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MPPT Based Optimization of Photovoltaic System Using DC-DC Converter

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Abstract

This Paper looks at the performance of photovoltaic system in nonideal conditions that causes multiple maximum power points (MPPs) on the power-voltage (PV) characteristics curve. Since the efficiency of PV-panel is low, advanced power electronics converter are employed to improve the overall system efficiency.In this paper Solar panel is modeled and analyzed in MATLAB/SIMULINK. To get the maximum efficiency and maximum power the entire system must be linked with MPPT technique. Here Perturb & Observe and Incremental Conductance algorithms are compared on the basis of tracking capability and stability under rapidly and gradual changing weather conditions where Inc proved to be better than P&O. Pulse width modulation type DC-DC Boost converter is used for matching load impedance with PV arrays.

***IndexTerms**: Maximum power point tracking (MPPT) Photovoltaic (PV) array, Perturb and observe (P&O), Incremental Conductance (InC), DC-DC Converter*

I. Introduction

With the decrease in conventional energy sources and increase in energy demand, has driven research and development to the alternate energy sources like biomass, wind and sunlight. Among them solar energy is considered as the most promising, since sunlight is present almost everywhere on the earth and thus the photovoltaic (PV) systems are worldwide accepted. [1]

There are basically two types of photovoltaic power system exist, they are 1)Stand-alone system 2)Grid-connected system [2]. The operation of stand-alone photovoltaic systems is independent of the electric utility grid. Grid Connected systems have experienced a large growth, which works parallel with electric utility grid and supply solar power via grid.

The performance of solar cells depends on many parameters such as insolation, temperature and spectral characteristics of sunlight, shading, dust. Thus various methods were proposed to improve the performance among which "maximum power point technique" (MPPT) is accepted. The output of the PV panel depends strongly on the drawn current to load. The operating point of PV array is seldom at maximum power point (MPP) when a photovoltaic array is connected directly to the load. So when DC-DC converter is combined with MPPT technique, the PV generator produces maximum continuous power irrespective of the changing solar radiation and temperature [3]. The techniques for detection of MPPT differ on the basis of performance and implementation, 19 such algorithms are known [4]. Few among them are: Perturb and Observe (P&O), Incremental Conductance (InC), Constant Voltage (CV), Constant Current method, Fuzzy logic Control method and Artificial Neural Networks (ANN) *etc*. [5]. Constant Voltage method is the easiest one that uses the concept that with change in insolation level operating voltage at MPP of PV panel (V_{mpp}) is linearly proportional to open circuit voltage. No costly digital controller or multipliers are need in CV method [6-7].Constant Current method uses the same phenomenon as CV method, current change under varying insolation level. However these methods cannot track the MPP in time when the

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atmospheric condition changes until the next reference time is reached corresponding to new time. These methods are used for small power say a few hundred of watts. On the other hand Fuzzy logic based controller can handle such nonlinearity, as it does not require any accurate mathematical model for implementation. Another technique based on microcontrollers is Artificial Neural Networks (ANN), which consists of three layers namely input layer, hidden layer and output layer. The input layer parameters can be solar irradiance and temperature or V_{oc} and I_{sc} on any combination among them. The output layer is generally the duty signal used to drive the switch-mode converter to system near to MPP [8]. Among these entire algorithms the best algorithms are Perturb and Observe (P&O) and Incremental Conductance (InC). Based on same technology they regulate the PV array voltage by setting the optimized point to represent voltage at maximum power point (MPP). InC algorithm tracks MPP accurately under rapidly changing irradiation level. Details of different model can be found in [9-12].

This paper aims to compare the performance of Perturb and Observe (P&O) and Incremental conductance (InC) algorithm under gradually and rapidly changing insolation levels and temperature , implemented through boost DC-DC Converter. The DC-DC boost converter helps in matching the load impendence with the internal impendence of the panel by adjusting duty ratio provided from MPPT algorithm. The performance of these algorithms is discussed in results.

II. PV PANEL MODELING AND CHARACTERSTICS

A PV module is formed by the combination of many cells connected in parallel or series manner to provide the desired voltage and current [13]. Figure 1 shows the equivalent circuit model of PV cell.

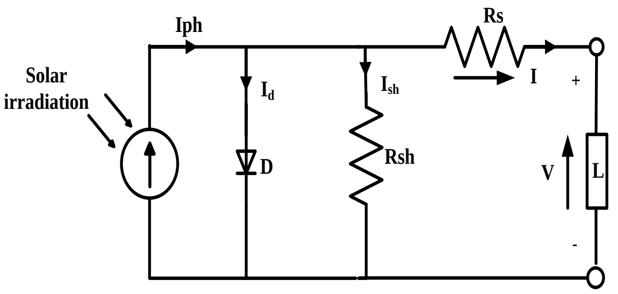


Figure 1. Single Diode Model of a Pv Cell

The basic solar cell equation that mathematically describes the I-V characteristics is given in eq. (1) [14-15]

$$I = I_{ph} - I_o[e^{\frac{q(V+IR_s))}{A.k.T}} - 1] - \frac{V+IR_s}{R_{sh}} \quad (1)$$

Where, I_{ph} is the module photo-current depends on operating temperature and solar irradiance and is given by eq. (2)

$$I_{ph} = \frac{S}{1000}\left[I_{scr} + K_i\left(T - T_{ref}\right)\right] \quad (2)$$

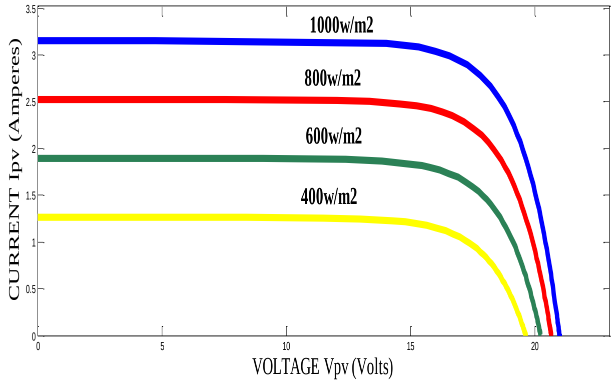
Here, I_{scr} is short circuit current at reference temperature of 25^{0}C and solar irradiance (S) of 1000W/m2, K_i is the temperature coefficient of cell, T and T_{ref} is the operating and reference temperature respectively in Kelvin (K).

The Io represents diode saturation current or holding current, it is thermally generated; depend on temperature as given in eq. (3)

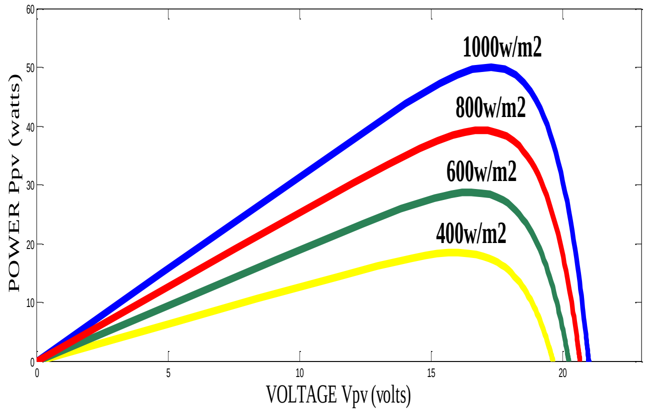
$$I_o = I_{rs}\left(\frac{T}{T_{ref}}\right)^3 \exp\left[\frac{q.E_g}{A.K}\left(\frac{1}{T_{ref}} - \frac{1}{T}\right)\right] \qquad (3)$$

I_{rs} is the cell reverse saturation current in ampere (A). $E_g$is the semiconductor's band-gap energy of. q is the electron charge=1.6×10^{-19}C, A is the diode ideality factor or completion factor=1.6.K is the Boltzmann's constant.

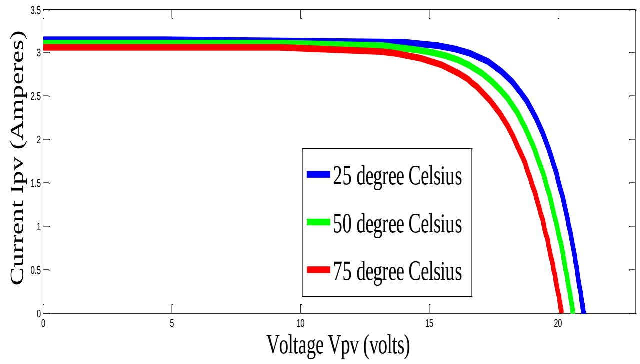
Equation (1) is valid for single diode model. Where R_s is the equivalent series resistance and R_{sh} is shunt resistance. Usually the value of R_{sh} is very large and the value of R_s is small thus they are neglected. Eq. (1) is used to implement the MATLAB/Simulink model. The output I-V and P-V characteristics has been plotted at different insolation level and temperature conditions as shown in Figure 2



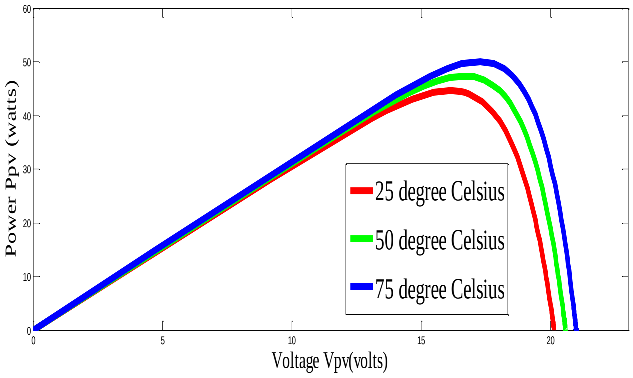
(a)



(b)



(c)



(d)

Figure 2. Simulated IV and PV Characteristics of Solar Panel (a) and (b) at Different Insolation Level, (c) and (d) at Different Temperature Level

III. DC-DC CONVERTER

The basic function of any switch mode DC-DC converter, in any PV system, as an intermediate power processor is that it changes the current and voltage level such that maximum power can be extracted from PV array [16].Changing voltage and current levels is nothing but converting a given fixed load to a variable load. The connected load may be of stand-alone sink type, battery, up-stream converters or combination of these.

The analysis is carried out under the following assumptions:

1) Switching elements (MOSFET and Diode) of the converter are assumed to be ideal.

2) The stray capacitance and equivalent series resistance of the capacitance are considered.

3) Passive components of the converter (R, L, and C) are assumed to be linear, time invariant and frequency independent.

4) Converter operation is assumed to be operating in continuous inductor current mode of operation.

Figure 3: shows the block diagram implementation of MPPT using Boost converter. A boost converter can also be called as the step-up converter because the DC voltage output is higher than the DC voltage input [19].

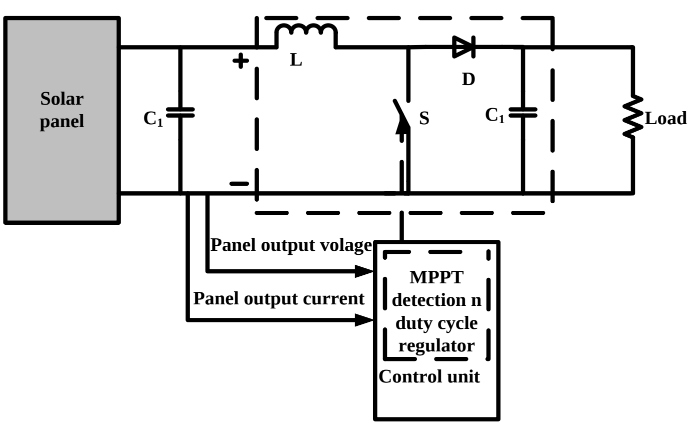


Figure 3. Solar Panel with DC-DC Converter for MPP Tracking

Its basic function is to adjust its input current and voltage level by changing the duty ratio. For this the converter replaces the constant load by an equivalent load that corresponds to the effective load value of the photovoltaic array where it can deliver maximum power to the load. MPPT condition depends mainly on 1) nature of load present on the converter, 2) nature of converter used etc [17].

Fundamental relationship among different voltage and current is shown in eq. (3) and (4) and reflected load across the solar panel is given by eq. (5)

$$V_{in} = V_o(1-D) \quad (3)$$

$$I_{in} = \frac{I_o}{\eta(1-D)} \quad (4)$$

$$\frac{V_{in}}{I_{in}} = R_{eq} = \eta R(1-D)^2 \quad (5)$$

Where, I_{in} and V_{in} are the input current and voltage (i.e. Solar panel output current and voltage), D is the duty ratio, η is the efficiency and V_o and I_o are the output voltage and load current of the converter. The intersection of current-voltage (I-V) curve and the load line gives the operating point of directly coupled PV module to the load. The satisfactory condition for boost converter to fulfill MPPT is, the connected load on the converter must be greater than corresponding equivalent maximum power load ($R>R_{mp}$) of PV array. If $R>R_{mp}$ then it is possible to bring down the load to the operating load (R_{mp}) by using duty ratio modulation. If $R<R_{mp}$, then it is not possible to convert provided load into R_{mp}. In ideal case duty ratio ranges between 0 to 1. But practically it is between 0.1 ~ 0.9. Hence by eq. (5) corresponding equivalent load should be in the range of

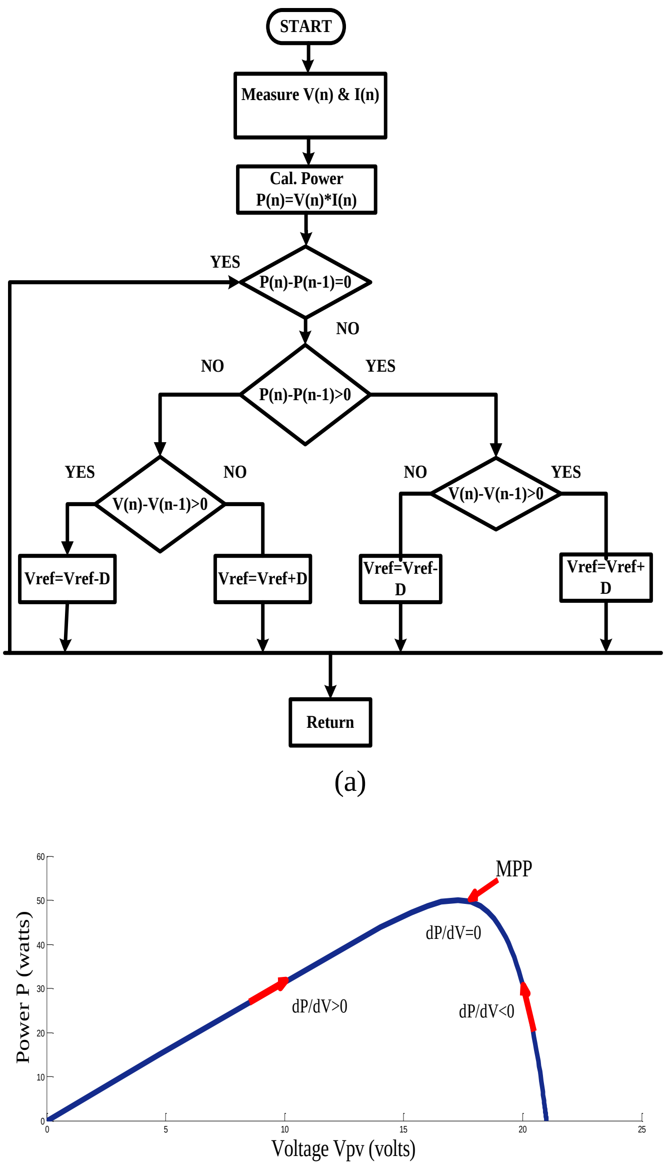
$$1.234R_{mp}<R<100R_{mp} \quad (6)$$

IV. MPPT ALGORITHM

According to maximum power transfer theorem, when the Thevenin impedance of the circuit matches with the load impedance, the output power of the circuit gives maximum power. There are several techniques reported in literature. But this paper P&O and InC Algorithm.

A. Perturb and Observe Control Algorithm

The P&O (also called as hill climbing) algorithms are used widely, because of its simple structure and reduced number of necessary measured parameters [20]. The flow chart of P&O algorithm is given in Figure 4 (a) and movement of operating point in the process of MPP identification is given in Figure 4 (b).



(a)

(b)

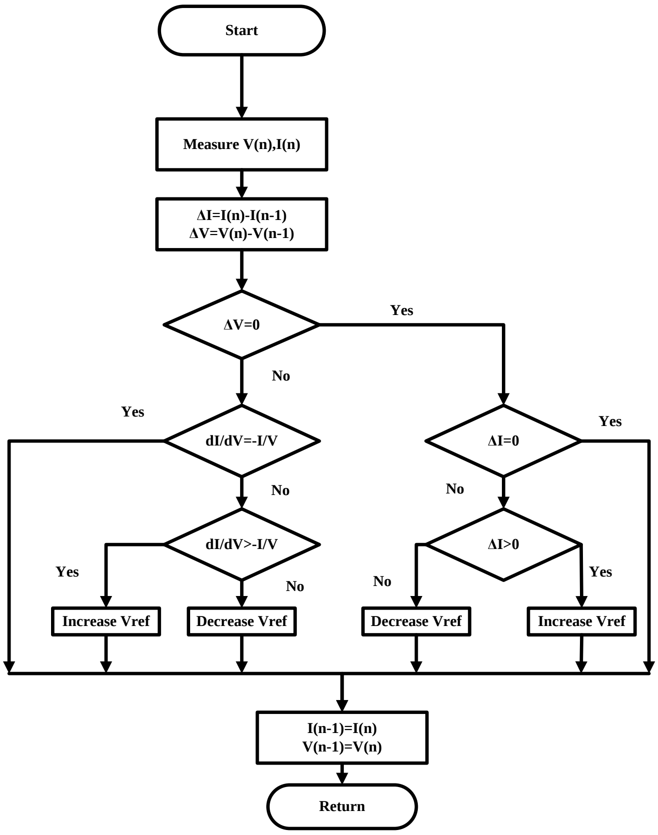
Figure 4. (a) Perturb and Observe Algorithm Flow Chart and (b) Principle of P&O on PV Characteristics

The steps involved in the MPPT realization are: 1) identifying the direction of operating point, 2) identifying the sign of incremental power, 3) comparing the present operating point with that of maximum power point using power band constraint [16]. If the present operating power is to the left of MPP, the power varies against voltage as dP/dV>0 and if it is to the right side as dP/dV<0. If dP/dV>0 along with small perturbation in operating voltage then that perturbation moved the panel's operating point towards the MPP and the algorithm continue to perturb the PV panel voltage in the same direction. If dP/dV<0 then perturbation in voltage changes in operating point moved away from the MPP. In this situation the algorithm reverses the direction of the perturbation. At steady state algorithm oscillates around the peak point. Thus there occurs some power loss due to this perturbation under fast varying atmospheric condition [15].

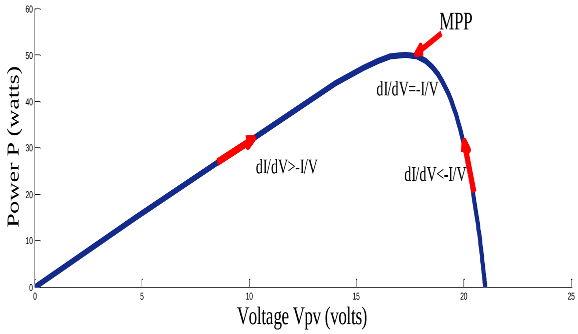
B. Incremental Conductance Control Algorithm

The InC Algorithm was developed to overcome the drawbacks of P&O algorithm under rapidly changing weather conditions. It uses the information of source voltage and current to find the desired operating point. From the P-V curve of a PV module it is clear that slope is zero at maximum point which means that the sum of the Instantaneous Conductance (I/V) and incremental conductance (dI/dV) equals zero Figure5. On the right-hand side of the MPP, the sum of thr instantaneous and incremental conductance is negative, while on the left-hand side of the MPP, the sum is positive. The InC algorithm compares the instantaneous conductance of a PV generator with its incremental conductance and decides whether to increase or decrease a control parameter accordingly. [21]. The condition in the flowchart (Figure5 (a)) to keep the control parameter constant when dI/dV=-I/V. This condition can be achieved only when thw weather conditions are stationary and change in array voltage tends to zero [18-22].

According to the principle of algorithm, increase the reference voltage (or decrease in the duty ratio) if the operating point is to the LHS of the MPP and decreases the reference voltage (or decrease the duty ratio) otherwise. Figure 5(a) shows the flowchart of InC algorithm and Figure5 (b) shows the principle of operation of the InC algorithm.



(a)



(b)

Figure 5. (a) Incremental Conductance Flow Chart and (b) Principle of InC on PV Characteristics

V. RESULTS AND DISCUSSION

The Matlab Simulink model of the complete system is shown in Figure 6. The details of the parameter used are summarized in Table.1. All the simulation results for boost converter have been shown. The complexity and simplicity have been derived from literature.

For changing climatic condition analysis the step input and the ramp input are given as input to the solar irradiance terminal. Step input gives the sudden change in insolation from 1000w/m^2 to500w/m^2, whereas for the gradual change ramp signal is used. The initial settling time of P&O is about 0.01 s while the InC takes only 0.003 s for achieving the fixed duty ratio.It clearly implies that InC algorithm is 3 times faster than P&O algorithm. Figure 19 shows that in P&O oscillates around the line of MPP which results in some power loss while in the InC there is no such oscillation. The current, voltage and power response on both the algorithms is shown from Figure 8 to Figure 18.

Table 1. Parameters of PV Module

Parameters	Values
Diode ideality factor, A	1.6
Temperature coefficient, K_i	0.0017A/K
Series resistance of cell, R_s	0.01Ω
Parallel resistance of cell, R_{sh}	1000Ω
Band Energy gap, E_g	1.12eV
Parallel no. of PV modules, N_p	1
Series no. of PV modules, N_s	36
Reference cell temperature, T_{ref}	298 k
Reference Photo current, $I_{ph\ ref}$	3.15 A
Reference solar irradiance, S_{ref}	1000w/m^2 - 500w/m^2

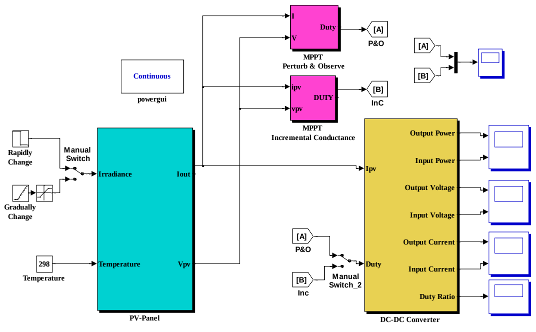


Figure 6. Simulink Block Diagram of Complete PV System

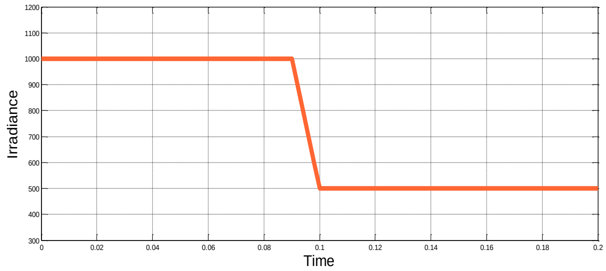


Figure 7. Gradually Changing Insolation from 1000w/m^2-500w/m^2

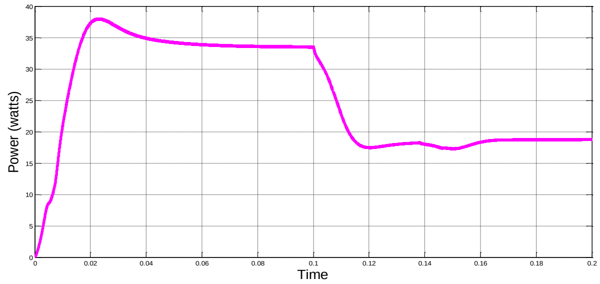


Figure 8. Input Power of Boost Converter for P&O Algorithm

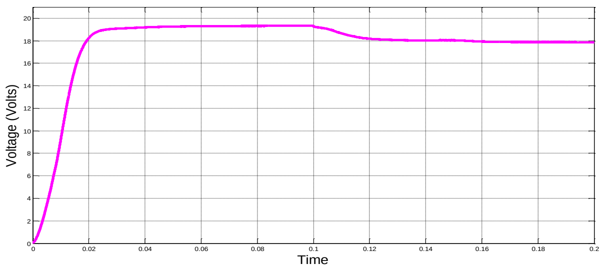


Figure 9. Input Voltage of Boost Converter for P&O Algorithm

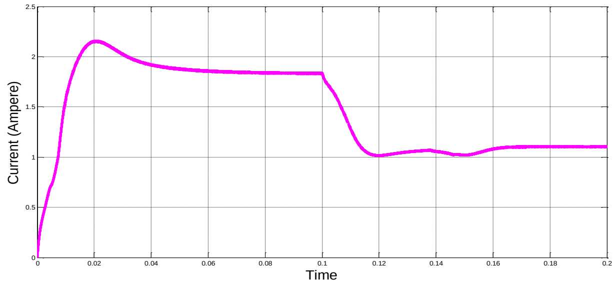
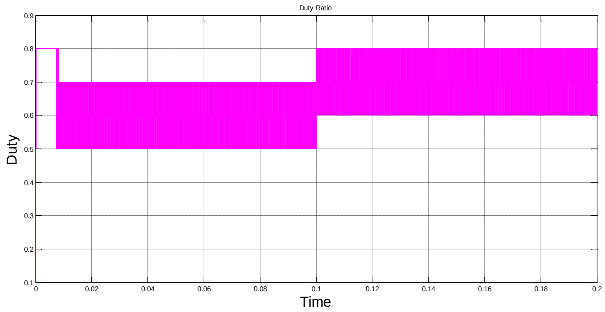
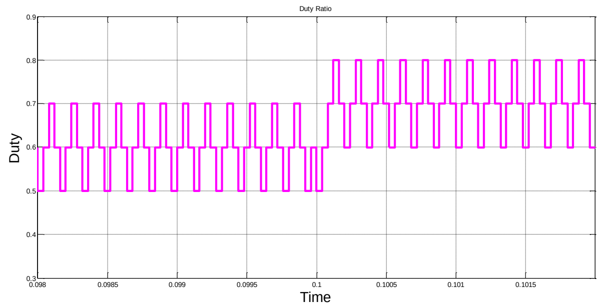


Figure 10. Input Current of Boost Converter for P&O Algorithm



(a)



(b)

Figure 11. (a) and (b) Duty Ratio of P&O Algorithm

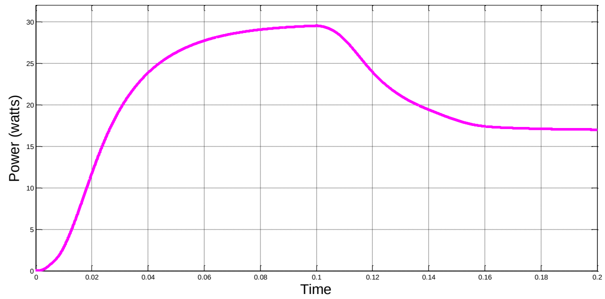


Figure 12. Output Power of Boost Converter for P&O Algorithm

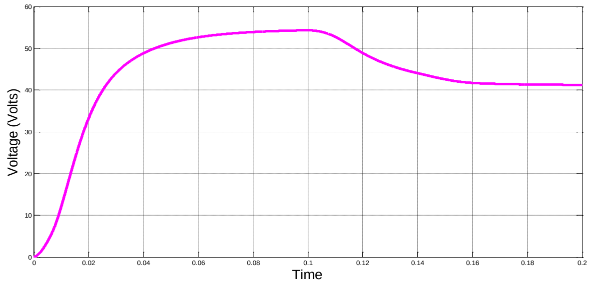


Figure 12. Output Voltage of Boost Converter for P&O Algorithm

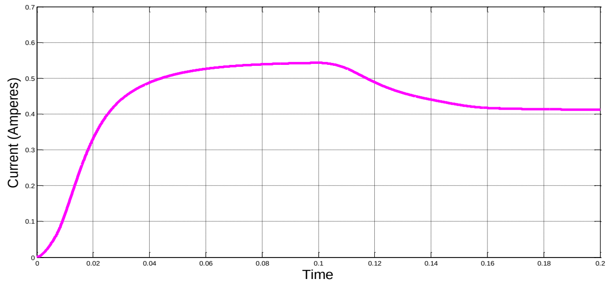


Figure 12. Output Current of Boost Converter for P&O Algorithm

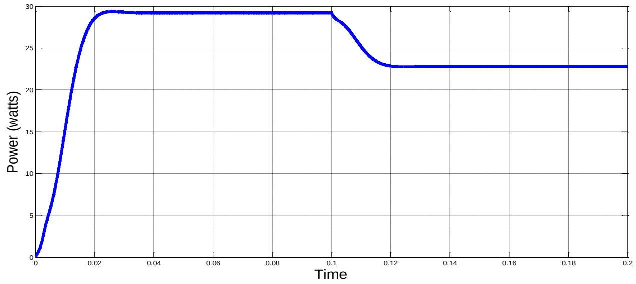


Figure 13. Input Power of Boost Converter for Inc Algorithm

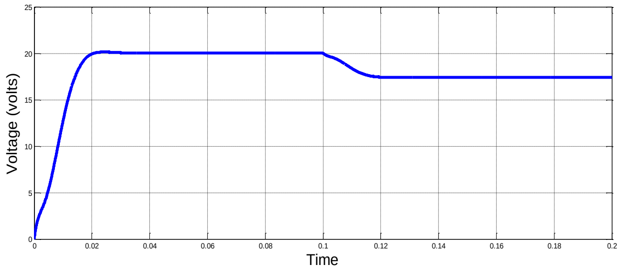


Figure 13. Input Voltage of Boost Converter for Inc Algorithm

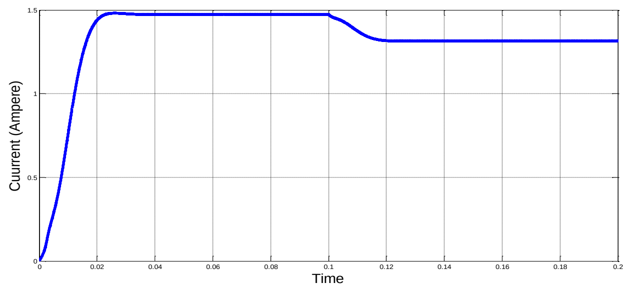
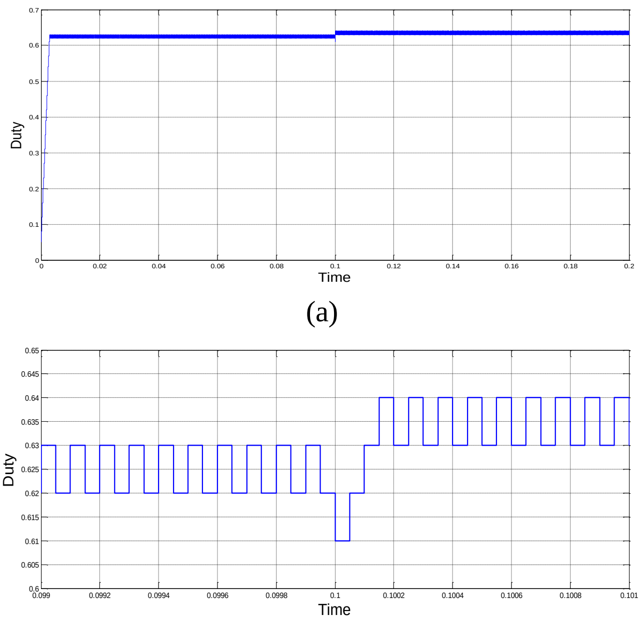


Figure 14. Input Current of Boost Converter for Inc Algorithm



(a)

(b)

Figure 15. (a) and (b) Duty Ratio of Inc Algorithm

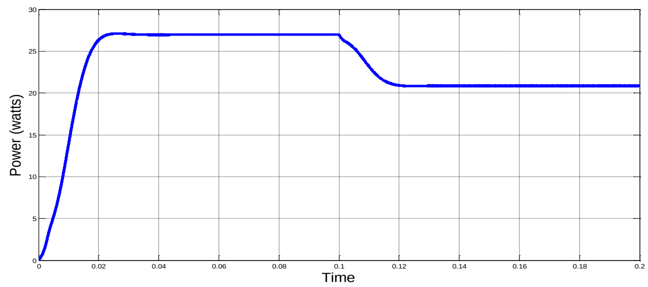


Figure 16. Output Power of Boost Converter for Inc Algorithm

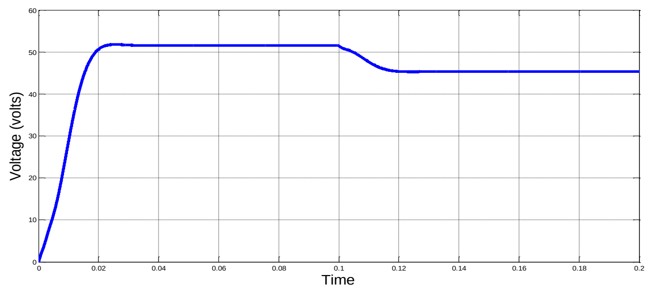


Figure 17. Output Voltage of Boost Converter for Inc Algorithm

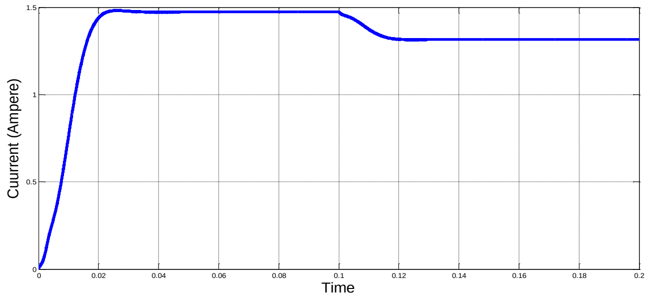


Figure 18. Input Current of Boost Converter for Inc Algorithm

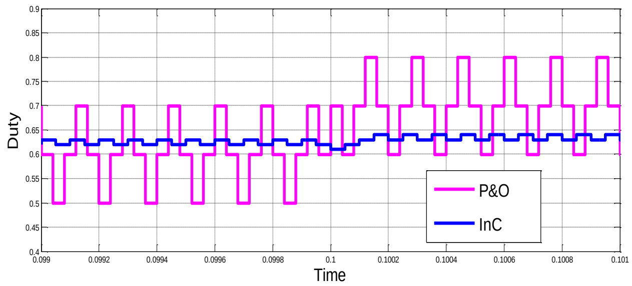


Figure 19. Duty Ratio Oscillation from P&O and Inc Algorithm

VI. CONCLUSION

This paper presents the comparison of two algorithm P&O and InC on a Stand-alone Photovoltaic system has been implemented, through Boost DC-DC converter. The study reveals that P&O algorithm shows oscillations when it reaches to MPP thus it results in power loss, but this is not observed in InC algorithm. InC tracks MPP three times faster than P&O. By giving a suitable fix operating load the Boost converter is capable to track the MPPT at different irradiations. The effect of change in irradiance has been studied and observed that InC algorithm gives satisfactory results.

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