Comparative Analysis of P&O and INC MPPT Algorithms for PV System under Variable Irradiance

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Abstract- Applications of Photovoltaic (PV) panels are increasing day by day in worldwide. Electricity generation through PV panels is one of the best example for utilization of renewable energy sources i.e., solar energy. Hence, operating PV panels at their best utilization is must to make system cost effective. Due to nonlinear characteristics of a PV system, identifying a locations corresponding to operating condition at maximum power delivery is required to make system more efficient. In order to achieve the best utilization of PV panels, a maximum power point tracking (MPPT) technique should be implemented. Hence, a MPPT method plays an important role in PV based power generation systems. However, an efficient algorithm is must to operate PV system at its MPPT level. In this paper a comparative performance analysis of two famous MPPT algorithms is presented in this paper. The Perturb and observed (P&O) and Incremental Conductance (IC) methods are developed in this paper for comparing their responses under variable irradiances. MATLAB/Simulink based results are presented in this paper under various operating conditions.

Keywords— MPPTs, power converters, photovoltaic, P&O, IC.

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1. INTRODUCTION

A photovoltaic (PV) cell is used to converter solar energy into electricity by photonic effect. A module can be made by using many number of PC cells with proper arrangements for producing voltage and rated current. Similarly PV array can be constructed with connections of multiple PV modules. However, the current and voltage characteristics of PV module/arrays are nonlinear in nature. Hence the operating points will be varying accordingly temperature and solar insulation or irradiances. Hence, a device is required to operate the PV system at its maximum level called as Maximum power point tracker (MPPT) circuit. Therefore, a MPPT network will be continuously tuned in a PV system for harvests maximum energy through solar panels at changing weather or load conditions.

Due to increasing of both load demand as well as global warming day by day, utilization or renewable sources for electricity production has increasing. A standalone system, grid connected systems, including small scale and large power generations, solar cells for electricity production is attracting many scholars. Increasing of utilizing renewable sources can reduce the emission of greenhouse gases. However, due to nonlinear behavior of PV panels, we must operate the device on maximum possible efficient. This can reduce the overall cost and size of the system by avoiding more number of panels. Hence, an MPPT device is must to incorporate in system to achieve a best operation under high efficiency. Many MPPT devices are available and month them, a boost convert is best to operate under low irradiances also.

Recently, many proposes are introduced for achieving MPPT operation. The amount of electric power generated from solar energy through a PV system is continuously varying accordingly Temperature and irradiations [1-3]**.** Due to the expensive system of installing a PV, it is required to use all of the available output power. Therefore, a PV array must be operated at its MPPT level irrespective of changes in temperature and solar irradiation level at all the time. Some of the popular methods are constant voltage method, constant current method, perturb and observe, incremental conductance, hill climbing approach, β approach, ripple correlation and system oscillation methods [4-8]. Generally voltage and currents of the PV system needs to be sense to find the best operating condition. A computer based programming or algorithm needs to develop for identifying a best location during changes in solar irradiance as well a temperature. However, partial shading on PV panels can be occurred at any time due to many factors. Under this scenario, an optimization technique should be hybridization with MPPT algorithm.

The performances of MPPT by using perturb and observe method and incremental conduction algorithm is presented in this paper for tracking behavior. However, PV panels produce DC electricity when sunlight shines on the PV array, without any emission of harmful gases. Hence, it is becoming increasingly because of various advantages such are no fuel costs, noise and pollution free, less maintenance, among others. The paper is organizing under following sections. The basic idea of MPPT is explained in the Section-2. A detailed mathematical modeling is provided in Section-3. Various MPPT curves are depicted in Section-4. MPPT with P&O algorithm and its results are included in Sections 5 and 6 respectively. MPPT with incremental conductance (IC) algorithm and corresponding results are included in Sections 7 & 8 respectively. Concussions ad references are arranged at the end of the paper.

2. BASIC PRINCIPLE OF MPPT

Maximum power can be deliver at load can be possible by matching load and source impedances according to maximum power transfer theory. This can be defined by using below expression.

$$Z_S = Z_L$$

Hence, the internal impedance of PV modules/array needs to be matching the converter impedance [2]. Hence, the system can get maximum power at any operating conditions. The PV array produces its variable power from the solar energy directly; it will be depending upon the atmospheric conditions. Voltage is boosting by controlling the current of the array with the use of proper control method designed with tuned PI controllers. The Fig 1 presents a simple PV system with MPPT converter (DC-DC converter). A constant voltage will be produced by this converter. Therefore, this method can be help to charge the batteries. The converter can able to regulate the output voltage of PV system according to requirement. Hence, the MPPT device is regulating input voltage or current by forcing the converter to operate it at maximum power point level through a proper control method [9-12].

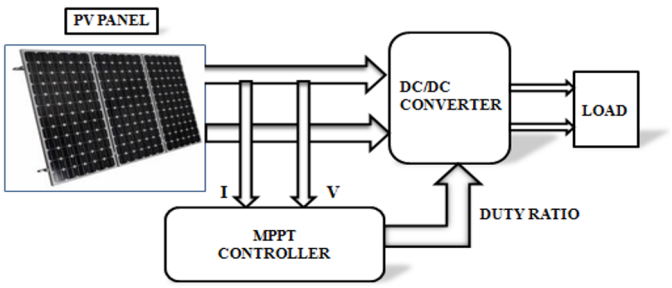

Fig.1. PV block with MPPT converter.

3. MATHEMATICAL MODELING OF PV ARRAYS

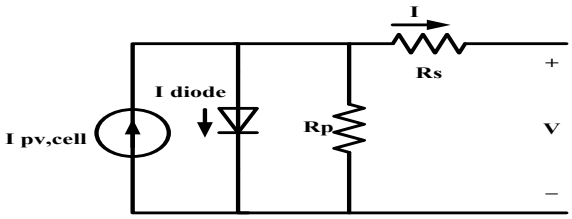

Fig. 2. Equivalent circuit of a Photovoltaic Cell.

Generally p-n junction diodes are using to make a solar cell which fabricated in thin layers of semiconductor devices. A simplest circuit is represented by a single current source with parallel diode as presented in Fig. 2. The output current of this circuit is varying according to the light falling on the cells (photocurrent I_{pv}, cell) .So the steps involved in modeling this circuit can be implemented based on below equations.

$$I = I_{pv,cell} - I_{diode} = I_{pc,cell} - I_{0,cell}\left[\exp\left(\frac{q \times V}{\alpha \times k \times T}\right) - 1\right]$$

Here,

$I_{PV,cell}$ is the current produced by the incident light.

I_{diode} is the Shockley diode equation.

$I_{0,cell}$ is the reverse saturation or leakage current of the diode.
T [K] is the temperature of the p-n junction.
$q = [1.6021764*10^{-19}C]$.
$k = [1.380650*10^{-23}J/K]$.
αis the diode ideality factor in range of 1 and 2 [13].

A DC-DC device is required with an efficient algorithm to achieve maximum power of PV module. By using different algorithms, it ensures the PV modules in a system always operate at their maximum power level under the variations in temperature, load and irradiation. Many algorithms were developed but P&O and IC algorithms are implemented in MATLAB Simulink platform in this paper. a comparative responses for various parameters are examined in the results section.

4. I-V & P-V CHARACTERISTICS

A. Change in Irradiance

Changes in solar irradiance will results in shifting of vertical position in I-V curves of a PV system as shown in Fig. 3. Shifting of maximum power operating position will be held with respective of current and voltage. A maximum reference power can be assign by any software programming [14-16]. Corresponding output curves of PV system are functioning with respect to changes in solar irradiance. The nonlinear characteristics which are affected by irradiance are exhibited by PV panels.

B. Changes in Temperature

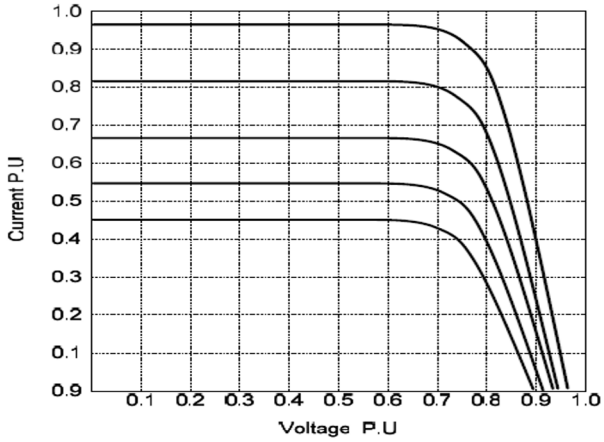

Fig.3. Change in I-V characteristics under various irradiances.

Changes in temperature are a slow process and it might be faster under floating partial shading conditions. This phenomenon will results in shifting the I-V curve horizontally as per Fig. 4 and is implemented as a function of sine with period of 6sec [14-16]. Fig. 4 shows the general characteristics with changes in temperature. Hence, characteristics are of nonlinear function as well as affect the output power.

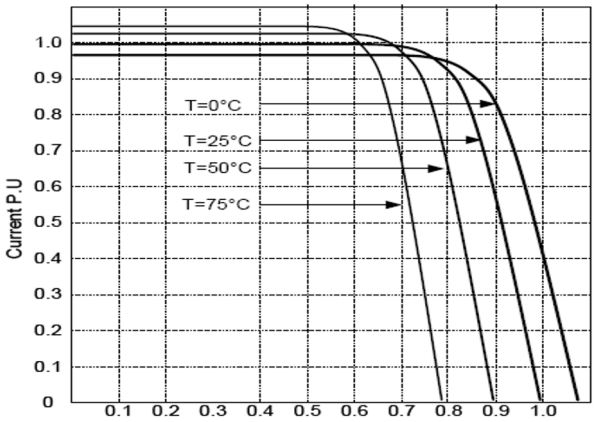

Fig. 4. Change in I-V characteristics of various temperatures.

5. MPPT USING P&O ALGORITHM

Perturb and observe (P&O) mechanism will work on observations of the output powers generated by PV system and on the perturbations (increments or decrements) of the power with respect to changes of the array voltage or current. Further, the process will work continuously changes the reference current/voltage according to their previous values with respect to sample instants. This method is very simple and required only sense of voltage and current of the PV array. Moreover, the implementing cost of this method is very less and easy to implement for any rating. It is having a very less complexity time of the algorithm. It is having a feature that it can reach very closely to the MPPT point.

The direction of MPPT voltage under the operation of P&O algorithm is depends on perturbation with small increment of power/voltage, hence results change in power ΔP is positive. The operating point goes away in case of negative ΔP [13]. Further, this process is required very small step change in voltage or current to identify accurate operating point.

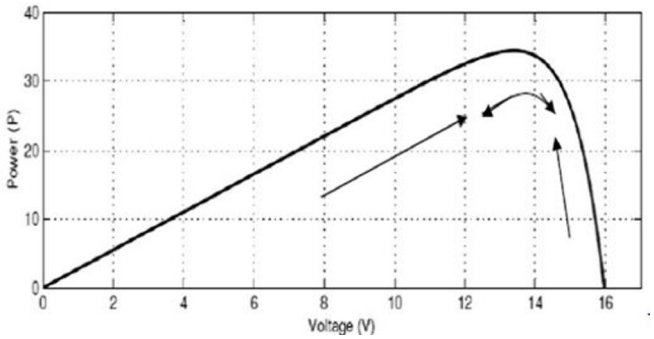

Fig.5 P and O Algorithm

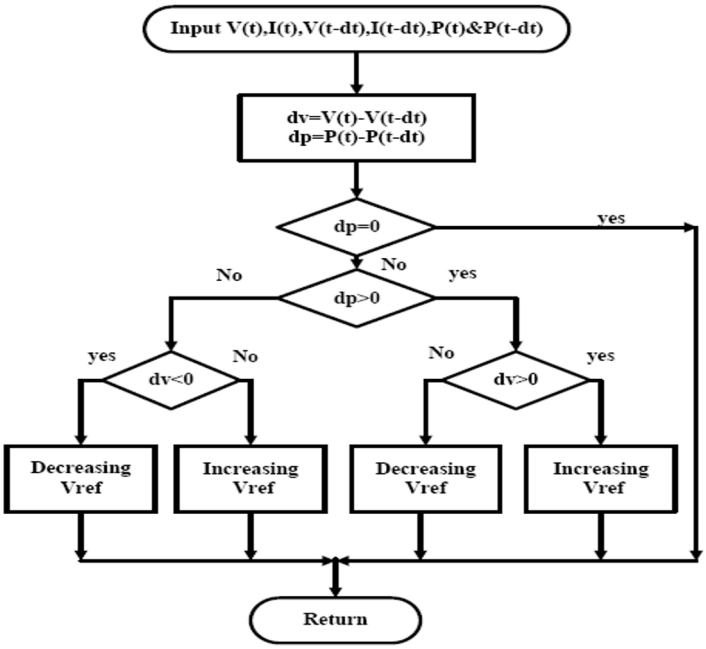

Fig. 6. Flowchart of P&O approach.

However, the P&O process has a slow dynamic response under consideration of small increment/change and low sampling rate. But, low change is necessary to reduce the steady state error. The lower the increment can helps to obtain the closer the peak. In order to achieve the satisfactory error of steady state, a small increment should be considered. However, the speed of the algorithm will be decided by the step change. A small change consumes more time but large change will have more error band in steady sate with creates more oscillations in output power of the PV system. To avoid this, a compromising is required between the step change and the sampling time [13].

The flowchart representation of the P&O algorithm is depicted in Fig. 6, and the P&O algorithm operates by periodically perturbing the operating voltage as per previous instant of the power. The voltage of PV array should be increased if changes in both voltage and power are positive. In case of any one is negative then the direction of next perturbation should be considered as negative. The increment of step in voltage will be positive in case of both changes in voltage and powers are negative. This process will be repeatedly going on until the system reaches its maximum power point level.

6. SIMULATION OF MPPT USING P&O ALGORITHAM

TABLE I

Parameter of Circuit	Values
Resistance of load.	R_1=30.0Ω
Filter Capacitance.	C_1=0.80mF
Filter Capacitance of boost circuit.	C_2=0.80 mF
Inductance of boost circuit.	L_1=0.30mH

TABLE II

PV Module parameters	Values
Number of cell (Ns).	36
Irradiance(So)	1000W/m^2
Ref.Temperature(T_{ref})	25°C
Resistance in series(R_s)	0.008Ω
Shunt Resistance(R_{sh})	1000Ω
Current when short circuited (I_{so}).	2.16e^{-8}A
Energy Band (E_g).	1.12eV
Constant (A).	1.20

RESULTS

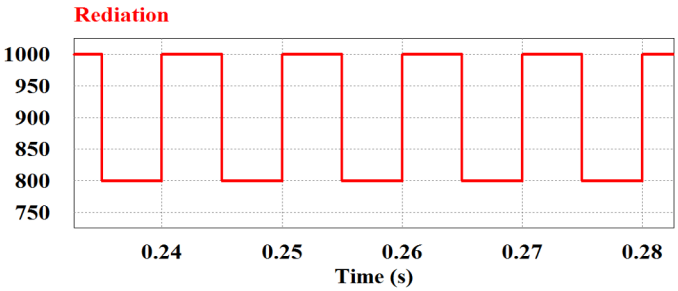

Fig. 7. (a) Radiation varies from 1000 to 800W/m^2.

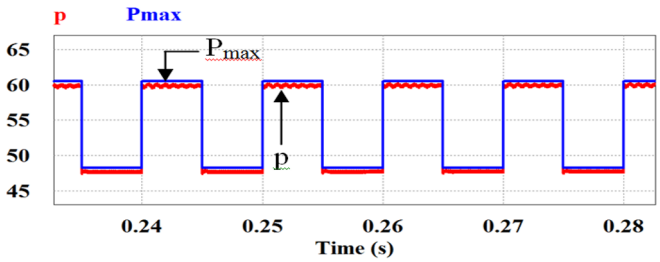

Fig. 7. (b) Corresponding output of Fig. (a).

During this simulation experiment, solar irradiance is vary from 1000to 800W/m^2 and temperature is maintained at 25℃. Under these changes in irradiation, the maximum PV power is changing from 48.0W to 60.0W. Fig. 7(b) represents that PV modules are tracking under maximum power phenomenal under the operation of the P&O algorithm. The maximum power of PV is denoted as P_{max}. Fig.8(a) and (b) represents corresponding changes of stable boost converter (V_boost) voltage and voltage at PV system (V_{cell}). This boost circuit boosted the output voltage by 78.1% of PV module. There is a bosted actual power is 73.2%.

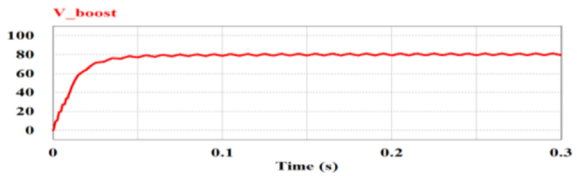

Fig. 8. (a)Voltage (V_ boost =80.750V).

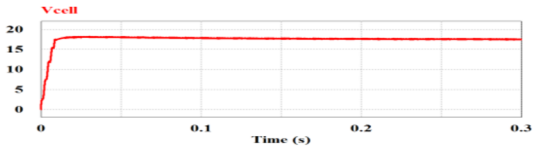

Fig. 8. (b)Voltage at PV module (Vcell=17.330V

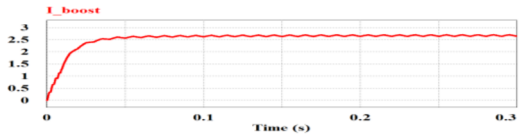

Fig. 8. (c) boost convert output current (I_boost=2.692A)

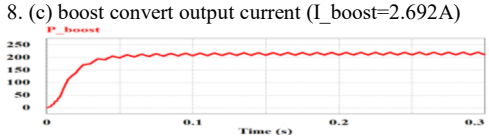

Fig. 8. (d)output power of a boost converter (P_boost=217.352W)

7. MPPT USING IC ALGORITHMS

The incremental conductance (IC) approach is proceeding by differentiating the power of the PV system with respect to voltage.

$$\frac{dP_{pv}}{dV_{pv}} = \frac{d(VI)}{dV} = V\frac{dI}{dV} + 1 = 0, \quad at\,MPP\,level$$

Hence,

$$\frac{dI}{dV} = -\frac{1}{V} \qquad (2)$$

In the above eq.(2), opposite of the PV system conductance is indicted by left-hand side, while the incremental conductance represented by its right side equation. So on the point of MPP, these two are equal but in opposite direction. , a set of inequalities can be derived from eq. (2) if the operating point is OFF of the MPP and further procedure represented by below equations.

$$\frac{dI}{dV} = -\frac{I}{V}; \quad \left(\frac{dP}{dV} = 0\right) \text{ at the MPPT} \qquad (3)$$

$$\frac{dI}{dV} > -\frac{I}{V}; \quad \left(\frac{dP}{dV} > 0\right) \text{ left of the MPPT} \qquad (4)$$

$$\frac{dI}{dV} < -\frac{I}{V}; \quad \left(\frac{dP}{dV} < 0\right) \text{ Right of the MPPT} \qquad (5)$$

The process to identify the new MPPT location continuously even once the MPPT is reached. This change in currents will proceeds depends on a change in irradiance. The equations (3)-(5) will help to identify the best operating location for obtaining maximum power from PV system.

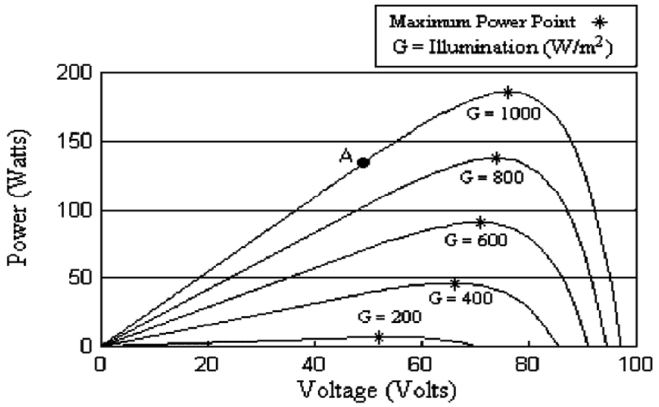

Fig.9.P-V of PV curves[1].

As presented in Fig. 9, the location of MPPT point will change as per the changes in solar irradiance. The location will move right side if change is voltage is positive. While decreasing of irradiance, the MPPT algorithm must increase the operating voltage of PV array..

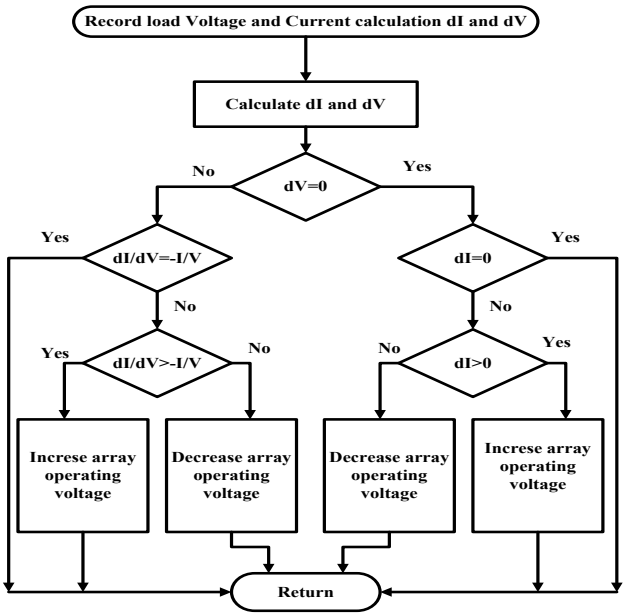

Fig.10.Flow Chart of Incremental Conductance Method.

A flowchart of IC process is depicted in the Fig. 10. The previous and present values of the solar array voltages and currents are identifying to achieve dV & dI. If both dV,dI are '0', then the MPPT point will stick at present values till changes in atmospheric parameters. If dI > 0, then MPPT point has been increased when increasing value of irradiance. Hence, it is required to increase the voltage of PV array for tracking the MPP. If dI<0, the MPPT point of voltage should decrease in case of less irradiance as compared to previous. If dP/dV > 0 and dI/dV > -I/V, then, the MPPT operating location will be on left side. Which means, the voltage of PV system should be increased towards the MPPT point. Similarly if dI/dV<-I/V, then dP/dV< 0 then it will move to its right side[1].

8. SIMULATION OF MPPT USING INCREMENTAL CONDUCTION ALGORITHM

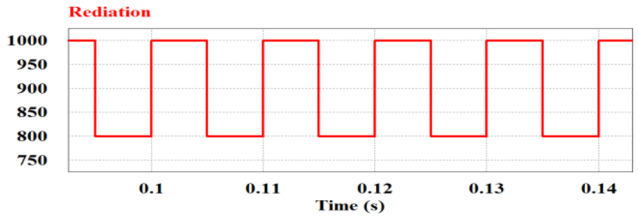

Fig. 11. (a) Radiation from 1000 to 800 W/m^2.

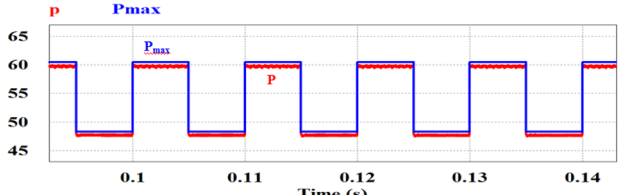

Fig. 11. (b) P max=60.535W and P=59.748W.

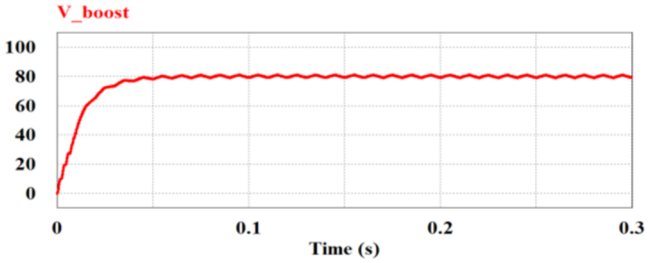

Fig. 12. (a)Voltage output (V_ boost =80.4583V).

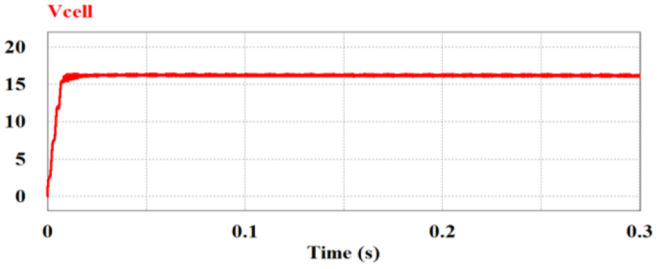

Fig. 12. (b)Voltage output (V cell=16.2717V).

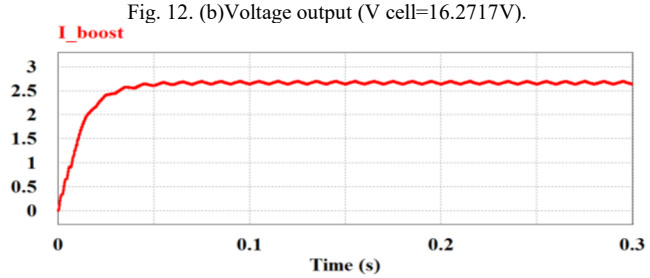

Fig. 12.(c) Current output (I_boost=2.6819A).

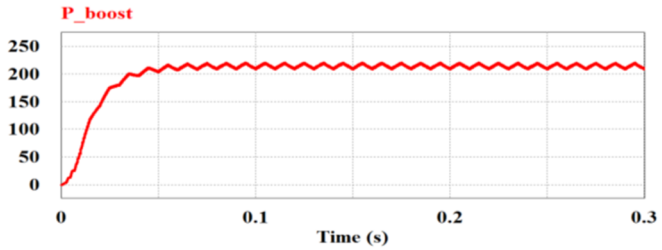

Fig. 12. (d) Power Output (P_ boost=215.7846W).

MATLAB Simulink platform is used to model the Fig. 1 to obtain various responses. The control parameters are adopted from data, and results are presented under various conditions.

Under the changes mentioned in previous section, corresponding responses of various outputs with IC methods are presented in Fig. 12. Comparisons are listed in below Table. From the Table, observed that the P&O algorithm having some priority in extracting maximum power under less oscillations.

Responses	P & O	IC
P(W)	59.77	59.75
PMAX(W)	60.535	60.535W
VCELL(V)	17.332	16.272
V_BOOST(V)	80.75	80.46
I_BOOST(A)	2.692	2.682
P_BOOST(W)	217.352	215.785

9. CONCLUSION

This paper is presented for the analysis of the IC and P&O algorithms by simulating them in MATLAB Simulink. Extensive results re presented for comparisons of MPPT operation. The simulation of a PV module under changing of irradiance is performed to obtain maximum power. Various results are shown that the tracking behavior of maximum power by its actual power(P) using IC and P&O algorithms. There is some more power extracted by using P&O as compared with IC method which is observed from various graphs under various operating conditions. Both methods are suitable to extract maximum power, but the P&O is more superior than IC since it is working based on voltage perturbs of PV system. However, for large value of current of PV system, then IC method will be more suitable.

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