A Comparative Analysis of series and parallel topologies of Perturb and Observe (P&O) and Incremental Conductance (InC) MPPT Algorithms for Photovoltaic System.

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ABSTRACT

Photovoltaic (PV) is considered one of the most important sources of energy in the world, owing to its inherent advantages of being cheap, environmental friendliness, and energy-efficient. To increase the output power of the solar PV system, it is most important to enforce it to operate at the highest possible maximum power point tracking (MPPT) algorithm lead an important role in optimization the performance of a photovoltaic (PV) generation systems. This paper compares two widely used MPPT algorithms, namely the Perturb and Observe (P&O) method and the Incremental Conductance (IC) method, known for their low cost and eases of realization. The algorithms were evaluated based on important parameters such as voltage, current, and power output for different combinations, with and without shading. The performance of the photovoltaic array was evaluated using the MATLAB Simulink toolbox. The simulation results demonstrate that the IC method can rapidly detect the maximum power point (MPP) when irradiance changes suddenly, with faster convergence and higher accuracy than the P&O algorithm. Simulations are performed to test the controller's capability oftracking the MPP when sudden variations in weather condition.

I. Introduction

Renewable green energy has gained popularity for its environmental and economic benefits,and among the various sources, photovoltaic (PV) generation is considered one of the most promising. The direct conversion of solar energy to electrical energy by PV cells makes it a clean, inexhaustible and low-maintenance source of power. However, PV panels and arrays generate DC power which needs to be converted to AC at standard power frequency to feed loads, requiring interfacing power converters between the PV arrays and the grid. Despite these advantages, PV systems face a significant challenge in the probable mismatch between the operating characteristics of the load and the PV array.

When a PV array is directly connected to a load, it often fails to achieve the Maximum Power Point (MPP) of the PV array as the system's operating point occurs at the intersection of the I-V curves of the PV array and load. To overcome this issue, an MPPT is used to maintain the PV array's operating point at the MPP. However, it is not predetermined where MPP occurs in the I-V plane, so a model of the PV array and measurements of irradiance and array temperature are required to calculate it. These measurements can be costly, and the parameters for the PV array model may be insufficiently understood. Therefore, the MPPT continuously searches for the MPP, and different MPPT algorithms utilizing solar panel characteristics and MPP location have been proposed in the literature. [1,4]

To achieve the highest power output from a solar PV module and transfer it to the load, an MPPT is employed. The MPPT acts as an intermediary between the load and the module, and a dc/dc converter is utilized. The load impedance is varied to match it to the peak power when the duty cycle is changed, resulting in the maximum power being transferred. To maintain the PV array's operating at its MPP, different MPPT techniques are required, such as the Perturb and Observe (P&O) method, Incremental Conductance (IC) method, Fuzzy Logic Method, etc [3]. Of these, the Perturb and Observe (P&O) and Incremental Conductance methods are the most popular and have been extensively studied. [4]

The paper is structured as follows: Section 2 discusses the mathematical models of the PV module and the DC/DC boost converter. Section 3 provides a detailed explanation of the P&O and InC MPPT algorithms. In section 4, the simulation results of the PV array, MPPT algorithms, and their comparison with and without shading are discussed. Finally, the last section concludes and provides scope for further work.

II-1.Mathematical Modeling of the PV Modules

A solar generator is composed of a PV generator, which consists of individual solar cells as its fundamental building blocks. The PV cell's electrical analysis involves a distinct equivalent circuit that incorporates a diode, series resistances, and parallel resistances, with the sun acting as the source of energy. The equivalent electrical circuit of a solar cell can be illustrated using a one-diode model, as depicted in Figure 1.

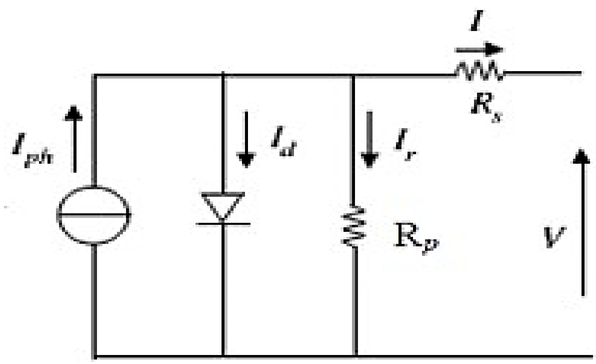

Figure. 1: General model of PV cell in a single diode model

The basic model of a solar cell comprises a photocurrent source, a diode, a shunt resistor (Rp) that represents leakage current, and a series resistor (Rs) that describes internal resistance to current flow. Figure 1 illustrates the electrical characteristics of the PV cell under solar irradiance (G), expressed in terms of PV cell output current (I) and PV cell voltage (V). These electrical characteristics can be described by the fundamental equations of Kirchhoff's first law, as stated in reference [5].

The voltage and current relationship at the array terminal is given as follows:

$$I = I_{ph} - I_D - \frac{V + I R_S}{R_P} \qquad (1)$$

$$I = I_{ph} - I_0\left[e^{\frac{q(V+IR_S)}{nKT}} - 1\right] - \frac{V + I R_S}{R_P} \qquad (2)$$

$$I_{ph} = I_{SC}\frac{\phi}{1000} \qquad (3)$$

The equation for the relationship between output current I and output voltage V of a photovoltaic cell includes various parameters such as generated photo-current I_{ph}, diode reverse saturation current I_D, diode ideality factor (n), series resistance R_S, parallel resistance R_P, and absolute temperature in Kelvin (T). Additionally, the equation involves physical constants like the elementary charge constant q ($1,602.10^{-19}$ C) and Boltzmann constant k ($1,380.10^{-23}$ J/K).

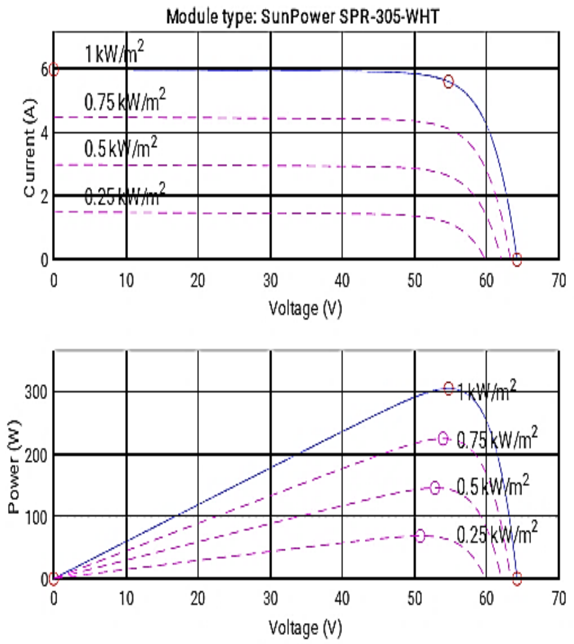

Figure 2. The P-V and I-V The Photovoltaic module's characteristics. were measured at 25°C and different levels of irradiance.

II-2 DC/DC Boost Converter

II-2.1Analysis of DC/DC Converter

The boost converter is a primary form of DC/DC converter that can alter the transformation ratio by electronically modifying the duty cycle between 0 and 1. Its design is based on the conventional correlation between the input signal, output voltage, and duty ratio. The equation (4) expresses the output power.

$$V_{out} = 1/(1-\alpha) \times V_{in} \qquad (4)$$

Where;

V_{in}: The input voltage supplied to the converter.

V_{out}: The output voltage supplied by the converter.

D: The duty cycle of the switch's'.

Figure 3 illustrates the Electric structure of the boost power converter

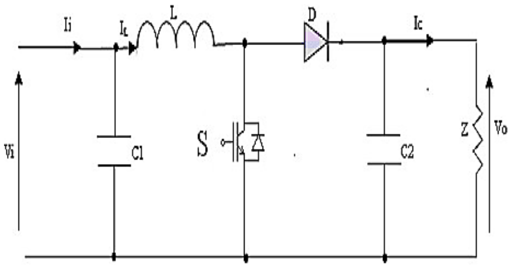

Figure.3. Electric structure of the boost power onverter [5]

A DC-DC power switching converter is widely employed in solar systems to convert Direct Current power between different voltage levels. Moreover, it is commonly utilized in maximum power point trackers to enhance the energy conversion process.

II-2.2 Control of DC/DC converter

The DC-DC converter control strategy is established by calculating the optimal input voltage reference to extract the maximum power from the PV array. An MPPT algorithm is used to determine the voltage reference, which detects the changes in PV array power to set the appropriate voltage reference. These systems are typically situated close to the PV module, and they distribute the energy harvested from it. Additionally, forecasting studies are conducted for photovoltaic applications.

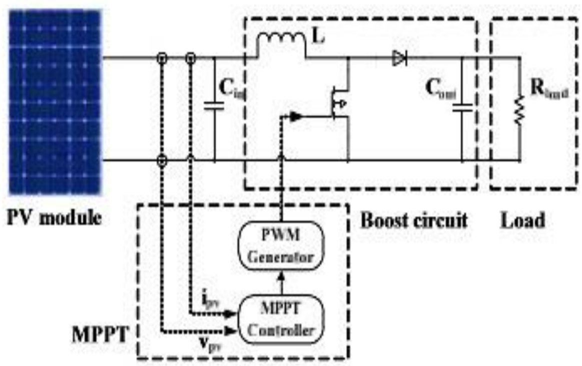

Figure 4. PV array utilizing MPPT control. [6]

III-MPPT Techniques

Numerous methods have been developed for implementing MPPT, varying in terms of their cost, speed, efficiency, and implementation. In this work, we focus on two approaches: P and O , and the INC method. The suggested system's MPPT algorithm involves directly adjusting the duty cycle of the DC/DC converter based on sequential measurements of current and voltage. The accuracy and efficiency of the controls are influenced by these measurements.

III-1 Perturb and Observe method

This MPPT technique involves a small disturbance being introduced to the solar module's power, leading to continuous fluctuations. When the power increases due to the perturbation, it continues in the same direction until the maximum power point is reached. At this point, the power at the next instant decreases, and the perturbation is reversed. The algorithm oscillates around the peak point until it reaches a steady state. To prevent large power variations, the perturbation size is kept very small [4]. The flowchart shown in Figure 5 provides an easy-to-understand visualization of the algorithm.

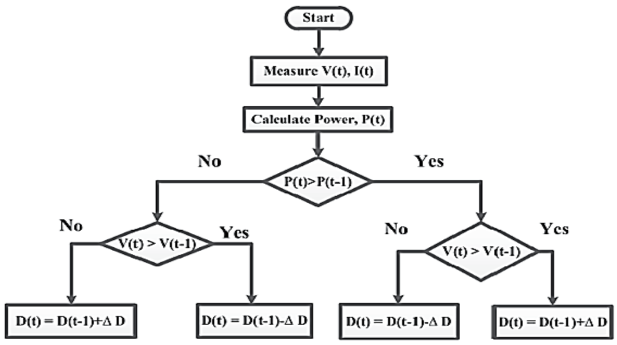

Figure 5. Flowchart for P&O Method [6]

The algorithm is developed in such a manner that it sets a reference voltage of the module corresponding to the peak voltage of the module.

III-2 Incremental Conductance (INC) Algorithm

The Incremental Conductance (IC) method was specifically designed to address the limitations of the Perturb and Observe (P&O) method in tracking the peak power of a solar PV module under fast-changing environmental conditions. Unlike the P&O method, the IC method can detect when the Maximum Power Point Tracker (MPPT) has reached the MPP and adjust the operating point accordingly. This is achieved by using the correlation between dl/dV and –I/V to calculate the direction in which to perturb the operating point if the MPP has not yet been reached. The IC method can accurately track rapidly changing irradiance conditions, which can be challenging for the P&O method. However, the IC algorithm is more complex than the P&O method, as it requires additional calculations to determine the direction of perturbation. [4].

A flow chart that illustrates this algorithm is provided in Figure 6 and is easy to comprehend.

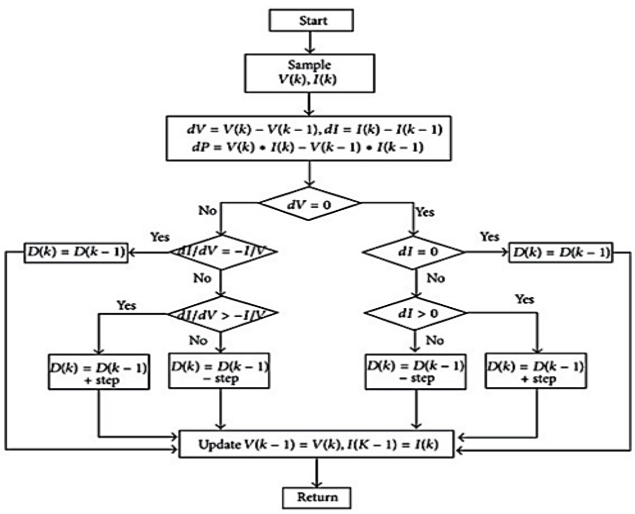

Figure 6 Flowchart for Incremental Conductance Method [6]

V- Results and discussions

The simulations were performed using the Simulink toolbox in MATLAB., was used to simulate the overall system represented in Figure 7. For this comparison study, the following MPPT approaches were considered: P&O and Incremental conductance

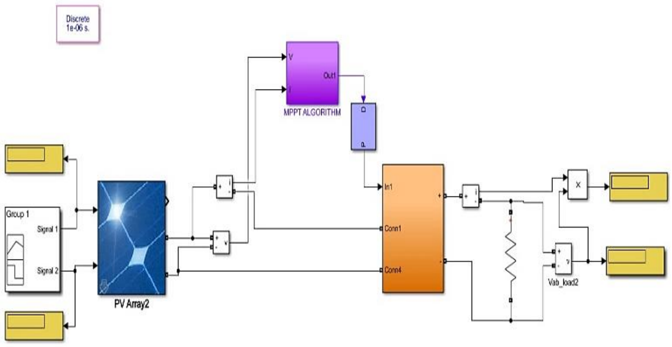

Figure7. Simulink representation of the PV system

Case 1; without shading

The comparison between the employed MPPT methods is initially carried out under constant conditions of 1 kW/m^2 and 25°C, as illustrated in Figure 8.

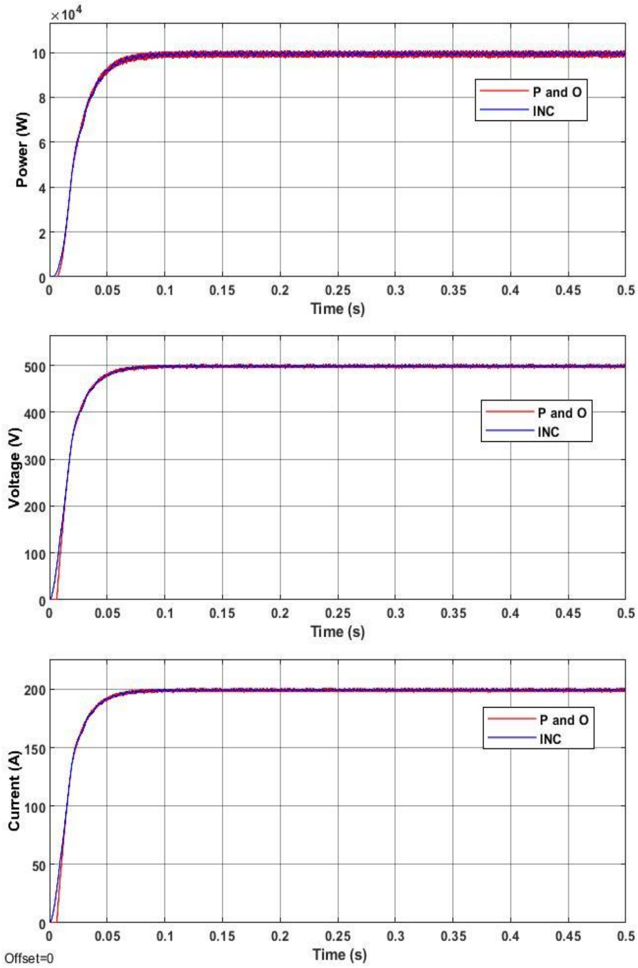

Figure 8 The output power, voltage, and current of the photovoltaic system under STC conditions.

Figure 8 indicates the output power, voltage, and current of the analyzed methods at STC

INC and P&O yielded power outputs of 102 KW and 98.3 KW, respectively. It is evident that INC attained a higher level of efficiency than P&O. In order to extent the robustness of the MPPT techniques, settling time is an essential tool. The settling time in STC for INC, and P&O is 0.08s and 0.1s respectively. So, INC ensures the convergence to the MPP more rapidly.

During transient states, noticeable oscillations may occur in P&O, causing power loss and fluctuations, in the steady-state operating point near the MPP.

The results suggest that INC MPPT technique excels in swiftly identifying the MPP. It displays the shortest duration for MPP tracking, minimal small oscillations around the MPP.

Case 2: With Shading

The MPPT is utilized to maintain the PV operating voltage and current at the Maximum Power Point on the Photovoltaic curve constantly, given that the PV panel is presently exposed to varying environmental conditions.

To evaluate the effectiveness and reliability of the studied methods for tracking and re-tracking the MPP under varying weather conditions, the cell temperature was maintained at a constant value of 25°C while the irradiance level was altered Solar irradiance of 1 KW/m² is applied to the Photovoltaic system during the time period of t ϵ [0, 0.7s]. Afterwards, it is reduced to 250 W/m2 between 1.2 and 1.5s, then increased back to 1000W/m2 between 2 and 2.3s., and it is changed again to 250W/m2 between 2.3 and 2.65 s . Finally, it is stepped to 1000W/m2 between 2.65 and 3s as shown in Figure 9

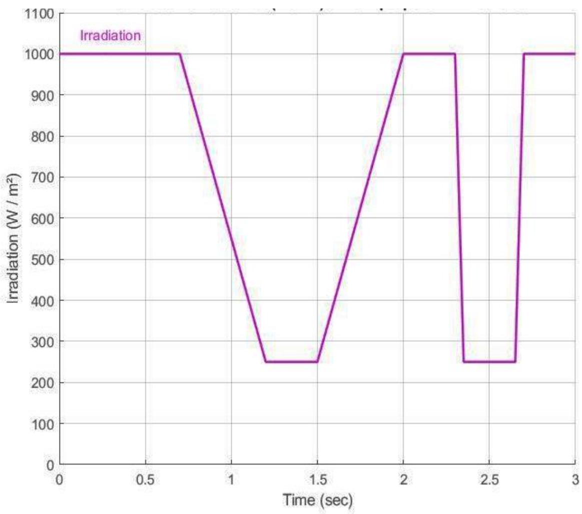

Figure 9. Changes in Irradiation

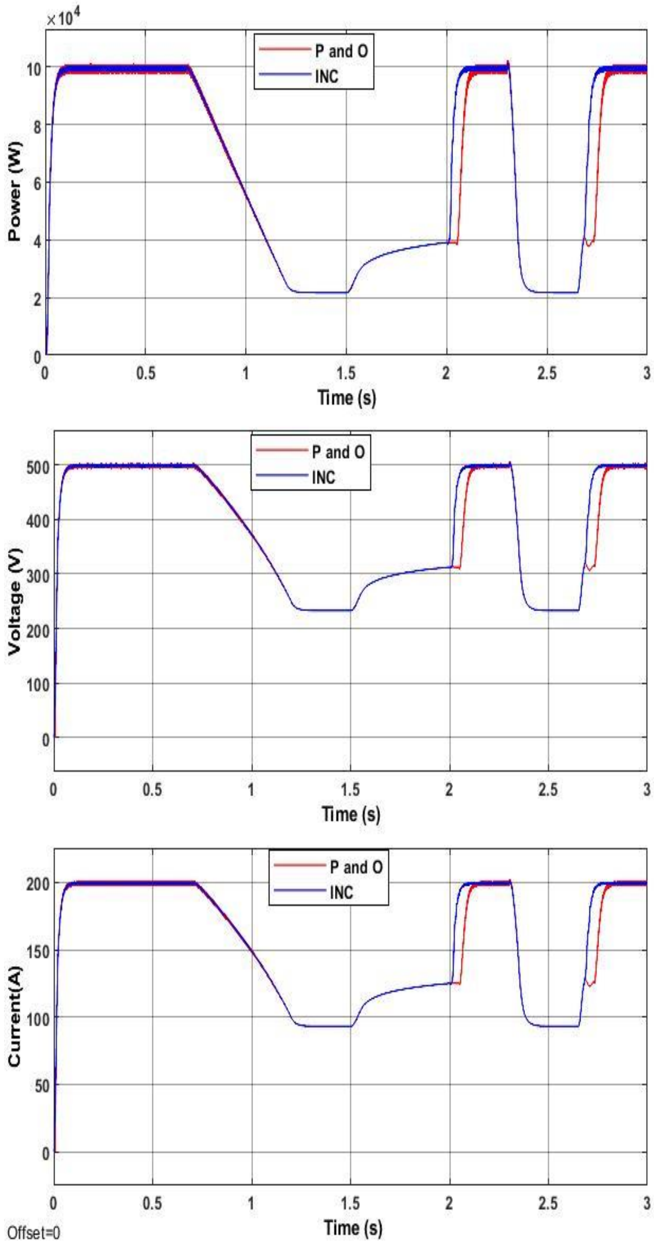

Figure. 10 The output power, voltage, and current of the photovoltaic system during a sudden change in irradiation.

Figure 10 shows that where the irradiance level is changed from 1000 to 250 W/m^2. The INC and P and O successfully track the maximum power point in real time. In the interval from 1.5 to 2s and from 2.6s to 2.7s , irradiance changed from 250W/m^2 to 1000W/m^2 The INC method reaches the MPP quickly, while the P&O method reaches the MPP with a significant overshoot. The P&O method exhibits significant fluctuations near the MPP.

Despite rapid changes in irradiance, the INC algorithm outperforms the P&O algorithm in terms of stability and power extraction. The results demonstrate that INC method can rapidly detect MPP when irradiance changes suddenly. With a faster convergence and higher accuracy rate than the P&O algorithm, The P&O algorithm's main flaw is its poor response to the reaction to changes in irradiance.

Converters in series

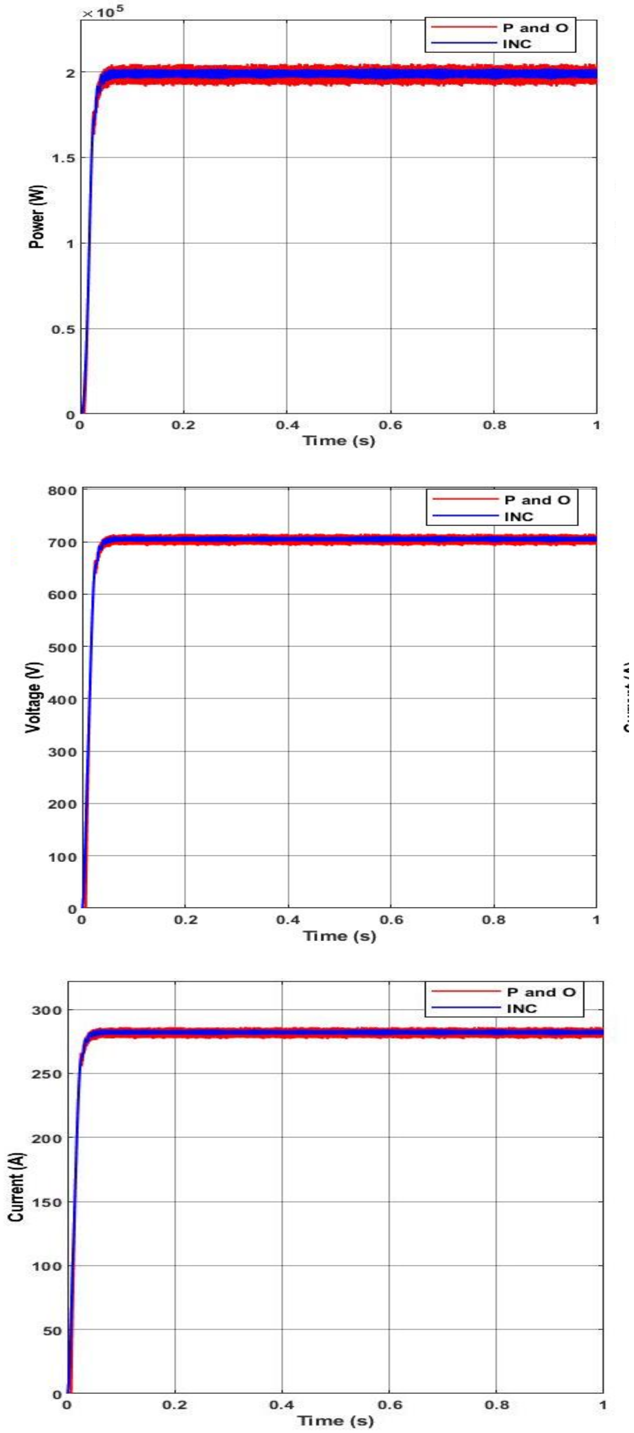

Fig. 11. PV system's power output, voltage output; and current output at STC condition (converters are connected in series).

Fig 11 shows the power, voltage and current output of the considered methods at STC. (converters are connected in series).The power achieved by INC and P&O was: 201 KW and 199.3 KW respectively. The efficiency achieved by INC and P&O was 99.8%, and 99.1% respectively. We see that INC achieved higher efficiency than the P and O.

Converters in parallel

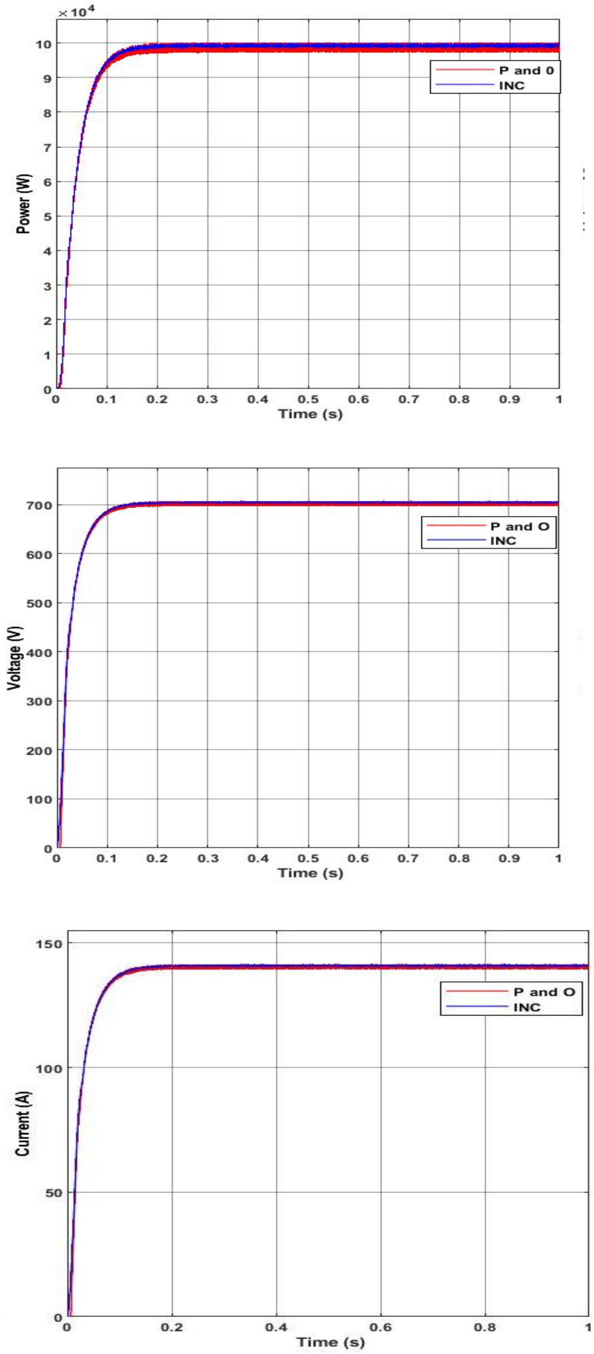

Fig. 12. PV system's power output, voltage output; and current output at STC condition (converters are connected in Parallels)

Figure 12 shows the power, voltage and current output of the considered methods at STC.(Converters are connected in parallels) The power achieved by INC and P&O was:

100.2 KW and 99.6 KW respectively. The efficiency achieved by INC and P&O was 99.5%, and 98.9% respectively. We note that the time of tracking the MPP is 0.16 s;0.22s , INC ensures the convergence to the MPP more rapidly.

VI-Conclusion

A comparative analysis is presented in this paper between some important MPPT algorithms. This comparison is focused on the analysis of these MPPT' results, such as efficiency and response time. a MATLAB Simulink-based mathematical model of the SPR-305E-WHT-D solar panel for maximum power point tracking algorithms. The study explores and compares the effectiveness of two popular MPPT algorithms: Perturb and Observe (P&O) and Incremental Conductance. The simulation results demonstrate that the Incremental Conductance method outperforms the P&O algorithm. Because of its higher steady-state accuracy and environmental adaptability (responds quickly to changes in irradiance) it is widely implemented tracked control strategy. The main disadvantage of the 'Perturb and Observe Method' is to track the peak power of the solar panel under the fast-varying atmospheric condition. This disadvantage can be overcome by using Incremental Conductance method. The implementation of these algorithms results in enhanced performance in both the dynamic and steady states of the photovoltaic system. Additionally, they also improve the efficiency of the DC-DC converter system.

The conventional P&O and INC methods usually use a small and constant iteration step size, which compromises the dynamic tracking speed especially under rapidly changing irradiation conditions. To address this trade-off between steady-state oscillations and dynamic behavior, various modified P&O and INC methods with adaptive variable iteration step sizes have been proposed. The future work will focus on exploring these modified methods. Compared to conventional tracking algorithms Perturb and Observe (P&O) and incremental conductance (INC).

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