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ENHANCEMENT MAXIMUM POWER POINT TRACKING OF PV SYSTEMS USING DIFFERENT ALGORITHMS

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ABSTRACT

In the last decades, the use of renewable energy resources instead of fossil fuels pollution has increased exponentially to overcome the rapid growth of energy demand. This paper, presents a Perturb and Observe (P&O) algorithm and Incremental conductance technique for extracting the maximum power from a stand-alone PV for use in pumping system. The PV system comprises a solar panel, DC-DC boost converter, MPPT and permanent DC motor driving a Centrifugal pump. Results are accomplished by modelling and simulating the complete MPPT with PV pumping system using MATLAB/Simulink .MPPT algorithms performance is measured to confirm its significantly improved power extraction performance under different sunlight condition.

KEYWORDS*:* **Photovoltaic array, Boost converter, Maximum Power Point Tracking, Perturb and Observe algorithm, Incremental conductance Technique, Photovoltaic water pumping system.**

I. INTRODUCTION

Photovoltaic systems (PV) are one of many resources of renewable energy; these systems are providing a clean infinite and domestic source of energy. It is heavily encourage using unlimited green source of energy, which reduces global carbon emissions; therefore it has a lower effect on the environment, and plays an important role in the energy security of nations when the dependency on imported sources is reduced. Solar energy is often considered the best power source for applications, such as water pumping in rural areas in developing countries. Previous studies on photovoltaic-generator driven water pumping systems have previously considered a number of suitable pumps and motors[1, 2].

It is important to improve the performance of the PV system and to extract the maximum power point under any environmental condition is necessary to track the maximum power point using control methods. The MPPT algorithm calculates the MPP in each instant of time for any irradiance and temperature[3].the DC motor and pump are operating the PV array far from the MPP.Due to nonlinear V/I characteristics of the PV array. It is challenging to track the MPP to avoid these problems; many algorithms have been developed to provide maximum power.

This paper provide a comparative study on maximum power point tracking (MPPT) controller for boost converter based on Perturb and Observe (P&O) algorithm and Incremental conductance technique applied to PV array, DC motor and pump. The system is simulated and analyzed using Matlab/Simulink and the energy efficiency is calculated for different level of irradiation.

2.PV SYSTEM MODELLING

A PV cell can be modelled using a current source in parallel with a diode, but all the energy that is generated by the PV cell is not transferred to the external circuit. To account for the power drop, series and parallel resistances are used in the model.

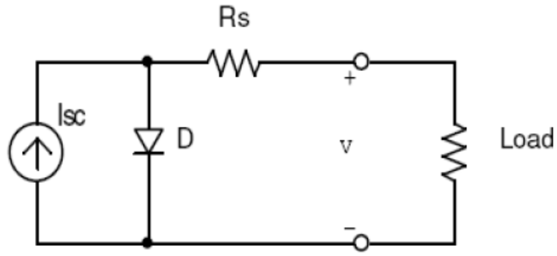

Fig. 1. Single diode model of PV cell.

The current (assuming R_{sh} is high and is neglected) that can be derived from a PV cell is given by (1), which is dependent on isolation and ambient temperature.

$$I = I_{sh} - I_o\,[e^{(q((V + IR)/nkT))} - 1] \quad (1)$$

Where: **I** is the cell current, **V** is the cell voltage, **T** is the cell temperature in Kelvin (K), $\mathbf{I_o}$ is the reverse saturation current of diode (A), q is the electron charge (1.602×10-19 C), **K** is the Boltzmann's constant (1.381×10-23 J/K).

First, calculate the short-circuit current (Isc) at a given cell temperature (T):

$$I_{sc}(T) = I_{sc}(T_{ref}).\ [1+ a\ (T - T_{ref})] \quad (2)$$

Where: $\mathbf{I_{sc}}$ at $\mathbf{T_{ref}}$ is given in the datasheet (measured under irradiance of 1000W/m2), $\mathbf{T_{ref}}$ is the reference temperature of PV cell in Kelvin (K), usually 298°K (25°C), a is the temperature coefficient of $\mathbf{I_{sc}}$ in percent change per degree temperature, it is also given in the datasheet.

The short-circuit current ($\mathbf{I_{sc}}$) is proportional to the intensity of irradiance, thus I_{sc} at a given irradiance (G) is:

$$I_{sc}(G) = \left(\frac{G}{G_o}\right) I_{sc}(G_o) \quad (3)$$

Where: Go is the nominal value of irradiance, which is normally 1000W/m2. The reverse saturation current of diode ($\mathbf{I_o}$) at the reference temperature ($\mathbf{T_{ref}}$) is given by:

$$I_o = \frac{Isc}{\left(e^{\frac{qVoc}{nkT}} - 1\right)} \quad (4)$$

The reverse saturation current (I_o) at a given temperature (T) is calculated by the following equation:

$$I_o = I_o(T_{ref}).\left(\frac{T}{Tref}\right)^{\frac{3}{n}} .e^{\frac{-qEg}{nk\left(\frac{1}{T}-\frac{1}{Tref}\right)}} \quad (5)$$

The equation for R_s at the open circuit voltage is:

$$R_s = -\frac{dV}{dI(Voc)} - \frac{\frac{nkT}{q}}{Io.e^{\frac{qVoc}{nkT}}}$$

(6)

3. MODELLING OF DC WATER PUMP

Permanent magnet DC Motor: While the output produced by PV generators is DC power, a DC motor is usually employed as a replacement for of AC motors in the PV pumping systems, because DC motors can be more easily interfaced with PV generators without using DC to AC power conversion. Therefore, the overall system cost and complexity will significantly reduce. In this work, a permanent magnet DC motor is used to drive a centrifugal pump load. The permanent magnet DC motor has some advantages such as reliability, high efficiency and relatively infrequent maintenance [4]. Moreover, the PMDC motor coupled with centrifugal pump has suitable matching characteristics with the PV array characteristics and its starting low torque is low compared to other PV electro-mechanical systems [4] and [5].Fig 2. illustrates the equivalent circuit of the permanent magnet DC motor with the pump load.

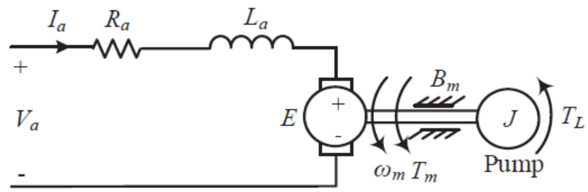

Fig. 2: Circuit model for PMDC motor with pump load.

In Fig. 2, R_a is the armature winding resistance (Ω), L_a is the armature self-inductance (H), I_a is the motor armature current (A) and V_a is the applied voltage (V).
According to the equivalent circuit shown in Fig. 2, the armature DC voltage can be calculated using equation (7).

$$V_a = R_a I_a + L_a \frac{dIa}{dt} + K_e W_m \quad (7)$$

e is the induced voltage when the motor is turning, and is known as a back emf. The induced voltage e is proportional to the angular speed of the rotor (ω_m) and the back emf constant proportionality (K_e) as given by:

$$(e = K_e \omega_m) \quad (8)$$

The torque balance equation is given by equation (9).

$$Te = K_t I_a = J \frac{d\omega m}{dt} + B_m \omega_m + T_L \quad (9)$$

Where $\mathbf{K_t}$ is the torque constant, **J** is the moment of inertia, $\mathbf{B_m}$ is the torque constant for rotational losses, $\mathbf{T_e}$ and $\mathbf{T_L}$ are the electromagnetic torque and the load torque respectively.
Centrifugal pump load: There are two types of pump usually used in PV pumping systems: volumetric pump and the centrifugal pump. However, it was reported in [6] that, a load composed of a DC motor driving a constant volumetric pump represents a non-matched load for a PV generator because the motor driving a constant volumetric pump requires a nearly constant current. Conversely, it was found in [7] that the PV sourced energy utilized by the centrifugal pump is much higher than with the volumetric pump, because the centrifugal pump works for longer periods even for low insolation levels. Moreover, the characteristics of the DC motor and centrifugal pump combination are well matched with the maximum power locus of the PV generator. Centrifugal pumps are inexpensive, simple, require low maintenance and are available in a wide range of flow rates and heads. Therefore, a centrifugal pump is considered in this work.
The centrifugal pump load develops speed-dependent torque. The speed-torque relationship for a centrifugal pump including friction torque is given by equation (10) [8].

$$T_p = T_L = A_L K_L \omega_m 1.8 \quad (10)$$

$\mathbf{T_p}$ is the torque required to drive the pump, $\mathbf{A_L}$ is the load friction (Nm) and $\mathbf{K_L}$ the proportional constant of the load torque N.m /(rad/sec)^2.

4. MAXIMUM POWER POINT TRACKER

The MPPT technique uses a DC-DC converter in order to allow the PV module to operate at its maximum power. This is achieved by an intelligent algorithm to solve the problems are related to the variation of temperature, the insolation and module load. Many tracking algorithms have been proven and used with variety of kind of DC-DC converters [9-11] among these algorithms, the Perturb & Observe (P&O) and Incremental Conductance (INC) methods are studied here.

It is to notice that the choice of the DC-DC converter in a photovoltaic system is important when a highest efficiency of the MPPT is desired. The boost DC-DC converter as shown in Fig 3. is able to follow the photovoltaic panel maximum power point, regardless of cell temperature, solar global irradiation and connected load.

The following voltage transfer function is:

$$\frac{\mathbf{Vo}}{\mathbf{Vi}} = \frac{\mathbf{1}}{\mathbf{1-D}} \quad (11)$$

The above equation shows that the output voltage is always higher than the input voltage (as the duty cycle goes from 0 to 1).

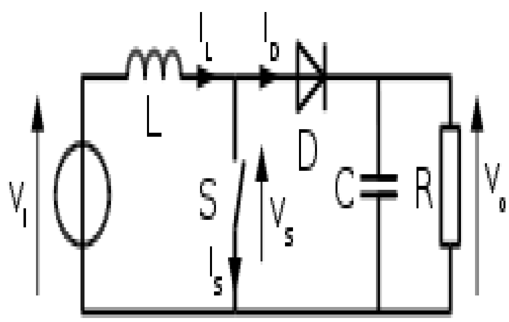

Fig. 3.boost DC-DC converter

Perturb & Observe Algorithm : The perturb & observe (P&O) algorithm, also known as the “hill climbing” method, is very popular and the most commonly used in practice because of its simplicity in algorithm and the ease of implementation. Fig. 4 shows the P-V curve, at the constant irradiance and the constant module temperature, assuming the PV module is operating at a point, which is away from the MPP. In this algorithm, the operating voltage of the PV module is perturbed by a small increment, and the resulting change of power, ΔP, is observed. If the ΔP is positive, then it is supposed that it has moved the operating point closer to the MPP. Thus, further voltage perturbations in the same direction should move the operating point toward the MPP. If the ΔP is negative, the operating point has moved away from the MPP, and the direction of perturbation should be reversed to move back toward the MPP. Fig. 5 shows the flowchart of this algorithm [9].

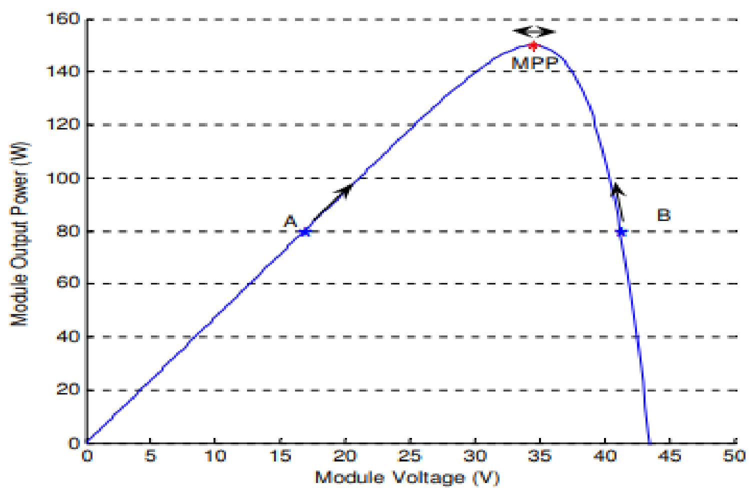

Fig. 4: P-V curve (1000W/m2, 25°C)

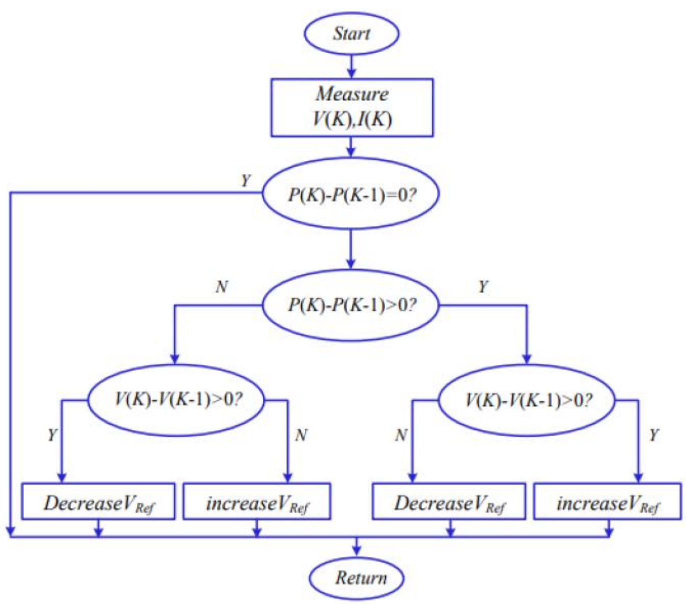

Fig.5: Flowchart of the P& O algorithm

Incremental Conductance Algorithm: The basic idea is that the slope of P-V curve becomes zero at the MPP, as shown in Fig 4. It is also possible to find a relative location of the operating point to the MPP by looking at the slopes. The slope is the derivative of the PV module's power with respect to its voltage and has the following relationships with the MPP [9]. Fig 6 shows the flowchart of incremental conductance method.

$$\frac{dP}{dV} = 0 \qquad \textit{at MPP}. \tag{12}$$

$$\frac{dP}{dV} = \frac{d(V.I)}{dV} = I.\frac{dV}{dV} + V.\frac{dI}{dV} = I + V.\frac{dI}{dV} \tag{13}$$

At MPP: $I + V.\frac{dI}{dV} = 0 \Rightarrow \frac{dI}{dV} = -\frac{I}{V}$ (14)

If the operating point is at the right side of the MPP, the equation (14) becomes:

$I + V.\frac{dI}{dV} > 0 \Rightarrow \frac{dI}{dV} > -\frac{I}{V}$ (15)

If the operating point is at the left side of the MPP, the equation (14) becomes:

$I + V.\frac{dI}{dV} < 0 \Rightarrow \frac{dI}{dV} < -\frac{I}{V}$ (16)

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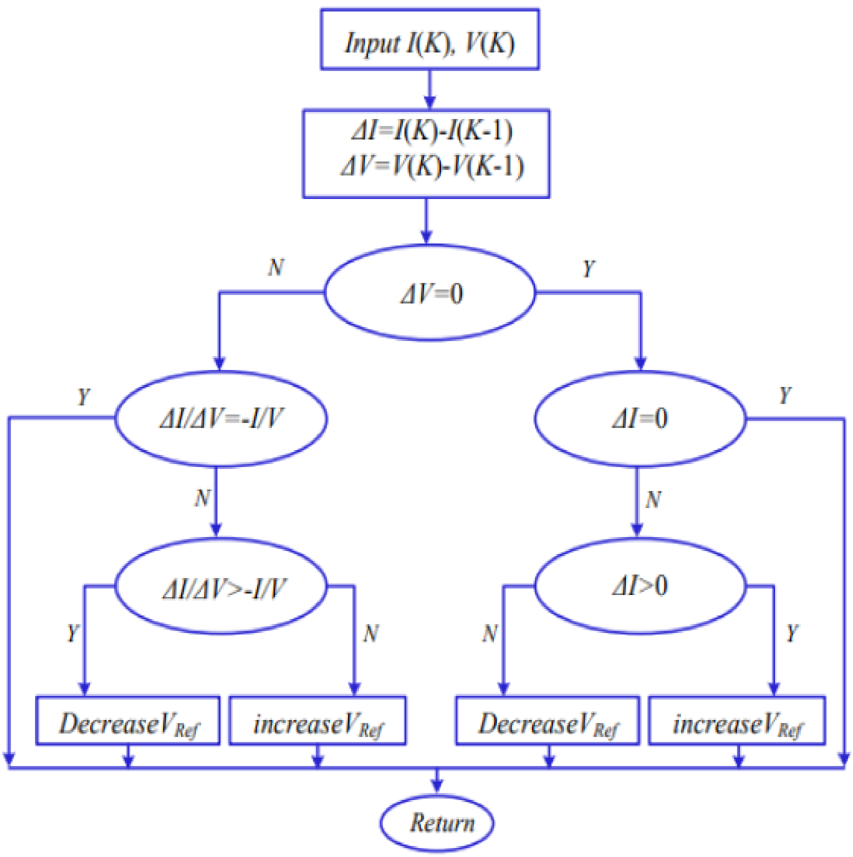


Fig.6: Flowchart of the INC algorithm.

5. SIMULATION MODELS AND RESULTS

The system is modelled in MATLAB/Simulink. A boost converter is used to interface a PV array with dc motor pumping system in Fig 7. To perform the maximum power point tracking, both P & O and IC algorithms have been implemented with all consideration of the optimization techniques. The simulation allows verification of the feasibility and relative performance of both algorithms under correctly the same conditions. Here, the main aspect to consider is the dynamic performance in terms of the speed at which the system converges on maximum power point, and the ripple in the power due to oscillations around the maximum power point is at steady state conditions. Both I-V and PV output characteristics of generalized PV model for a cell are shown in Fig. 8 and Table I shows parameters of Parameters of PV array, PM DC motor and the load pump.

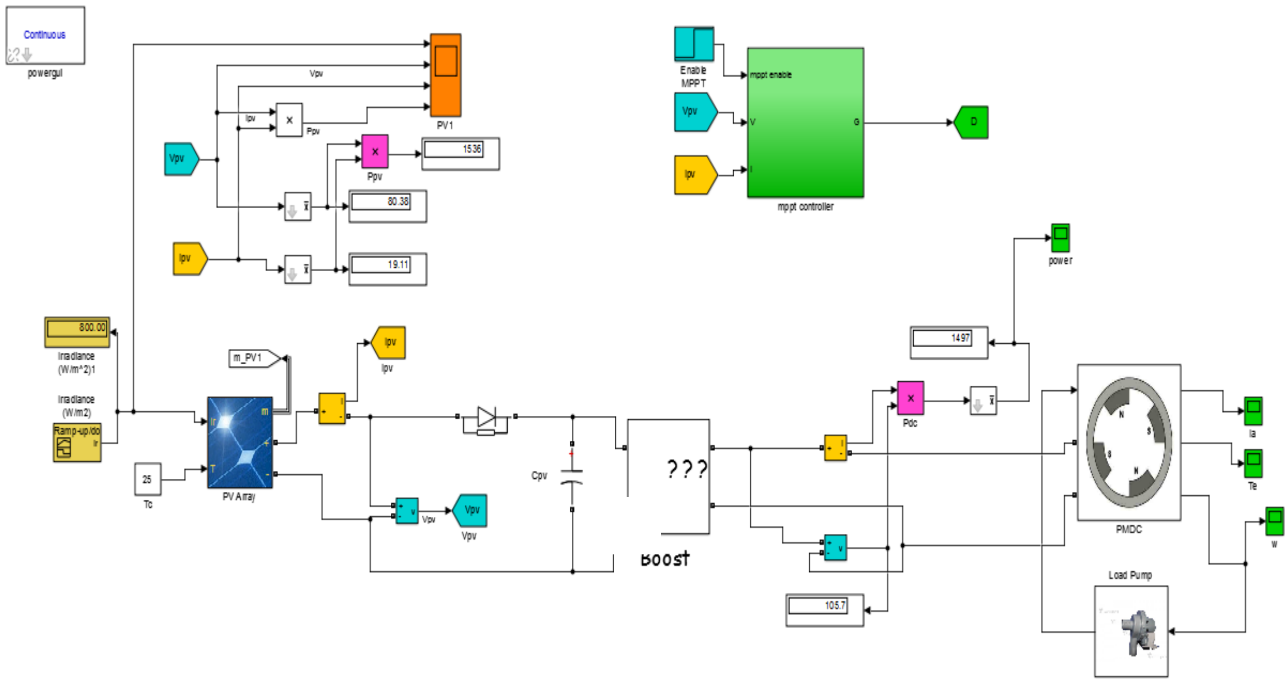


Fig.7 MATLAB Simulink model of MPPT for a PV module.

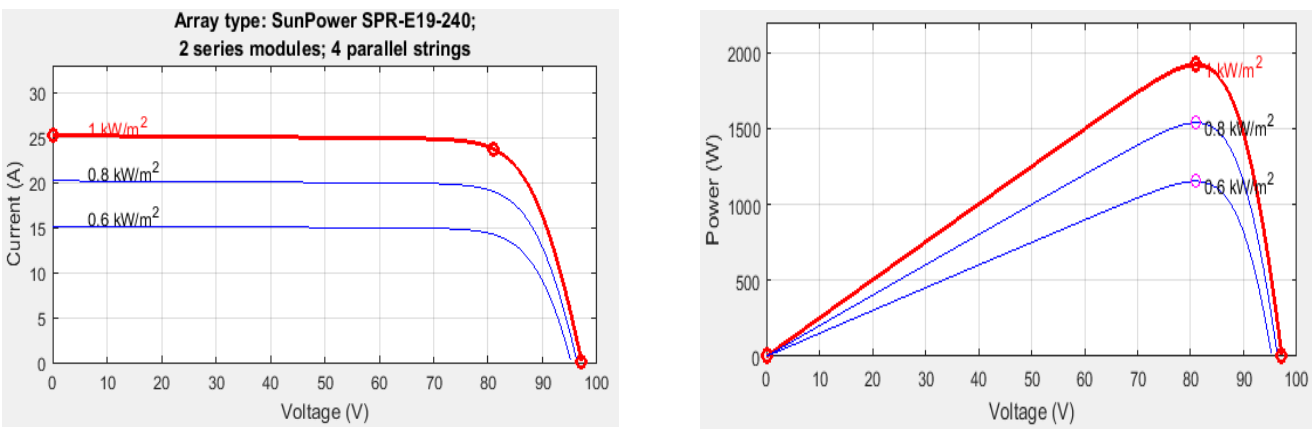


Fig.8 I-V and P-V characteristics of a typical PV array

Table I. Parameters of PV array, PM DC motor and the load pump

PV module data (Sun Power E19/240 solar panel)	
Maximum power (Pmax)	240 W
Maximum power point voltage (V_{mpp})	40.5 V
Maximum power point current(I_{mpp})	5.93 A
Open circuit voltage (V_{oc})	48.6 V
Short circuit current (I_{sh})	6.30 A
Cells per module	72
Parallel strings	4
Series-connected modules per strings	2
DC PM Motor data	
Rated motor voltage (V_a)	120 V
Rated motor current (I_a)	9.2 A
Rated motor speed (ω)	1500 (rad/sec)
Armature resistance (R_a)	1.5 Ω
Armature inductance (L_a)	0.2 H
Voltage constant (K_e)	0.67609 V/(rad/sec)
Torque constant (K_T)	0.67609 Nm/A
Load Pump data	
Moment of inertia (J)	0.02365 $Kg.m^2$
Friction coefficient (B)	0.002387 Nm/(read/sec)
Load torque constant (k_L)	0.00059 Nm/(read/sec)
Load friction (A_L)	0.3 Nm

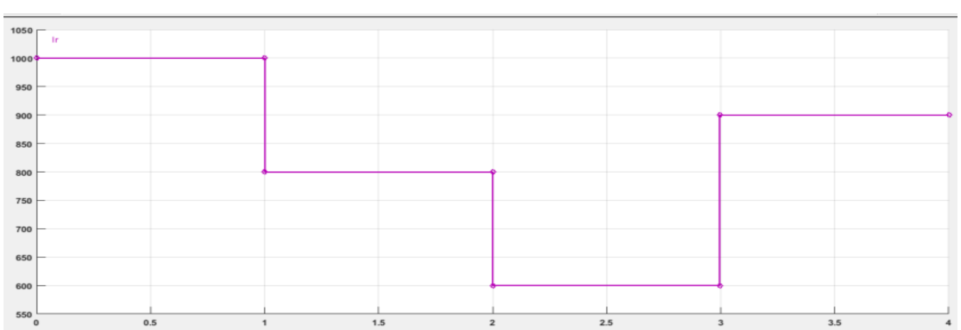
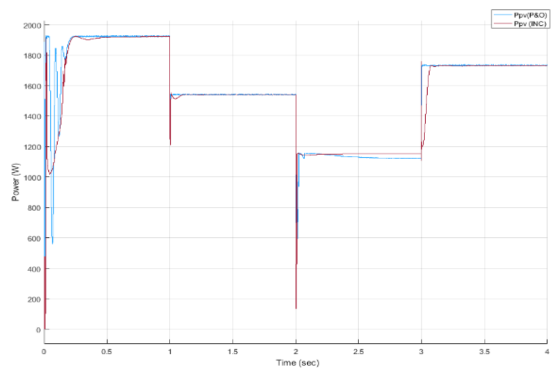
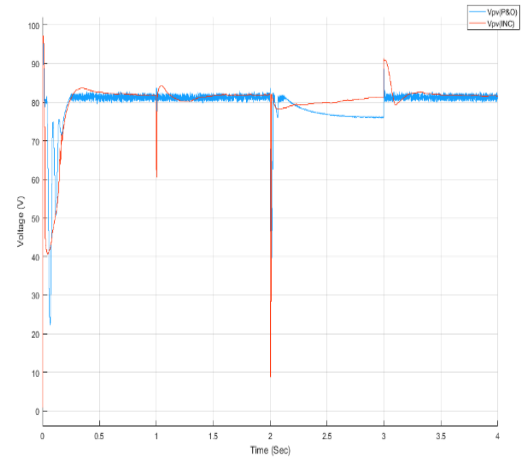


Fig. 9 Changing Irradiation level for comparison of P&O and INC based controller.



a



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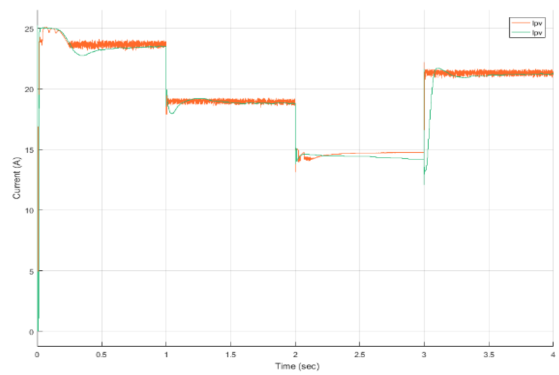

c

Fig.10 output power, voltage and current under different irradiance with P&O algorithm and incremental conductance algorithm.

To analyse and compare the performance of the MPPT method, we carried out the simulation for temperature is constant (25 ^{0}C) and the irradiance change from 1000 W/m^2 to 800 W/m^2, 600 w/m^2 and then increases to 900 W/m^2 as shown in Fig.9 and Fig10. (a) (b),(c) show output power, voltage and current under different irradiance with P&O algorithm and incremental conductance algorithm.

In order to validate the effectiveness of two MPPT methods, a comparative study is done between P&O and incremental conductance. The static tracking efficiency of two MPPT methods under different irradiance are simulated. The static MPPT efficiency is given by:

$$\eta\text{static} = \frac{\mathbf{Po}}{\mathbf{Pmax}}$$

Where P_o represents the output power of the PV module under steady state, P_{max} is the maximum power of the PV module under certain conditions[12]. From the results in Table II the static tracking efficiency of Perturb and Observe method is higher than Incremental Conductance method.

Table II: Tracking efficiency of MPPT during irradiance change

Theory	G(W/m^{2})	1000	800	600	900
	P (W)	1921	1540	1156	1731
	V (V)	82.1	81.2	81	81.7
	I (A)	23.4	18.96	14.27	21.18
P&O	P (W)	1920.5	1539.75	1154	1730.5
	V (V)	81.63	80.98	80.55	81.9
	I (A)	23.5	19.01	14.32	21.12
	η	99.97 %	99.98 %	99.82 %	99.97 %
INC	P (W)	1919.5	1538.75	1152	1730.25
	V (V)	82.16	81.22	80.25	82.15
	I (A)	23.36	18.96	14.35	21.06
	η	99.92 %	99.91 %	99.65 %	99.95 %

CONCLUSIONS

This paper presents comparison between the performance of P&O and INC algorithms for PV pumping system. A MATLAB/ Simulink model is built. The two methods are tested under the same atmospheric conditions, when the irradiance is varying. The simulation results, it is clear that the P&O algorithm has a fast response time and it is not complex and easy to implement. However, P&O has oscillator behaviour around the MPP. The INC algorithm has a relatively slow response time compared to P&O method, and the implementation of the algorithm is considered to be complex. The performance comparison of two proposed MPPT is carried out at the same irradiation levels. The best results show that PV water pumping shows higher overall efficiency with two proposed MPPT techniques. However, the highest system efficiency obtained with the P&O technique than INC algorithm.

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