is to find a practical means of improving the performance of both steady state dynamics and stable state dynamics. Fig. 4 explains the new method's basic idea.

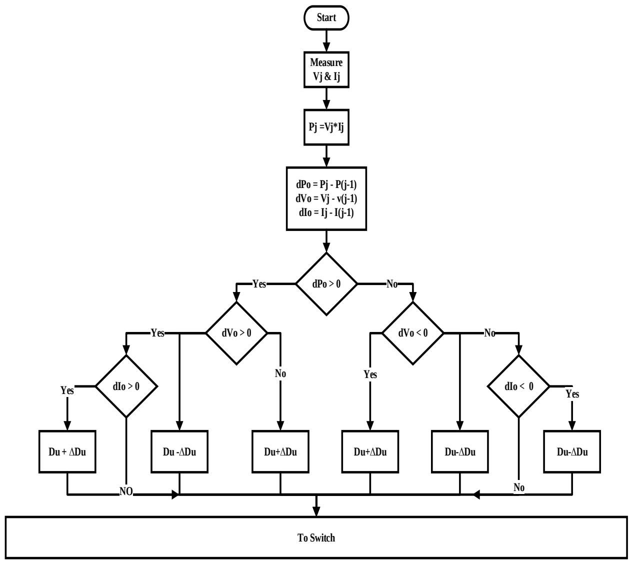


Figure 4. Modified P&O MPPT Algorithm (Flowchart).

4.3 Incremental Conductance MPPT Method

This MPPT approach tracks the power output (maximum) from a photovoltaic panel and maintains that power under various input environment circumstances. If a PV panel is not equipped with MPPT, it will produce an unsatisfactory and wasteful quantity of electricity. The MPPT serves as a controller, regulating the total output power of the photovoltaic system. The IC algorithm is used here. Both instantaneous conductance of approach (I/V) and incremental conductance of approach (dI/dV) may be calculated using this method [5]. Fig.5 explains the idea by flowchart.

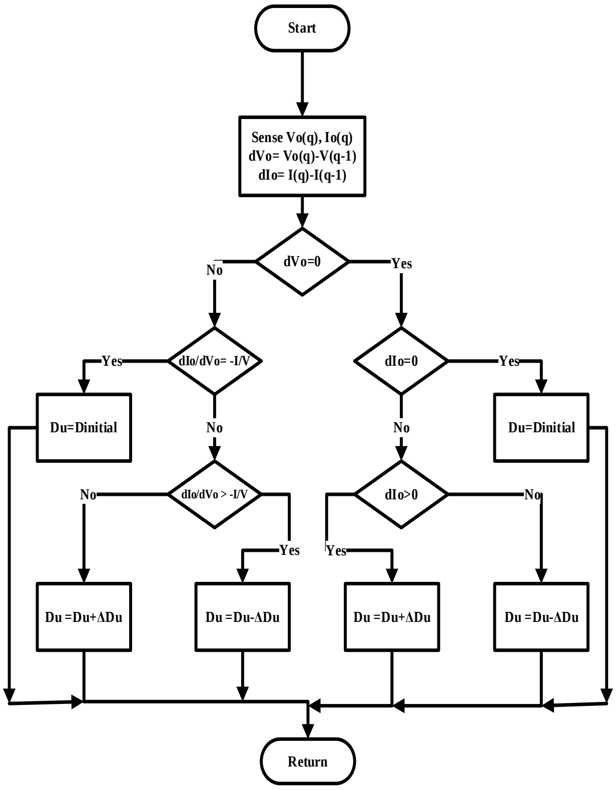


Figure 5. Incremental Conductance MPPT Flowchart.

Equations supporting flowchart:

$$\frac{dI}{dV} = -\frac{I}{V} \quad \text{On Point of Maximum Power} \tag{7}$$

$$\frac{dI}{dV} > -\frac{I}{V} \quad \text{Maximum Power Point (Left side)} \tag{8}$$

$$\frac{dI}{dV} < -\frac{I}{V} \quad \text{Maximum Power Point (Right side)} \tag{9}$$

4.4 Hill Climb MPPT Method

The hill climbing algorithm is a popular choice in real-world photovoltaic systems due to its ease of use, lack of need for source characteristic modelling or research, and ability to take into account drift in characteristics brought on by ageing, shadowing, or other operational abnormalities. First, the voltage (V(q)) and current (I(q)) of the PV array are measured. In light of this, the produced output power (P(q)) may be calculated and compared to its value from the previous iteration. Based on the comparison's outcome, the sign of a "slop" can either be supplemented or left unaltered, and the PWM output duty cycle can be adjusted as necessary. Fig. 6 depicts the method for climbing hills.

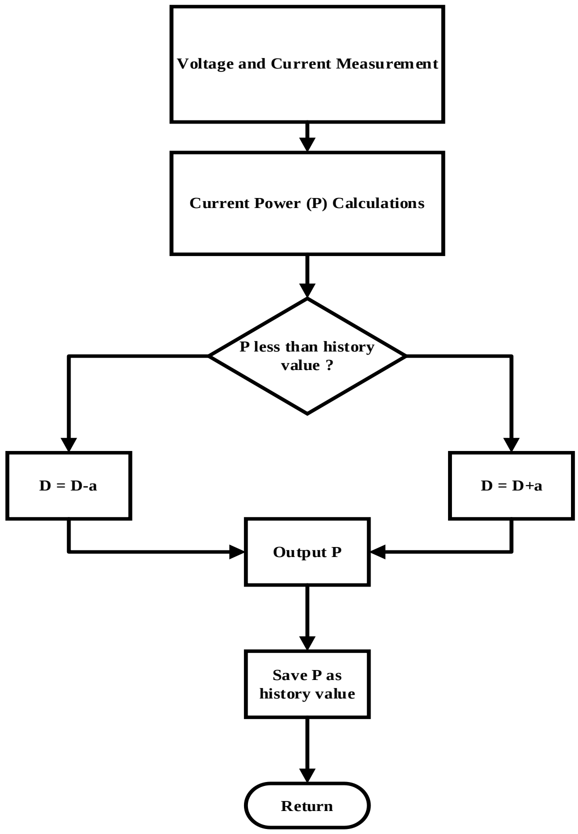


Figure 6. Hill Climb MPPT Technique.

4.5 Solar PV Characteristics

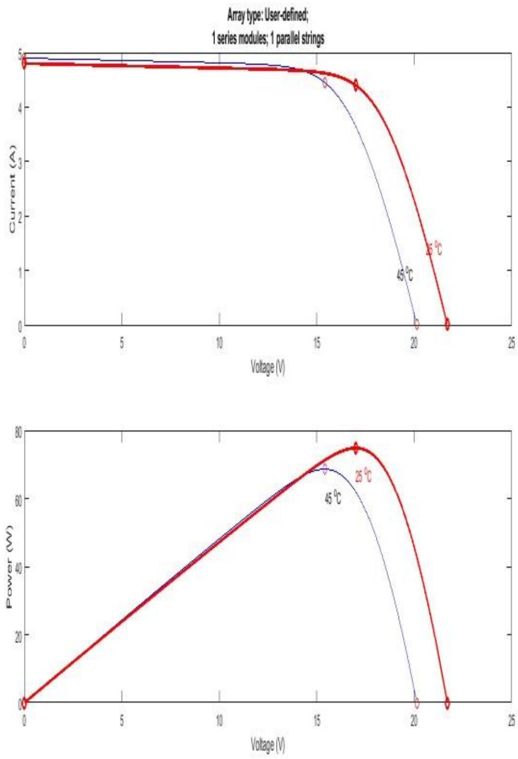


Figure 7. Solar panel characteristics graph.

5. SIMULATION MODELS FOR DIFFERENT MPPT TECHNIQUES

5.1 Simulation Model using P&O

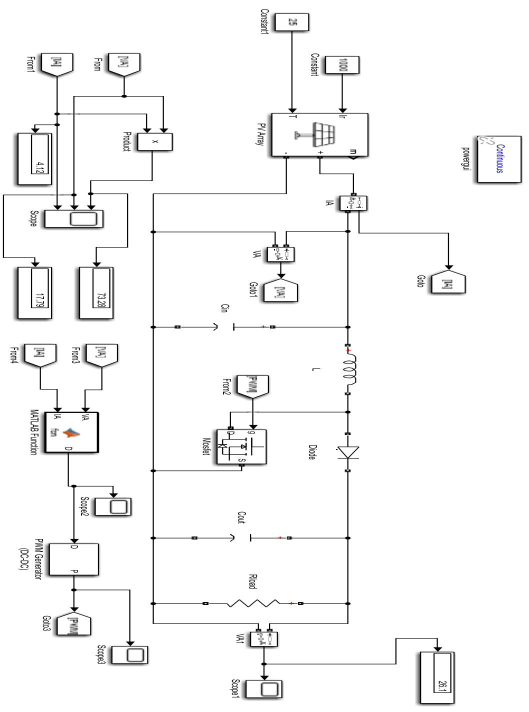
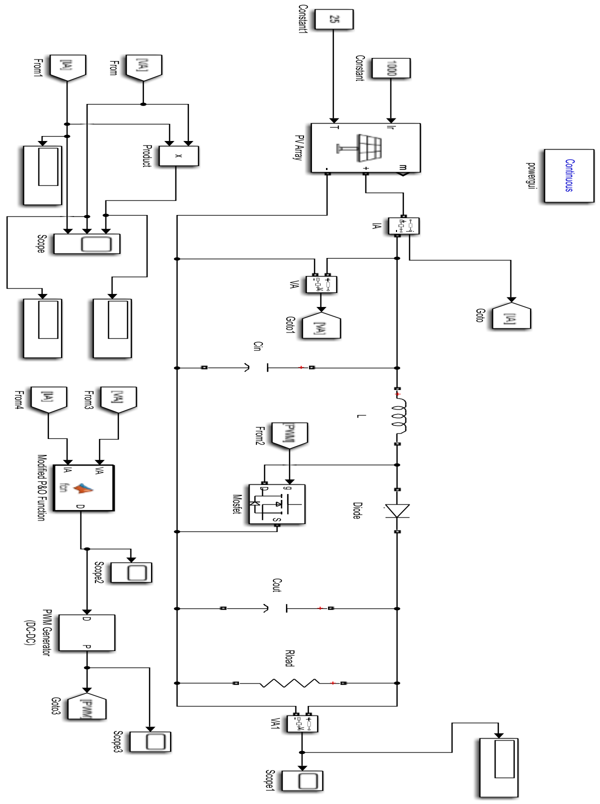


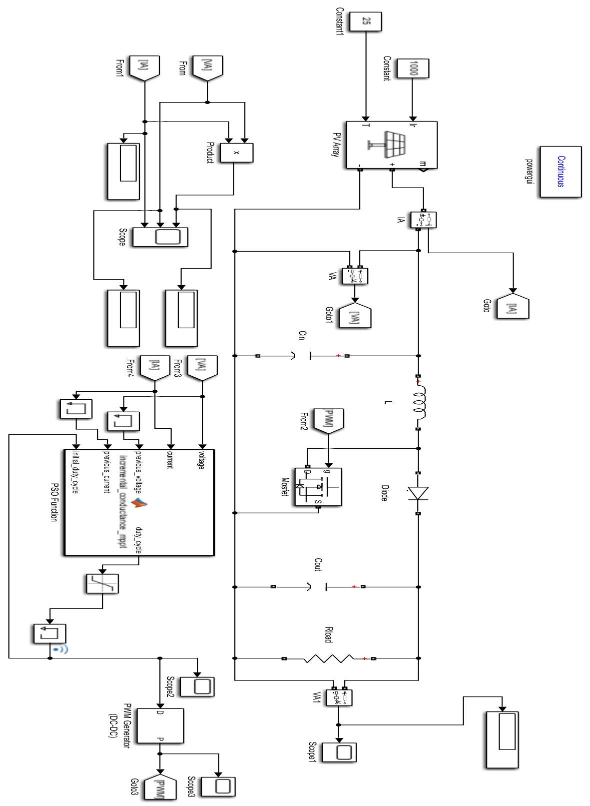
Table 1. Solar panel specifications.

Particulars	Specifications
Maximum power of PV panel (Pmpp)	75W
Voltage of PV panel (Vmpp)	17V
Current of PV panel (Impp)	4.4A
Open circuit voltage of PV panel (Voc)	21.7
Short circuit current of PV panel (Isc)	4.8A.

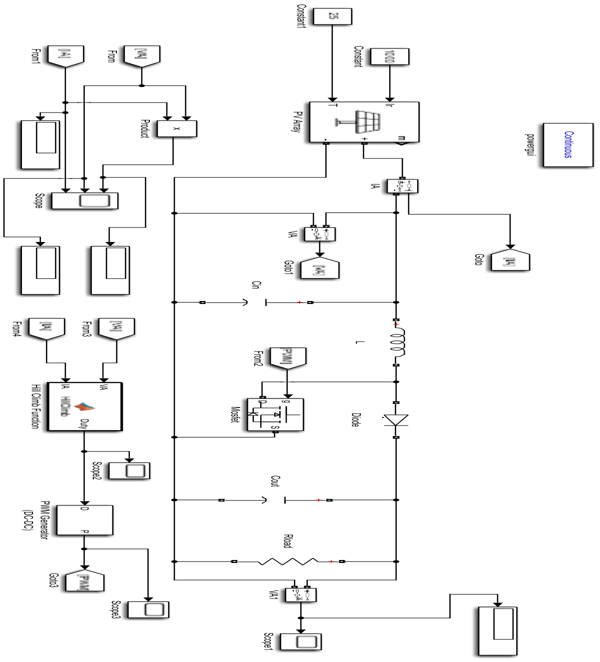
5.2 Simulation Model using Modifies P&O



5.3 Simulation Model using InC



5.4 Simulation Model using HC



6. RESULTS AND DISCUSSION

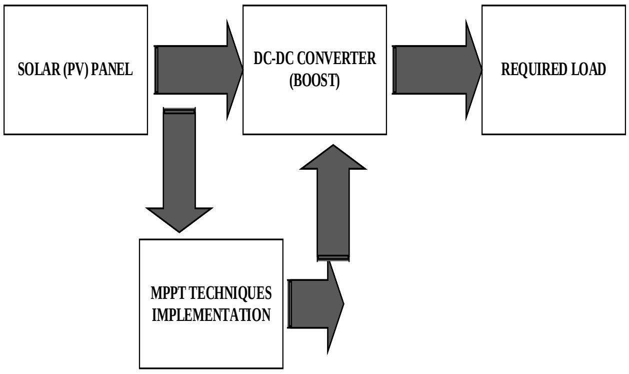


Figure 8. PV Panel coupled with MPPT coding.

6.1 Simulation Result by P&O MPPT

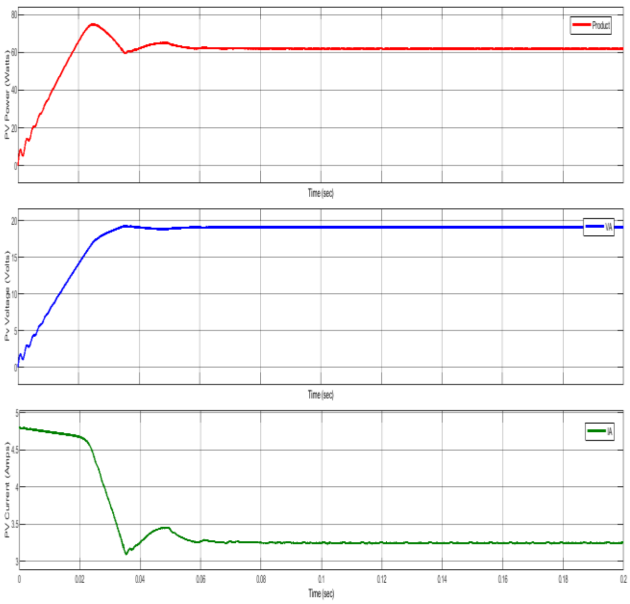


Figure 9. Output PV Power, PV Voltage and PV Current of Solar Panel by P&O.

The graph shows that the peak overshoot is high for PV output power when compared to the other methods. The drop in the PV current was also rapid.

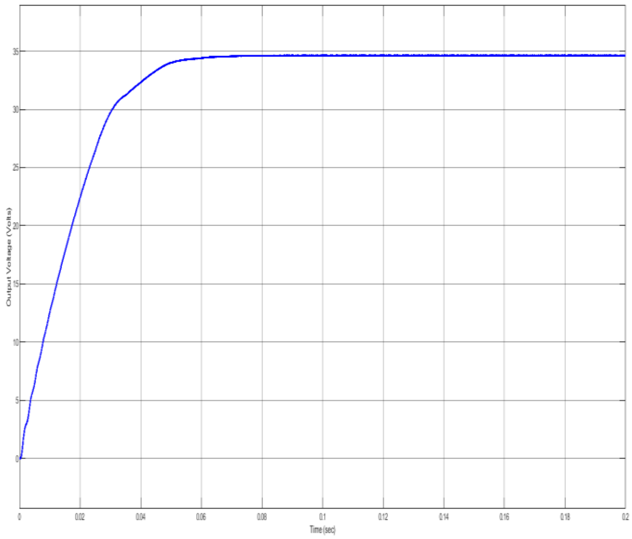


Figure 10. Output Voltage of Boost Converter using P&O

6.2 Simulation Result by InC MPPT

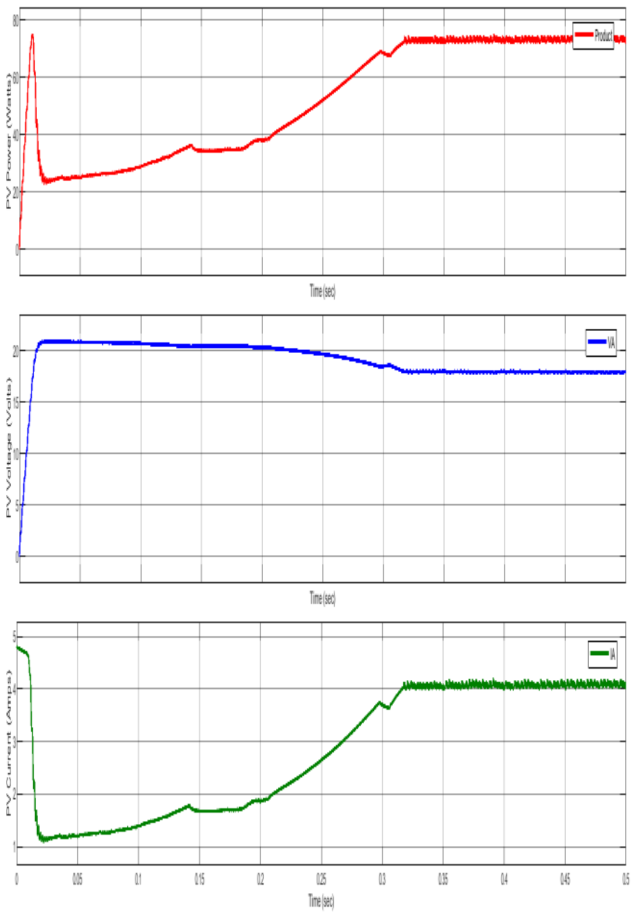


Figure 11. Output Power, Voltage and Current of Solar Panel by InC

There is a much time delay in settling time of the PV output power. Also, the PV voltage decreases a little with time affecting the performance of the solar panel energy delivery.

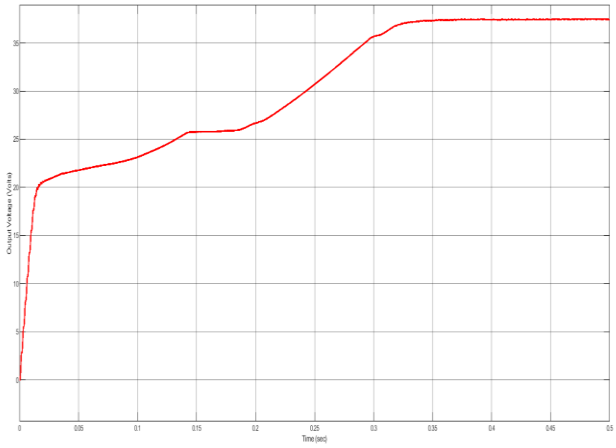


Figure 12. Output Voltage of Boost Converter using InC.

6.3 Simulation Result by Hill Climb MPPT

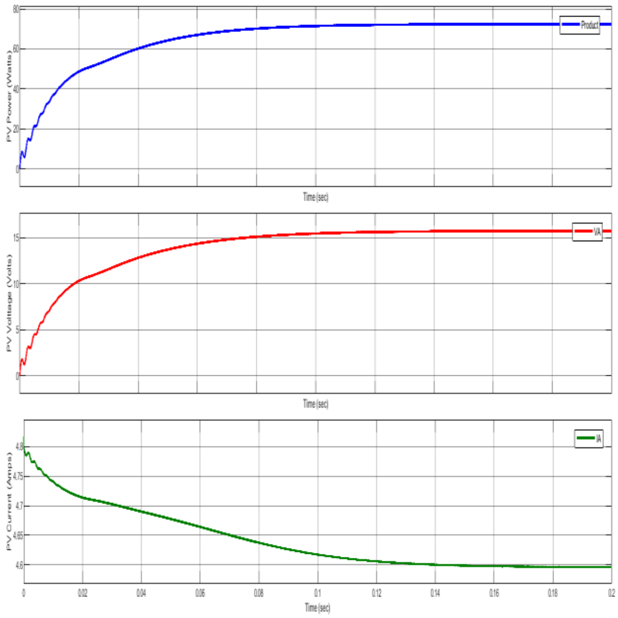


Figure 13. Output Power, PV Voltage and PV Current of Solar Panel by HC.

In the above graph it can be clearly seen that it is the smoothest graph among all with very little disturbances. The settling time is high compared to others.

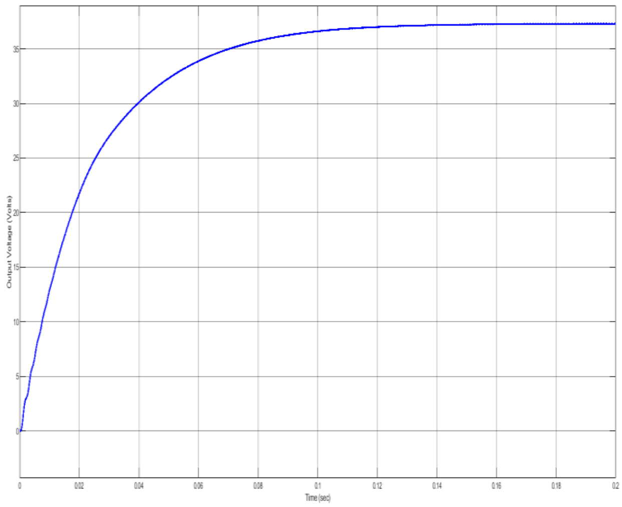


Figure 14. Output Voltage of Boost Converter using HC.

6.4 Simulation Results by Modified P&O

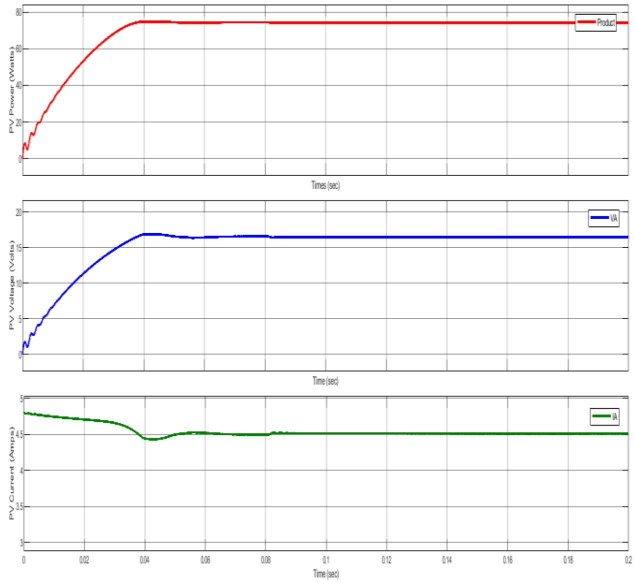


Figure 15. Output Power, Voltage and Current of Solar Panel by Modified P&O.

It is evident from all the graphs as well as numerical values that it is the best method compared to others in terms of overshoot, undershoot, peak time, settling time and others.

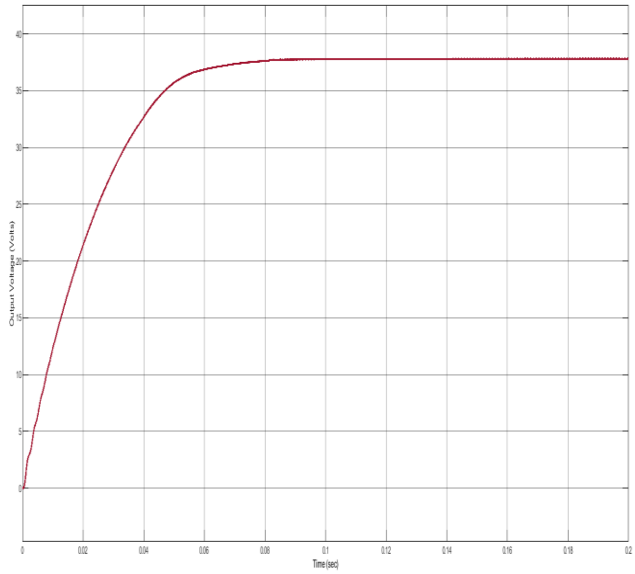


Figure 16. Output Voltage of Boost Converter using Modified P&O

7. CONCLUSION

This study employs four different MPPT techniques to regulate the boost converter's duty cycle. The MATLAB/Simulink platform is used to run simulation circuits of the photovoltaic (PV) system in order to assess the viability of the suggested MPPT strategies. Fig. 7 depicts a PV system with an MPPT controller, a pulse width modulation (PWM) generator, and a boost converter.

The table containing different parameters which is used to differentiate and compare each MPPT technique to determine that which MPPT technique is best that can reduce ripples, settling time as well as can operate the solar panel at MPP is shown below:

Specified Parameters	P&O	InC	HC	Modified P&O
PV Output Voltage (Volts)	19.7	17.95	15.76	16.46
PV Output Current (Amps0	3.252	4.038	4.596	4.511
PV Output Power (Watts)	62.11	72.49	72.43	74.28
Output Voltage of Boost Converter (Volts)	34.65	37.46	37.32	37.83
Overshoot (%)	27.344	6.633	2.545	0.685
Undershoot (%)	4.583	2.003	0.977	1.995
Slew Rate (/ms)	3.097	4.032	2.245	1.860
Settling Time (sec)	0.08	0.32	0.123	0.0188

According to the above table it is evident that the traditional P&O technique of MPPT has the worst performance amongst the four techniques but faster response.

The peak overshoot is very high, i.e.,27.344 % for traditional P&O MPPT whereas for Modified P&O the overshoot comes down to 0.685 %. Also, the HC and InC MPPT techniques lies within the P&O and Modified P&O in terms of overall comparative parameters.

The simulation results conclude that among all the for MPPT techniques discussed the Hill Climb technique reduces the ripples and overshoots but can't extract maximum power so the best is Modified P&O technique because it extracts the maximum possible power from the PV solar panel with less ripples and work at MPP, less settling time as well as low peak overshoots and undershoots.

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