CURRENT RESEARCH JOURNAL OF PHILOLOGICAL SCIENCES
(ISSN –2767-3758)
VOLUME 03 ISSUE 10 Pages: 01-22
SJIF IMPACT FACTOR (2021: 5. 823) (2022: 6. 041)
OCLC – 1242423883 METADATA IF – 6.925
Publisher: Master Journals


CURRENT RESEARCH JOURNAL OF PHILOLOGICAL SCIENCES
ISSN 2767-3758
2022
VOLUME-III
ARTICLES INDEXED ON
MENDELEY
Metadata Indexing
Impact Factor-6.925
SJIF 2021:5.823
DOI-10.37547/crjps

Journal Website: https://masterjournals.com/index.php/crjps

Research Article

COMPARATIVE STUDY OF P&O AND INCREMENTAL CONDUCTANCE METHOD FOR PV SYSTEM BASED ON THEVENIN EQUIVALENT CIRCUIT MODEL

Submission Date: October 5, 2022, **Accepted Date:** October 7, 2022,
Published Date: October 8, 2022
Crossref doi: https://doi.org/10.37547/philological-crjps-03-10-01

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ABSTRACT

For maximum power point tracking (MPPT) and power grid investigations, a photovoltaic (PV) source model is required. Environment Temperature, solar irradiation, and load (RL) all have an impact on the output power of (PV) arrays with nonlinear properties. To optimize the provided possible power, for photovoltaic (PV) power systems, numerous maximum power point tracking (MPPT) strategies have been researched and developed. Thevenin's equivalent model for a (PV) source is designed by piecewise linearization of the diode characteristic. Thevenin model is compared by using different MPPT algorithm methods perturb and observe (P&O) and Incremental conductance (INC) using MATLAB simulation program. The simulated PV system consist of (PV panels, DC-DC boost converter, and MPPT controller) and the comparison between the two MPPT algorithm methods (P&O and INC) to maximize the obtained solar power. The simulation results showed that Thevenin's equivalent model of (PV) produces a voltage-current characteristic which represents the PV source operation fairly well.

KEYWORDS

Photovoltaic (PV), Maximum Power Point Tracking (MPPT), Perturb and Observe (P&O), Incremental Conductance (IC).

INTRODUCTION

Renewable energy sources are a hot topic that is gaining traction around the world due to the consumption and expiration of fossil fuels [1]. One of the most important renewable energy sources is solar energy. Solar energy is clean, inexhaustible, and free, as opposed to conventional unrenewable resources such as gasoline, coal, etc..., [2]. In this context, international efforts have been made to promote the use of more renewable energy resources, one of which is solar photovoltaic, which is one of the most promising clean energy sources for global energy consumption. Approximately 90% of solar systems deployed across the world are grid-connected [3]. A PV cell, also known as a solar cell, is the most basic component of a photovoltaic PV power system [4]. Photovoltaics PV is a way of converting light into electricity using a semiconductor, commonly silicon [5]. Figure 1.1 shows Solar PV power production capacity on a global capacity [6]. The electrical energy that we get from solar panels is affected by several conditions such as temperature, the intensity of lighting, semiconductor material ... etc. So to improve solar energy production operators can't modify solar panel's material most of the time, but they can use MPPT techniques to adjust solar panel's power from sunlight intensity. As a result, MPPT techniques play a significant role in improving solar cell energy generation [7]. Therefore, the tracking of the maximum power point of the photovoltaic array is known as maximum power point tracker MPPT, where MPPT can be defined, which is an electrical circuit through which it is possible to control effective resistance to the load that you see PV array, and thus we can control the maximum point of the characteristic I-V characteristic at which system operates [8]. Figures 1 and 2 shows characteristics of PV array under the typical temperature T and radiation G conditions (G=1000W/m2, T=25°C). Due to nonlinear PV array properties, and additionally, the PV array only makes use of its maximum power at one location, therefore there must.

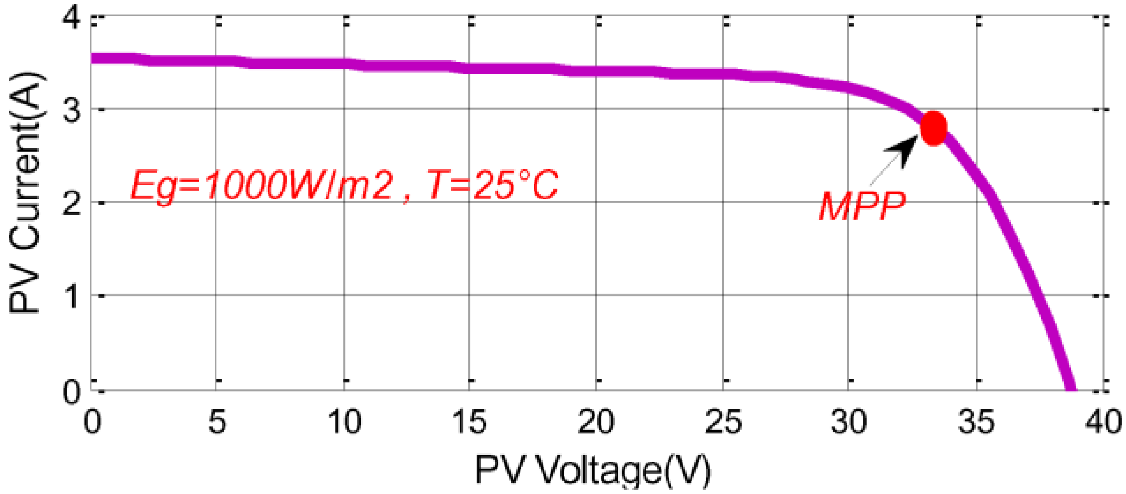

Figure 1 PV array I-V characteristic [9]

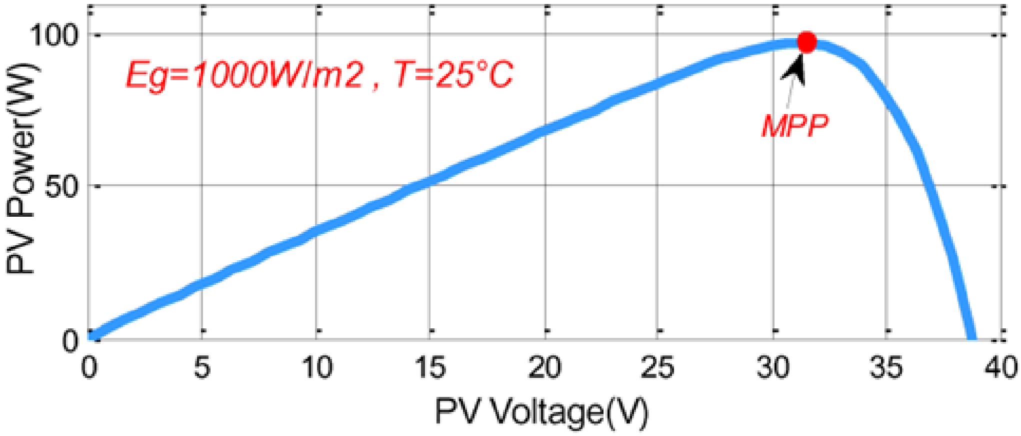

Figure 2 PV array P-V characteristic [9]

1.1 Types of PV models

A. PV array model [10]

The one-diode model, two-diode model, four-parameter model, and so on is the most often used PV cell models. They can be used for a variety of purposes [10]. The electrical equivalent circuit for the single diode PV model is shown in figure 3, and the electrical equivalent circuit for the two diode as shown in shown in figure 4.

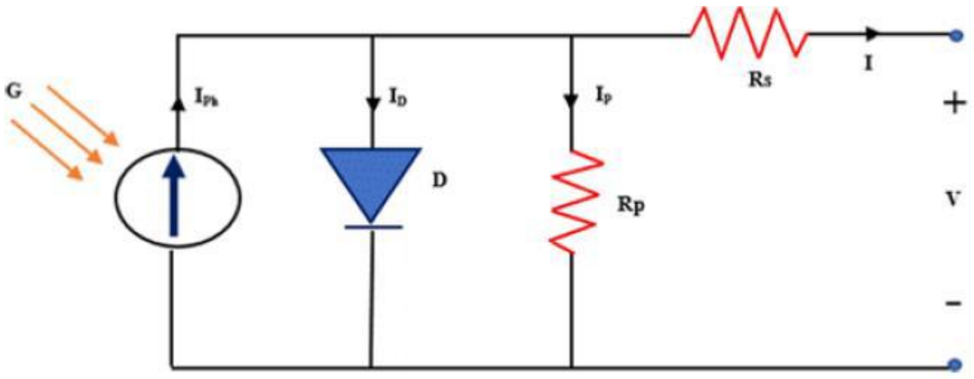

Figure 3 The single-diode PV model's electrical circuit [11]

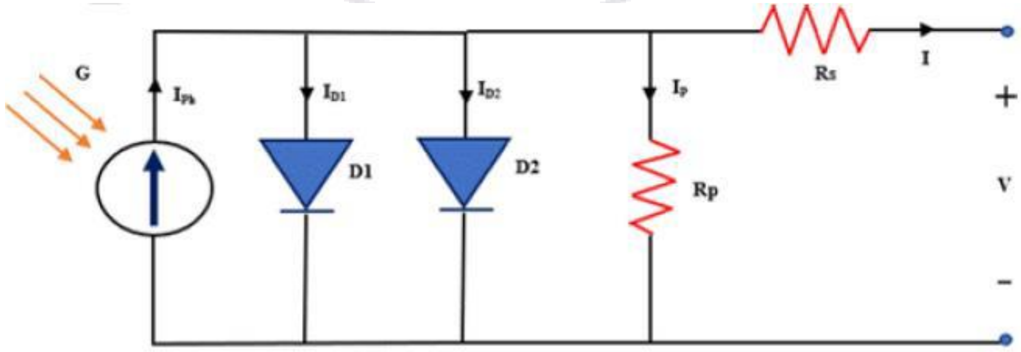

Figure 4 The double-diode PV models electrical circuit [11]

B. Thevenin's equivalent model [12]

The Thevenin equivalent model can be used to make simple the photovoltaic (PV) model [12]. Because the models are shown in the figures 3 and 4 are non-linear, linearization can be used to represent any nonlinear system as a linearized model with variable parameters. A PV model shown in figure 3 they can be now represented by Thevenin's equivalent resistance and voltage are depicted in the illustration 5 [13], [14].

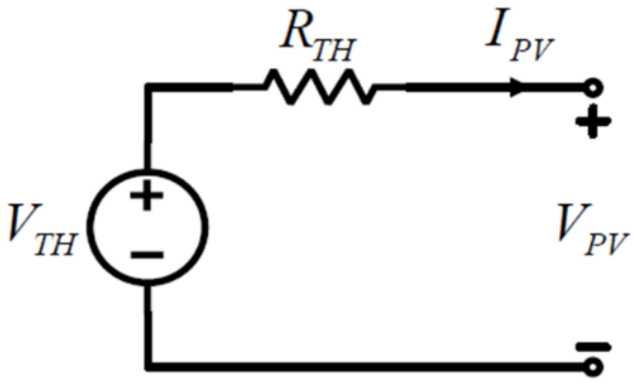

Figure 5 Thevenin's PV source for equivalent model [12]

2. Maximum Power Point Tracking (MPPT) Methods and Algorithms [16]

Tracking to maximum available power at PV array output is a common PV energy generation issue. In this regard, Numerous solutions to this issue have been proposed in the literature. Techniques, standards, limits, and applications change for each method. Since a PV cell's I-V curve is nonlinear, tracking the MPP requires an algorithm. A PV array works at maximum voltage and maximum current (VMPP), (IMPP) respectively, MPPT is occur. MPPT is fundamentally affected by irradiation and temperature [18]. Due to its simplicity and minimal computational resource requirements, the Perturb & Observe (P&O) method is an example of this; this is one of the most commonly used MPPT flowchart. [19], [20]. On the other hand, has drawback of being confused and resulting in MPP tracking in wrong direction during rapidly changing irradiance. Similarly, Incremental Conductance (INC) method is based on a slope analysis of the PV generator's P-V curve [21 – 25].

2.1 Perturb and Observe (P&O) Method [16]

P&O approach is implemented by following the procedures shown in figure 6. by using the output of the PV model the voltage and current it is measured subsequently, In order to perturb the voltage and make a comparison with an earlier operating point, the operating point (actual power point and voltage point) is computed (preceding power point and voltage point), this method of calculating the slope value of dP/dV. The perturbation is known to have moved the array's operating point nearer the MPP by using the slope value, and the algorithm will continue to perturb the PV array voltage along the same route if dP/dV > 0. However, if dP/dV< 0, the PV array will have moved away from the MPP and the P&O algorithm will have flipped the perturbation's direction. [18].

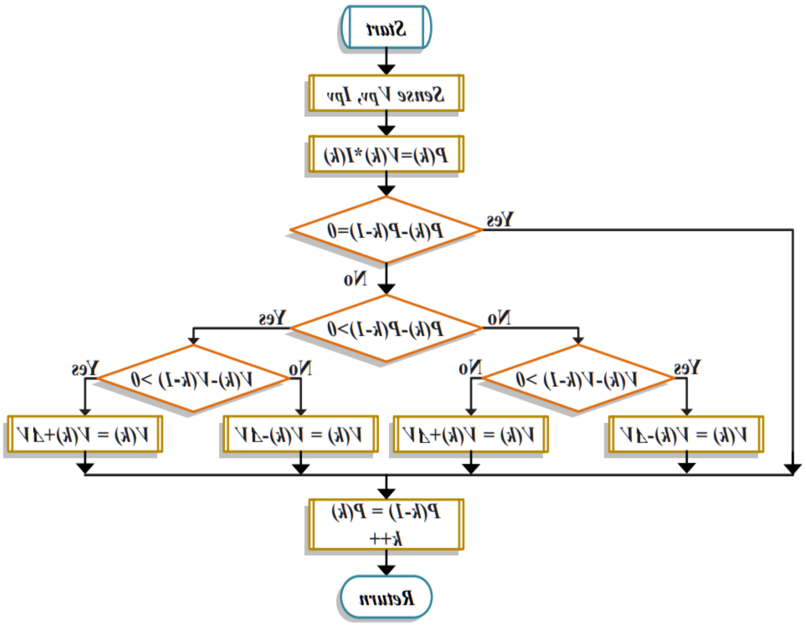

Figure 6 P&O MPPT algorithm flow chart [16]

2.2 Method of Incremental Conductance (INC)

Method of Incremental Conductance (INC) technique is predicated on the fact that the PV's power incline is zero at the Maximum Power Point (MPP), with dP/dV = 0. Both information on current and voltage at the output of the PV array are necessary for the (INC) technique, just like for the P&O method. However, INC technique does not need calculation of PV module power. The steady-state oscillations around the MPP of PV modules or arrays will theoretically disappear if the derivative of power with respect to voltage is null there. Nevertheless, due to the MPPT flow chart's digital implementation resolution, getting a null value of slope is challenging. Figure 7 illustrates how the INC MPPT controller tracks the MPP. [16].

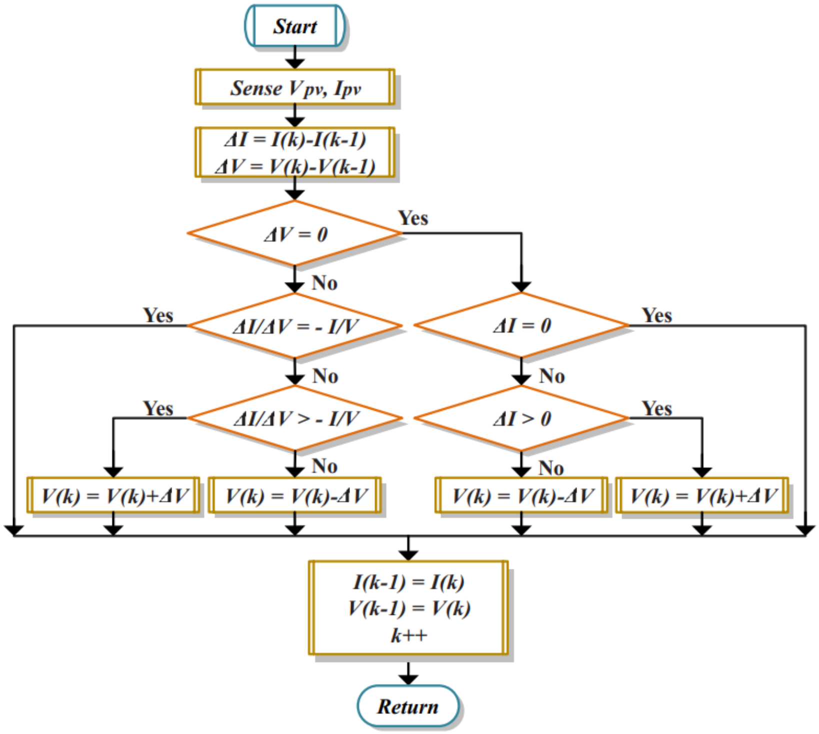

Figure 7 INC MPPT algorithm flow chart [16]

3. Design and Simulation of PV systems

3.1 A photovoltaic source model in Thevenin's equivalent circuit

Using the MATLAB Simulink toolbox, the Thevenin's equivalent circuit model for a PV source is created depends on the figure 8 and equations that describing the PV of Thevenin's equivalent model characteristics that calculated from equations (1) and (2), and modeled using suitable blocks from the Simulink library and codes of the m-file. The complete Simulink model of the PV module is shown in figure (9) and the (I-V), (P-V) characteristics are shown in figure (10).

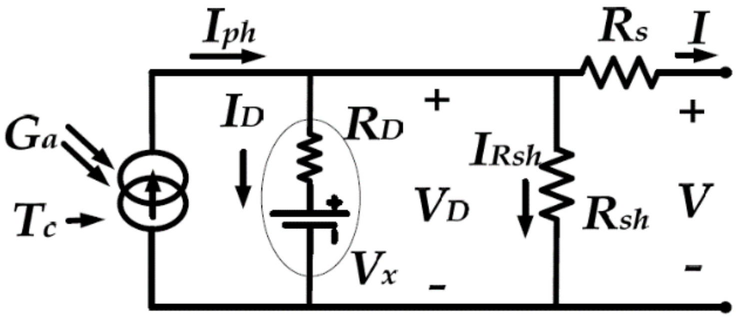

Figure 2.12 PV model with linearized diode [17]

V_{Th} *and* R_{Th} stand for the equivalent voltage and resistance of Thevenin model respectively.

$$V_{Th,i} = V_{x,i} + R_{D,i} \cdot \frac{I_{ph} \cdot R_{sh} - V_{x,i}}{R_{sh} + R_{D,i}} \quad (1)$$

$$R_{\mathrm{Th,i}} = R_s + \frac{R_{sh} \cdot R_{D,i}}{R_{sh} + R_{D,i}} \quad (2)$$

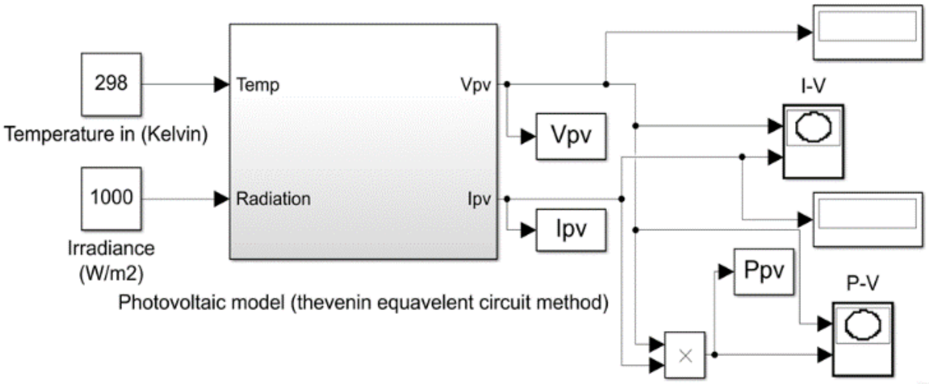

Figure 9 photovoltaic model (thevenin equivalent circuit method).

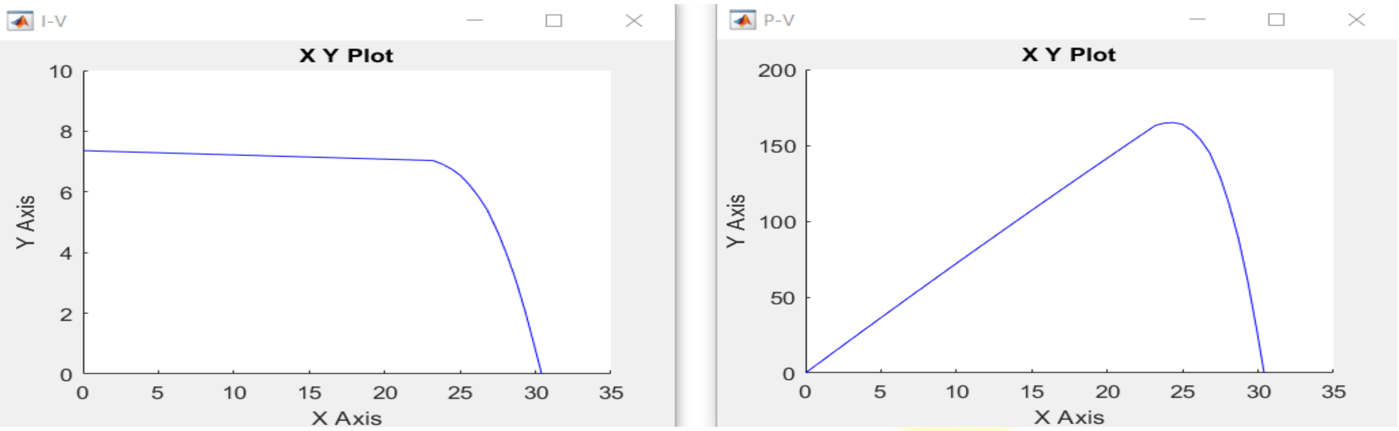

Figure 10 I-V and P-V for Thevenin's model at (25°C and 1000 W/m²).

From the above figure it is conclude that, the model's output characteristics curves match to the PV-MF165EB3 solar panel's characteristics referred to in table 1. The PV model operation characteristics are also studied under a variety of operating environments (temperature, irradiation) and physical qualities (series resistance, parallel resistance, ideality factor and so on).

Table 1 Module datasheet values and estimated parameters

Datasheet Values		Estimated Parameters	
I_{sc}	7.36 A	I_{ph}	7.36 A
V_{oc}	30.4 V	I_o	0.104 µA
V_{mpp}	24.2 V	A	1.310
I_{mpp}	6.83 A	R_s	0.251 ohm
n_s	50	R_{sh}	1168 ohm
Temperature coefficients			
K_i	0.057%	K_v	-0.346%

3.2 DC-DC Boost Converter Design

Figure (10) shows of MPPT stand-alone PV systems with resistive load that contain boost dc-dc converter's circuit. For steady-state operation, its output voltage V_o is always greater than the input voltage V_i. The boost converter, especially in PV applications, not only amplifies the output PV voltage to the desirable level, but also conducts maximum power point tracking (MPPT) control. A components of converter are two semiconductors (MOSFET and the diode), a filter composed of a capacitor, an inductor for energy storage, resistive load, and the PV panels (DC source). The MOSFET here is like a switch to variation the duty cycle (D), and transfer maximum power from the input source to load resistance.

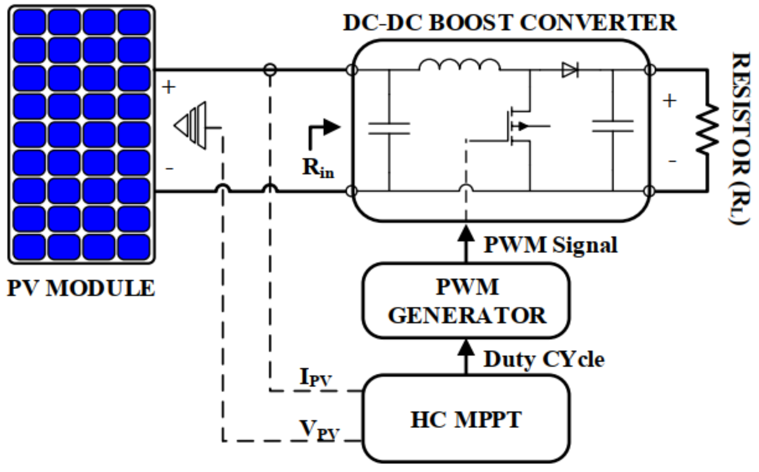

Figure 10 PV systems with MPPT stand-alone and load resistor

3.3 Design of MPPT techniques

Two MPPT controller techniques have been chosen for comparison in this work; Perturb and observe (P&O) technique, and Incremental conductance (INC) technique.

A. Technique of perturb and observe (P&O)

The m-file MATLAB code is used to implement this algorithm, as represented in figure (11). The photovoltaic voltage (Vpv) and current (Ipv) are inputs into the block, and the duty cycle (D) is the output. The initial duty cycle was selected to be (0.3) and when the result become close to the steady-state value the duty cycle step size is selected to be (1×10^{-3}).

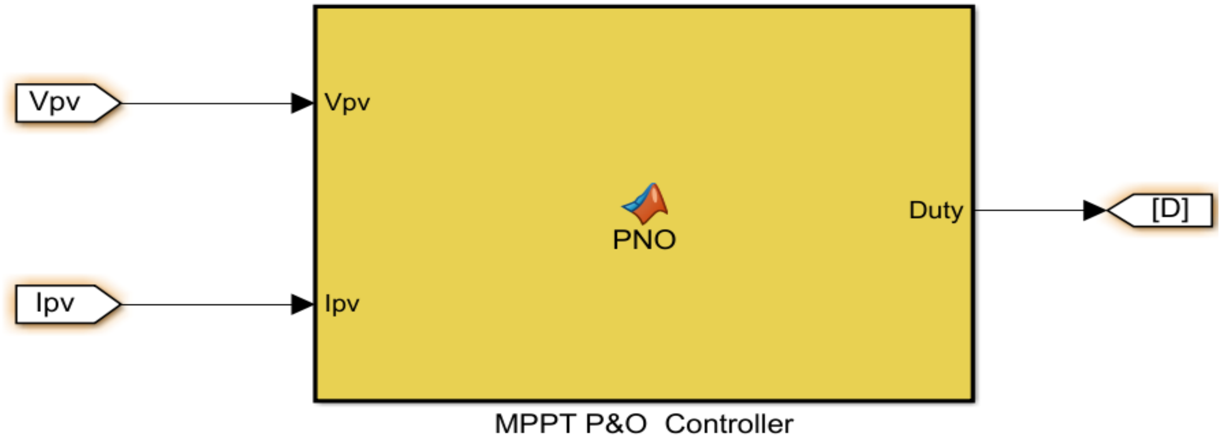

Figure 11 Block diagram of the P&O algorithm in Simulink.

B. Incremental conductance (INC) technique.

The m-file MATLAB code is used to implement this algorithm, as represented in figure (12). The photovoltaic voltage (Vpv) and current (Ipv) are inputs into the block, and the duty cycle (D) is output. The initial duty cycle was selected to be (0.3) and when the result become close to the steady-state value the duty cycle step size is selected to be (1×10^{-3}). For the same reason, the same initial duty cycle value (0.3) and duty cycle step size (1×10^{-3}) are used, as well to compare the output results of the two algorithms.

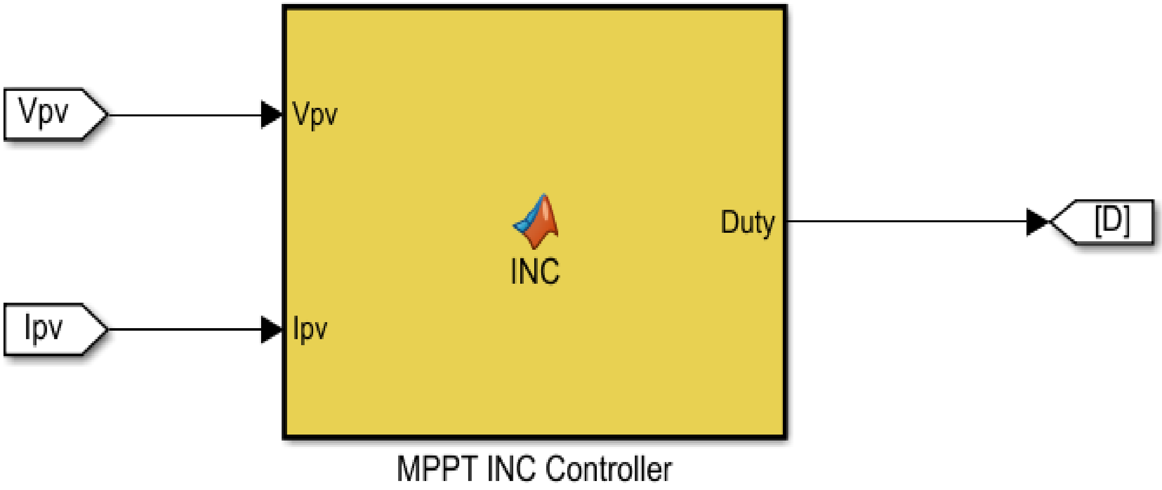

Figure 12 Block diagram of the INC algorithm in Simulink

4. Simulation and Results and Analysis

4.1 Thevenin's Equivalent Model Characteristics

The same procedure above was used to calculate the characteristics of Thevenin's equivalent model of photovoltaic model source. I–V and P–V characteristics under variable irradiation and constant temperature are shown in figures (13) and (14) respectively. The solar irradiation varies between (400, 600, 800 and 1000 W/m2).

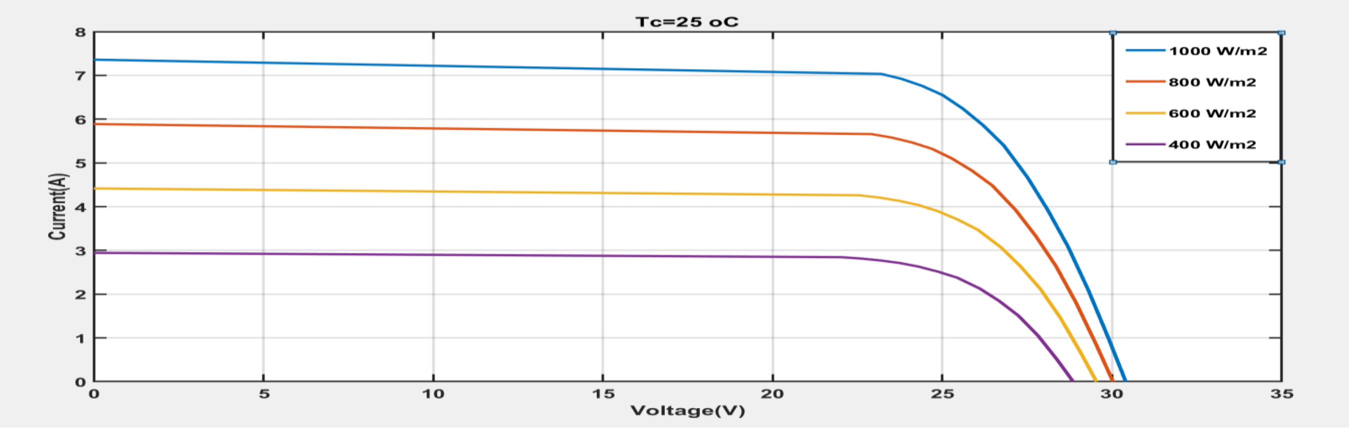

Figure 13 I–V characteristics with variable irradiation - constant temperature

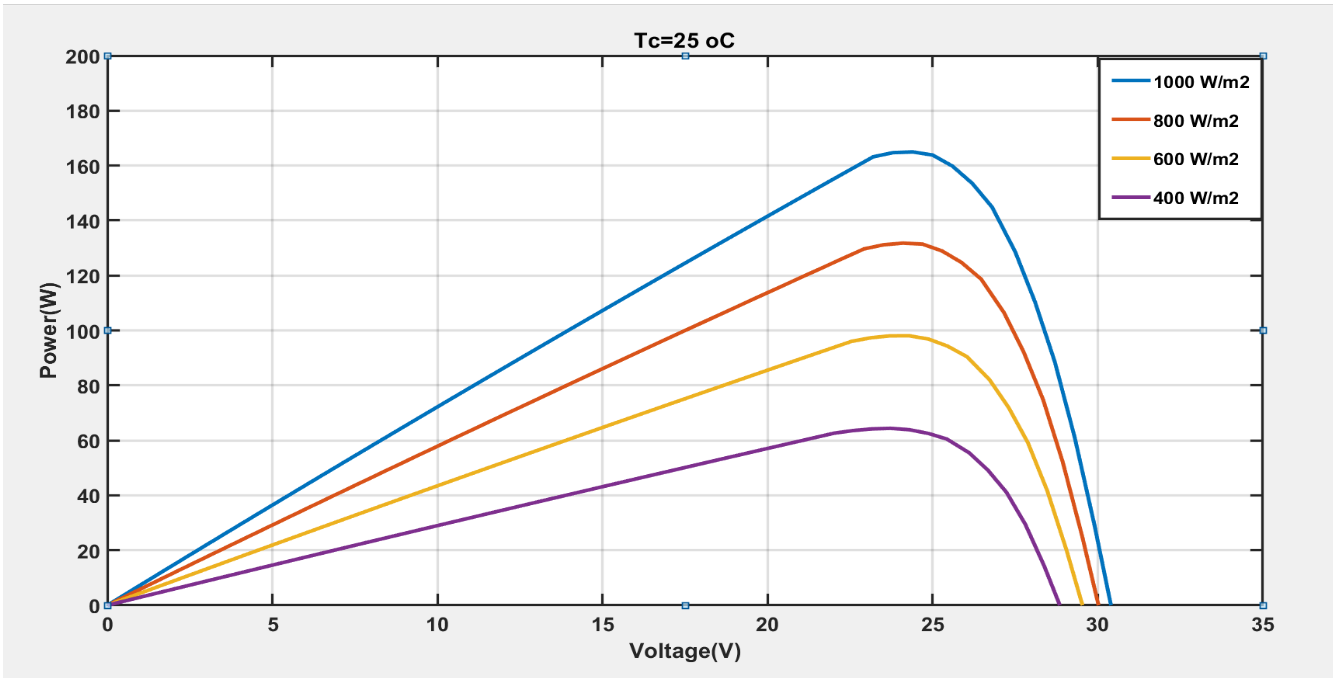

Figure 14 P–V characteristics with variable irradiation - constant temperature

The I–V and P–V characteristics under variable temperature and fixed irradiation are acquired in figure (15) and (16) respectively. The temperature changes between (25, 50 and 75°C), respectively, while the irradiation level remains constant at 1000 W/m².

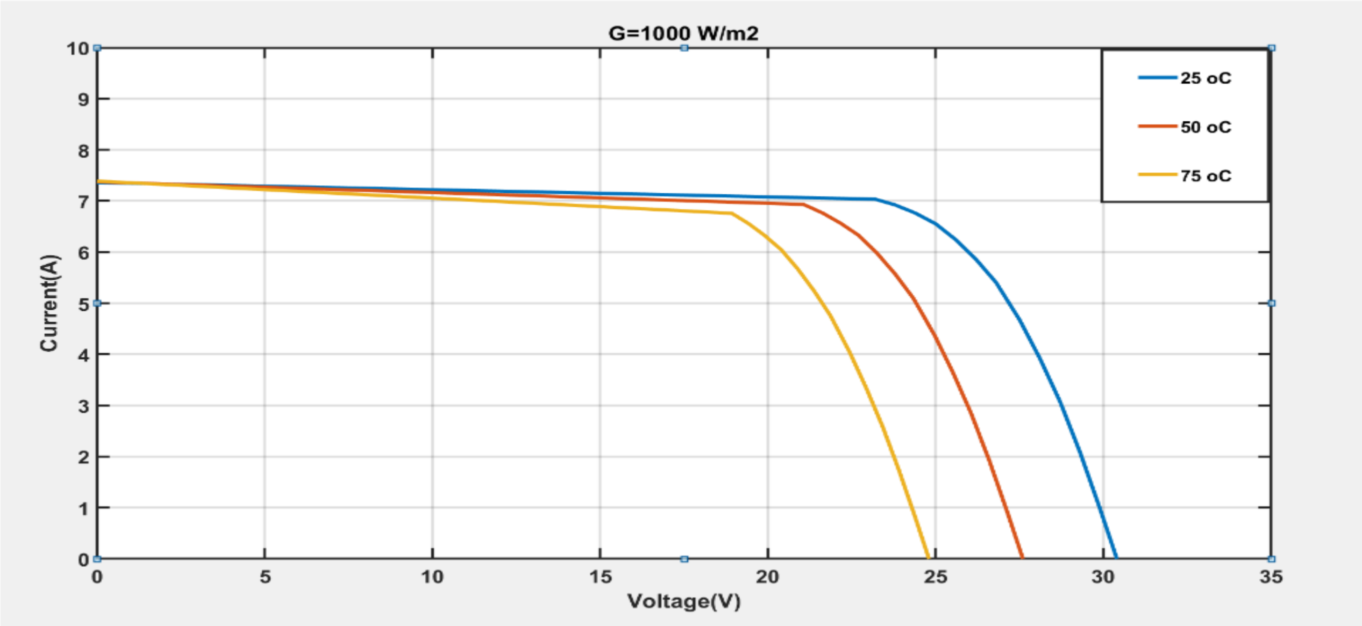

Figure 15 I–V characteristics with variable temperature - constant irradiation

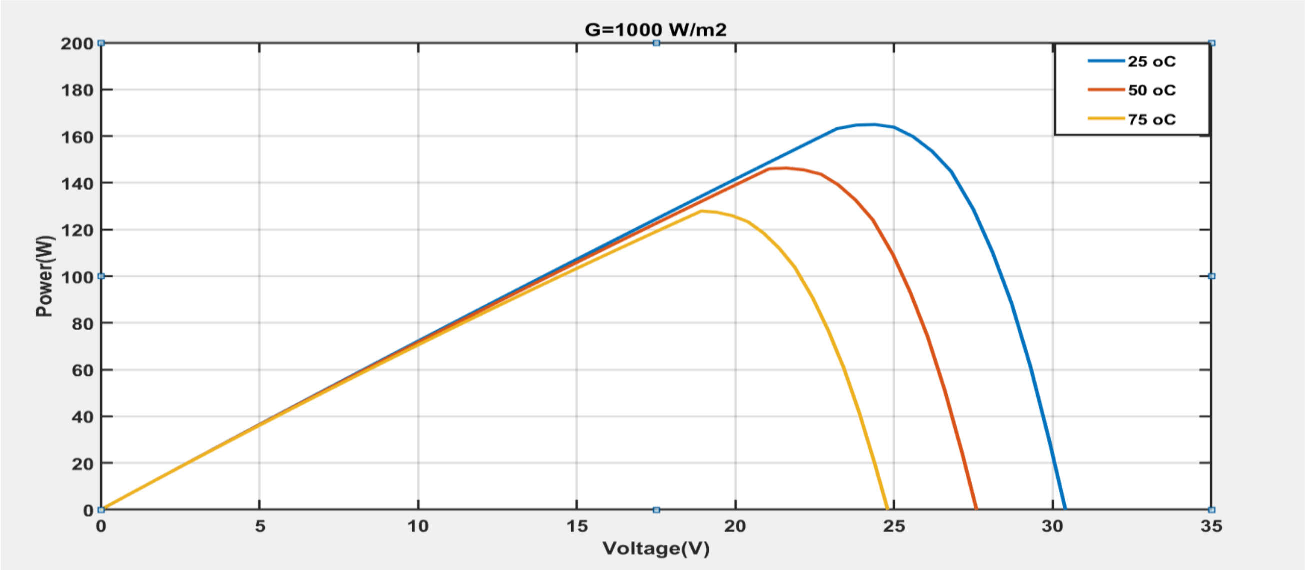

Figure 16 P–V characteristics with variable temperature - constant irradiation

4.2 Results from the System Simulation Using Thevenin's Equivalent Model source.

The PV model system was simulate based on the Thevenin's equivalent model as photovoltaic source model with P&O and INC algorithms, and boost converter to improve (MPPT) and the hence PV system performance. Figures (17) and (18) depict the block diagrams of the P&O and INC MPPT algorithms using the Thevenin's equivalent of photovoltaic source model.

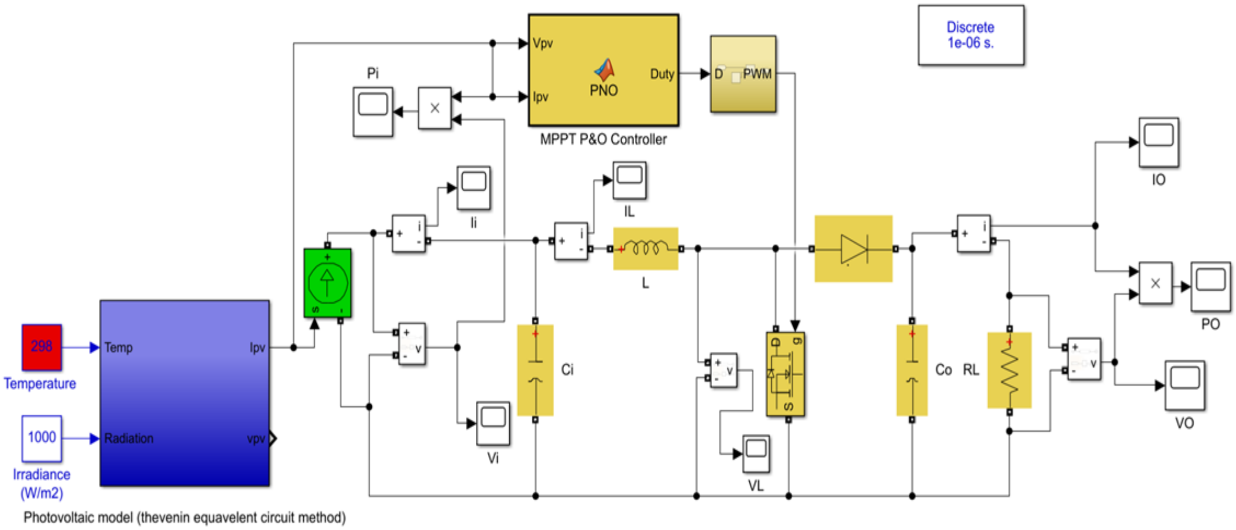

Figure 17 PV system with P&O MPPT algorithm

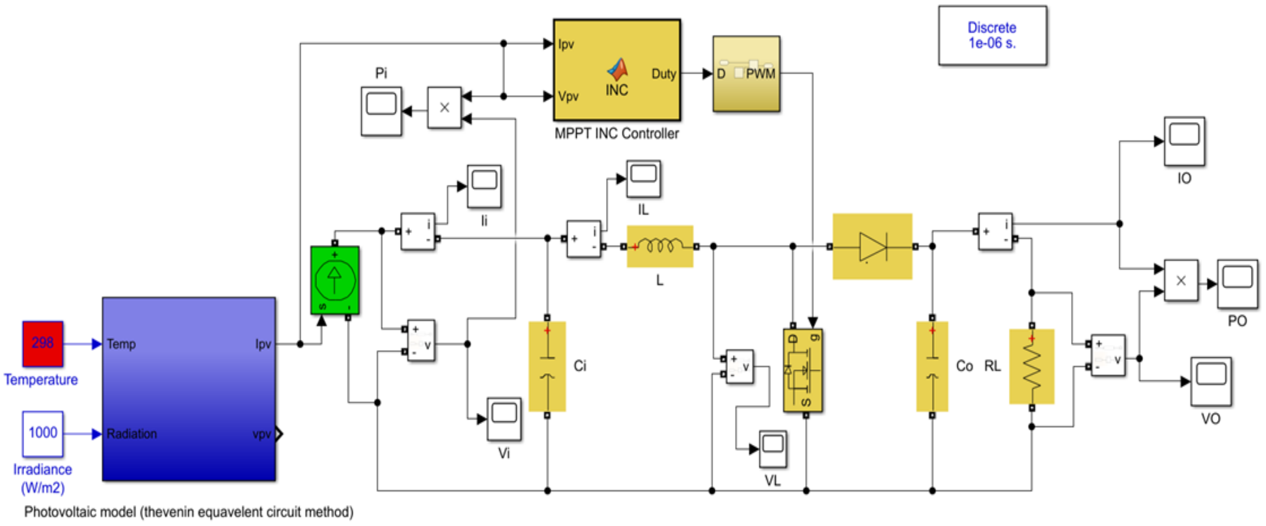

Figure 18 PV system INC MPPT algorithm

4.3 System Simulation at Constant Irradiation and Variable Temperature.

The system is tested when temperature changes while level of irradiance kept fixed at G=1000 W/m². A temperature was first 25°C, then it changed to 75°C after 0.4 seconds, and then back to 25°C after 0.62 seconds as shown in figure (19). Figures (20) and (21) shows characteristics of PV system for input and output power under constant solar level of irradiance (G = 1000 W/m²) and different temperature (T) conditions for P&O and INC MPPT algorithms.

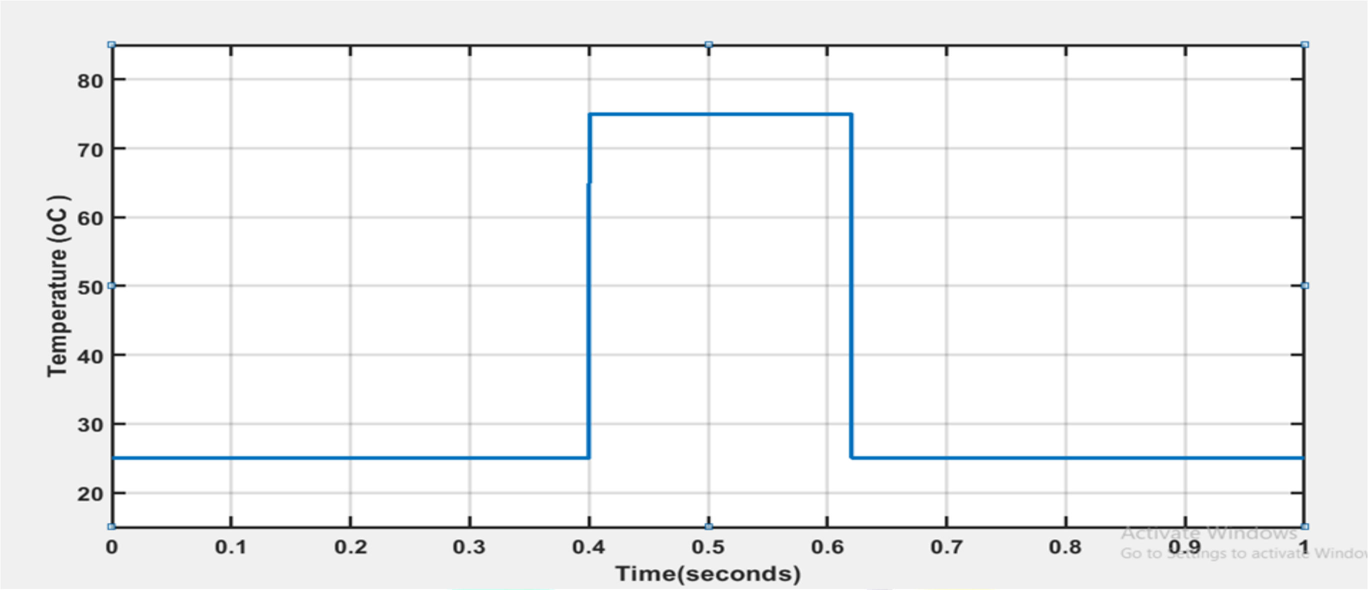

Figure 19 Temperature variation

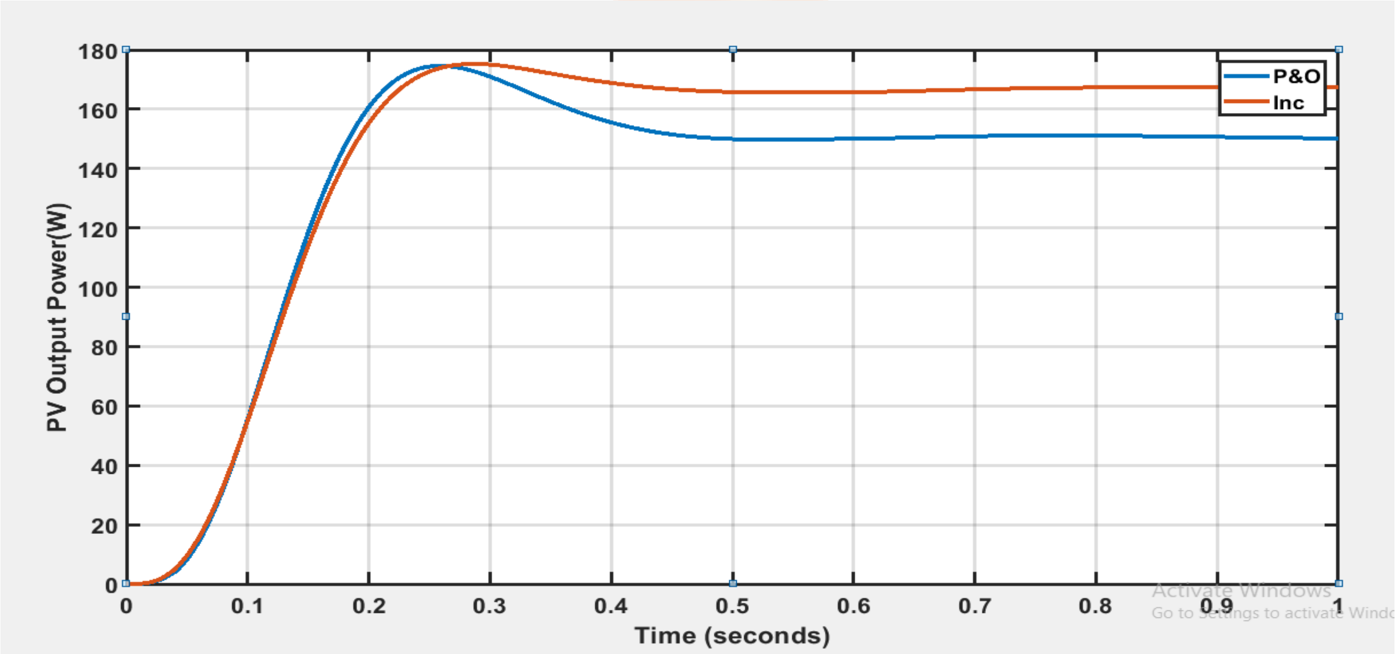

Figure 20 PV output power.

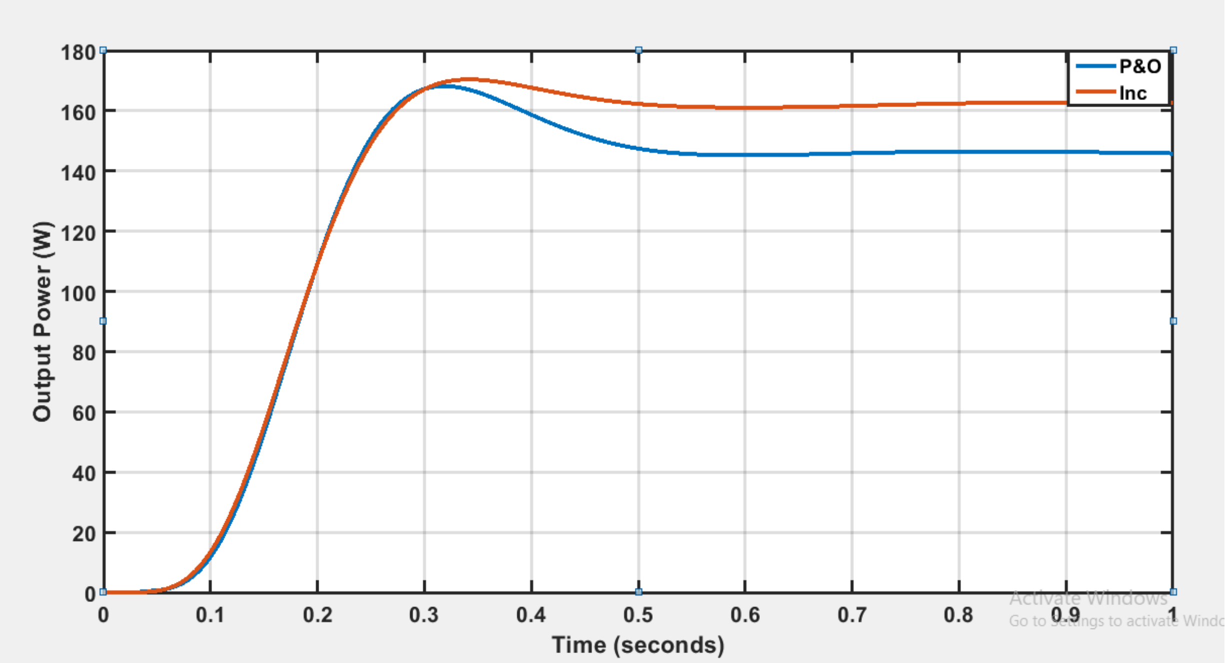

Figure 21 Converter output power.

4.10.3 System Simulation at Constant Temperature and Variable Solar Irradiance Level.

The system was tested under different levels of irradiation while maintaining a constant temperature at 25°C. The insolation level was 1000 W/m² at first, then after 0.357 seconds, it was changed to 600 W/m² and at 0.476 seconds, solar irradiation increased at 1000 W/m² again, shown in figure (22). Figures (23) and (24) shows characteristics of PV system for input and output power under constant temperature (T = 25°C) and variable solar irradiance level (G) conditions with P&O and INC MPPT algorithms.

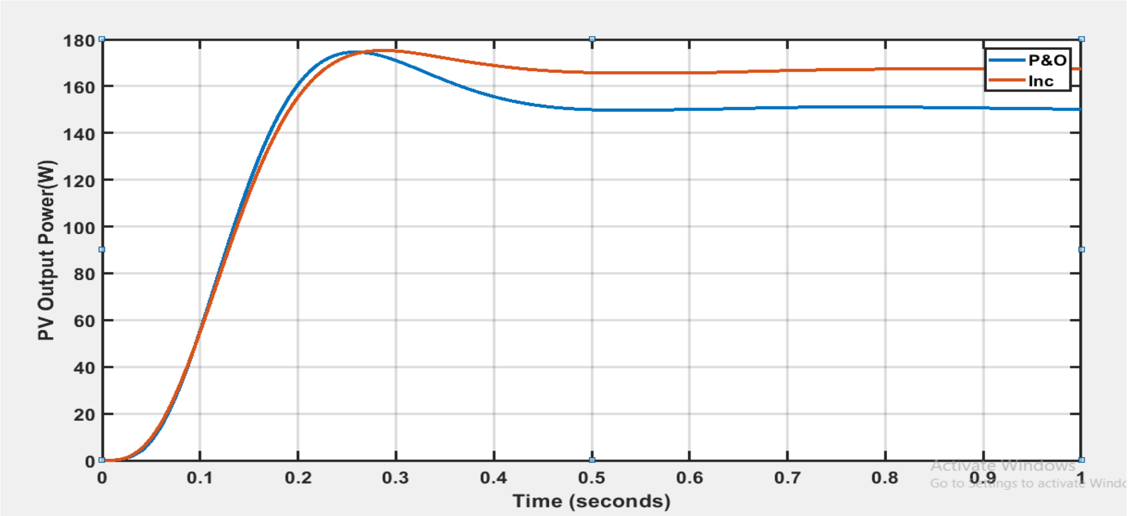

Figure (22) Changes in insolation levels.

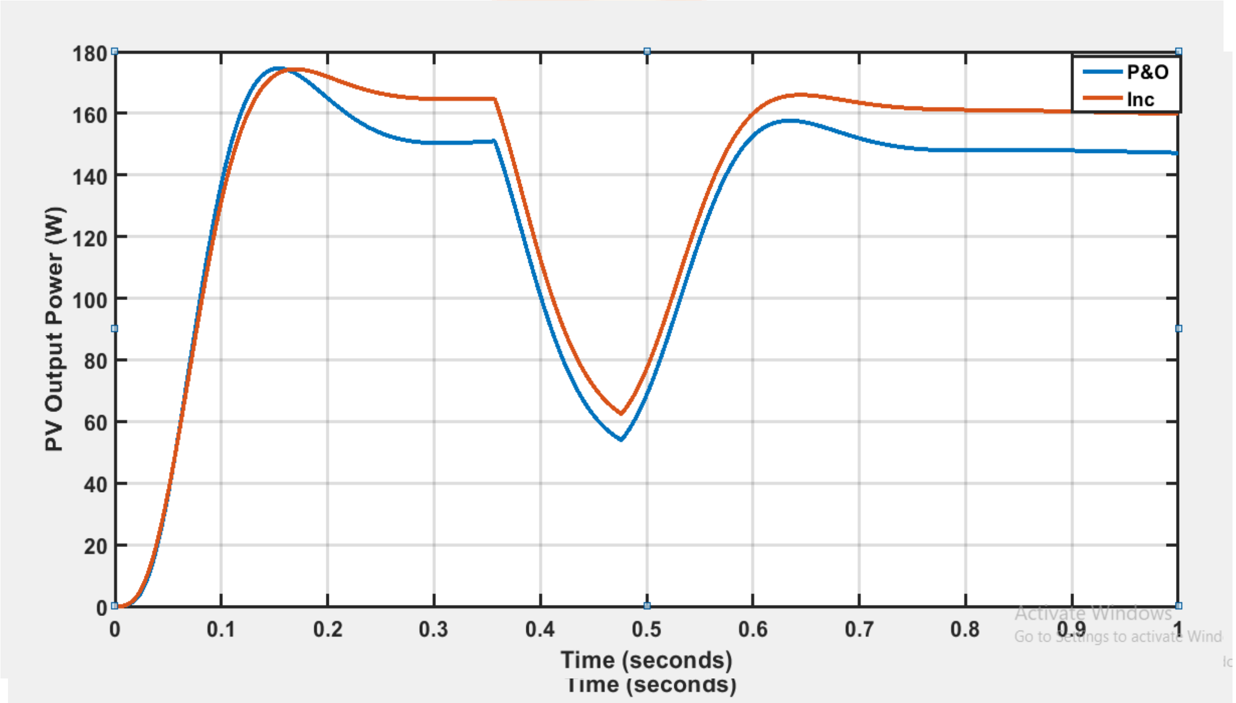

Figure 23 PV output power

Figure 24 Converter output power.

Under the standard test conditions (25°C and 1000W/m²), the P&O and INC MPPT algorithms are tested and compared..Table1 shows the results of the comparison for Thevenin's equivalent model using P&O and INC MPPT algorithms.

MPPT	PV system output power (W)	P.P ripple value (W)	Stability Time (s)	Absolute Percentage error	Efficiency (%)
P&O	145.8	0.2	0.16	11.58 %	97.2
IC	160.9	0.22	0.125	2.5 %	98.29

Table 1 Comparison between P&O and IC algorithms for Thevenin's equivalent model.

5. Conclusion

In this paper, the INC MPPT algorithm tracks the maximum power point more accurate than the P&O algorithm, according to the simulation findings, and the INC method requires an addition sensor in comparison to the P&O algorithm, (INC) technique requires two variables to be sensed, whereas (P&O) approach only requires one. It has a faster response with less oscillation in both stable and transient conditions of unexpected changes in the environment temperature and solar irradiation.

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