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Optimization and Simulation of the Perturb and Observe Algorithm for Maximum Power Point Tracking in Photovoltaic Systems

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ABSTRACT

This paper simulates and investigates the "Perturbation and Observation" (P&O) algorithm, applied in the maximum power point tracking (MPPT) technique for photovoltaic (PV) systems: This work explores how dynamic adaptations to temperature and solar radiation can raise the efficiency of solar panels thereby optimizing power extraction from the photovoltaic system. Under study are a solar module, a DC-DC boost converter, a maximum power point tracking controller, and an electrical load. Using MATLAB/Simulink, the performance of the algorithm under three separate operating conditions—variations in temperature at a constant solar radiation, variations in solar radiation at a constant temperature, and simultaneous variations in both solar radiation and temperature—was evaluated. The results show that the method offers fast dynamic reaction and great tracking of the greatest power point, therefore improving the efficiency of photovoltaic systems. The results of the study show that fast changes in solar radiation might affect the effectiveness of the algorithm, thereby stressing the need of more complex management techniques to preserve accurate and stable tracking.

Introduction

Due to the increasing population density and the increasing demand for electrical energy, research institutions have begun to investigate alternative energy sources that may help counteract the adverse effects of the widespread reliance on conventional fuels. Due to the efficiency of industrial production and their modern lifestyle, more and more people are accustomed to being suckers these days. Research indicates that in recent years, the limitations of conventional energy sources like coal and gas have surfaced [1].

Renewable energy, particularly solar energy, has emerged as one of the most intriguing substitutes, garnering significant interest from the scientific community. Low maintenance requirements, environmental friendliness, and accessibility as a free, abundant resource in many places are characteristics of solar energy. These characteristics make solar energy a viable solution for the sustainable escalation of energy consumption few elements that have a major impact on solar cell efficiency are temperature, sun irradiation, and spectral characteristics. Additionally, external factors that impact performance include dirt buildup, overcast skies, and the sun's position throughout the day, which typically results in relatively low solar cell efficiency.[2] Maximum Power Point Tracking (MPPT) techniques are largely responsible for resolving these issues and optimizing energy output. By using voltage-current (VI) characteristics, these methods dynamically adjust photovoltaic (PV) system operations based on shifting environmental conditions, ensuring optimal performance. MPPT has proven to be an effective solution for boosting energy collection in a variety of settings.[3]

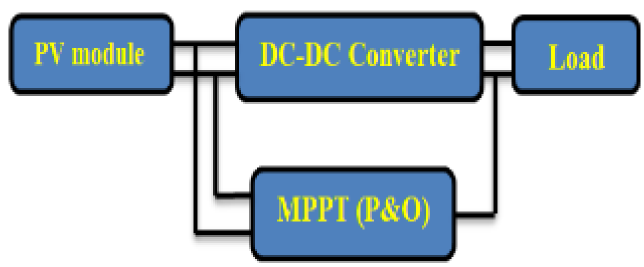
The Perturb and Observe (P&O) algorithm is one of the most widespread Maximum Power Point Tracking (MPPT) techniques. It is also one of the most straightforward to use and implement. This method creates power fluctuations by altering a solar system's operating voltage or current. The perturbation remains in the same path if the power increases; otherwise, it is inverted. However, the simplicity of P&O may result in oscillations around the maximum power point in steady-state conditions and decreased efficiency under rapidly fluctuating irradiation levels.[4], [5].

Tracks output power and gradually change the operational voltage of the photovoltaic (PV) system. Under continuous environmental conditions, this method guarantees efficient energy gathering by guiding the system to select the optimal path towards the maximum power point (MPP). P&O is generally relevant, however under fast changing environmental conditions it has performance constraints particularly in connection with sun irradiation patterns. Dynamic circumstances cause MPP mistracing that compromises system efficiency. To address these challenges, simulations have been extensively used to evaluate the effectiveness of the approach in numerous environments. Researchers can build and maximize an algorithm by simulating responsiveness, stability, and efficiency of it.[2]

In this study, a simulation of the P&O algorithm will be presented using MATLAB programming tools to analyze its performance under diverse environmental conditions, focusing on its efficiency and stability in achieving the maximum power point. Figure (1) show the overall block diagram of the used system.

Fig (1) Overall block diagram

In the following, the parts of the solar system that were



used in this work will be explained separately:

Photovoltaic Cell .1

Photovoltaic cells are made of semiconductor materials, and silicon is one of the most common of these materials. Where the photovoltaic cell consists of two layers, the first is the emitting layer, which represents by n and the second is the base layer, which represents p to be together pn junction[9]. Figure (2) shows the Photovoltaic cells that can be represented electrically by a current source connected in parallel with a diode in the presence of two resistors, one in parallel (Rpa) and the second in series (Rse)[10].

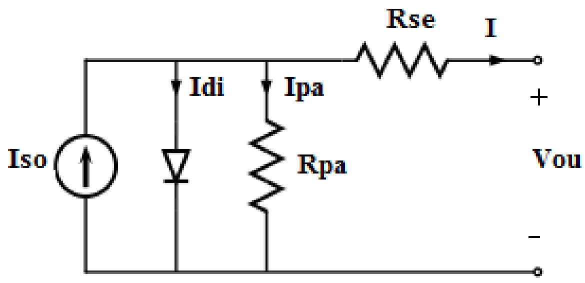


Fig (2) Photovoltaic Cell Circuit

Research studies have shown, as illustrated in Figure (3), that the voltage and current characteristics of photovoltaic cells exhibit non-linear behavior, which is significantly influenced by factors such as temperature, solar irradiance, and load conditions. These characteristics, along with their effects, are mathematically represented in Equation (1)[11]

$$I = I_{so} - I_0 \left\{ exp\left[\frac{q(V + R_{se}I)}{nkT_k}\right] - 1 \right\} - \frac{V + R_{se}I}{R_{pa}} \ldots (1)$$

Where:

Rse, Rpa: Series and parallel resistors of PV

Vou, I: Output voltage and current of PV

Iso: Light generated current

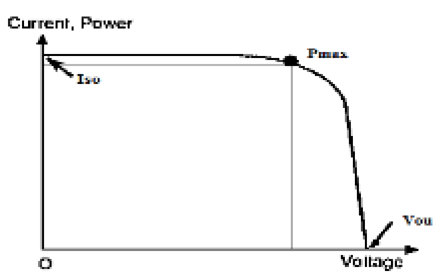
Io: Reverse saturation current

q: Electronic charge ($1.6 \times 10^{-19}c$)

n: Dimensionless factor

k: Boltzman constant ($1.38 \times 10^{-23} J/K$)

Tk: Temperature in k°



Fig(3) voltage and current characteristic

The solar system in general consists of a group of solar cells that are connected in a manner appropriate to each design, where they are connected in series or parallel or in groups that include both together solar cells panels, and these panels are the main component in the system of generating electrical energy through solar energy.[12]

2. Direct Current Convertor

DC-DC converters play a crucial role in renewable energy systems, especially in wind and solar applications, where they modify voltage levels to satisfy predetermined standards. Photovoltaic cells in solar energy systems usually produce a low output voltage of 0.5 to 0.6 volts per cell[13]. To achieve higher voltage levels suitable for various applications, Numerous cells are linked in series within a solar panel, resulting in a combined output voltage that can range from 20 to 40 volts or more, depending on the number of cells and panel configuration. However, even these voltages may be insufficient for certain applications, necessitating the use of DC-DC converters to step up the voltage to the desired level [14].

The convertor also used as a voltage regulator as the voltage generated by the solar panel cells is used to charge rechargeable batteries in some uses such as street lightening and cars based on solar energy or for the purpose of storing energy for cloudy or rainy days and in the case of charging these batteries directly without using a convertor it leads to damage the battery or reduce its functional life, so the converter is used to avoid these problems. The following figure (4) shows the method of connection the converter in the solar system, where it is connected in series with the panels of solar cells to obtain the maximum possible of efficiency.[14], [15]

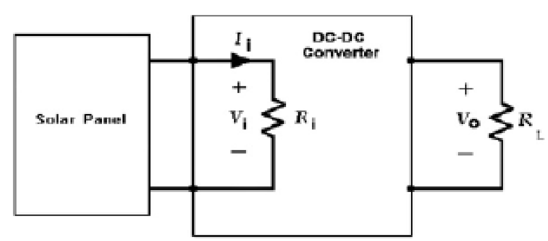


Fig (4) converter in Solar Panel Connection

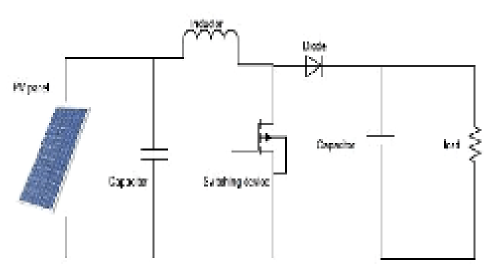
DC-DC converters are essential in various applications, with the most prevalent types being the Buck Converter, Boost Converter, and Buck-Boost Converter. Applications needing voltage reduction will find the Buck Converter appropriate since it lowers the input voltage to a smaller output value. The Boost Converter, on the other hand, raises the input voltage to a higher level when a voltage rise is needed. The Buck-Boost Converter combines the best parts of both types of converters to create an output voltage that is either higher or lower than the input voltage, depending on what is needed. This project is all about the Boost converter because it can raise voltage levels very well. [16]

Dc-Dc Boost Converter .3

A power electronic circuit called a DC-DC Boost Converter steps down a lower input voltage to a higher output voltage while keeping the same power level. The converter usually runs on an inductor, a switch (usually a transistor), a diode, and a capacitor. The Boost Converter works by storing energy in the inductor when the switch is "on" and releasing it when the switch is "off." This raises the output voltage. It works well for converting voltage, especially when a higher output voltage is needed from a lower input voltage. This is especially useful in battery-powered systems or renewable energy applications like solar power, where the input voltage could be lower than the required output. Boost converters are widely used in portable electronics, automotive systems, and renewable energy sources because they are simple, efficient, and can provide higher output voltage without the need for large transformers.[16]. This converter has been used in this work to raise the voltage as the solar panel cells provide rather low voltage.

shows how this converter is portrayed. Figure 5

Fig (5) Boost Converter Diagram



MPPT Algorithms: .4

One essential part of photovoltaic (PV) systems is Maximum Power Point Tracking (MPPT), which functions as the "brain" of the system by regulating the interaction between loads and solar panels. The system charges the battery at its best capacity by means of real-time detection of the voltage produced by the solar panels, constant tracking of the maximum voltage and current values (VI), therefore enabling the system. Many techniques are used, from basic to more sophisticated ones, in order to attain maximum power tracking[17]. Their complexity and efficiency help one to classify these algorithms into several groups.

- Offline Algorithms that contain Open Circuit Voltage and Short Circuit Voltage.
- Online Algorithms that contain Perturb and Observe, Incremental Conductance, and Slide Mode Control.
- Intelligent Algorithms that contain Fuzzy Logic Control, Artificial Neural Networks, and Particle Swarm Optimization.

Perturb and Observe Algorithm:

It is considered one of the most common techniques due to its simplicity and ease of implementation [17,18,19]. This method primarily relies on measuring the voltage and current values, from which the maximum power is calculated [20]. The maximum power point (MPPT) is achieved when the derivative of power with respect to voltage is zero, as depicted in Figure 6[7], [17].

δ Pertub and Observe$=\partial p/\partial v$….(7)

When p: power value and v: voltage value

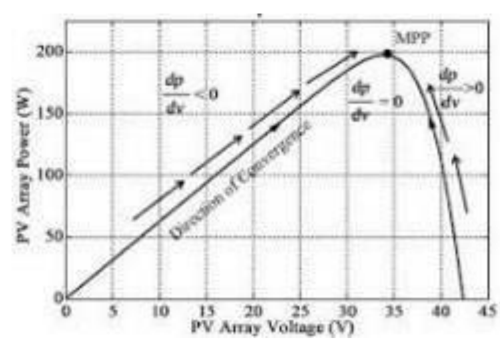


Fig (6) maximum power value

Initially the maximum power is calculated, then a perturbation is directed to a specific direction on the photovoltaic PV array, and then the value of the new power is calculated and compared to the previous reading, so if the value of new power is higher than the previous value, then it means that the direction of perturbation is correct and then dp>0 and continue towards the previous direction of perturbation until reaching the maximum power value MPPT. If the value of new power is less than the previous value, then the perturbation direction is wrong and then it is dp<0, this means that the maximum value of power is avoided and thus the direction will be reversed (opposite). In the figure (7) the flow chart of the Perturb and Observe Algorithm.[7], [20]

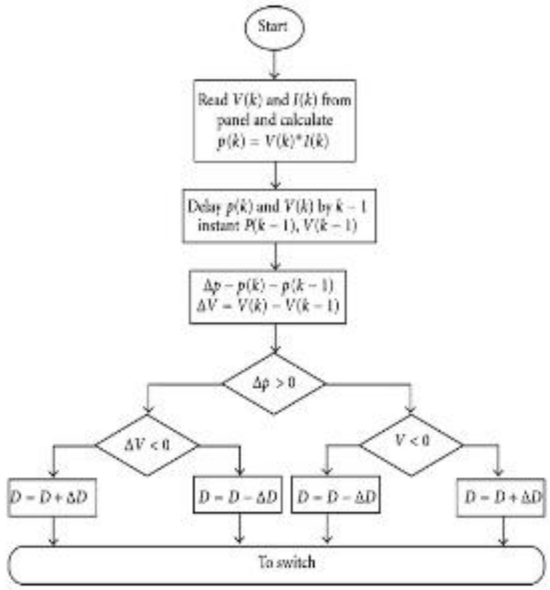


Figure (7): Flow chart of perturb and observe Method

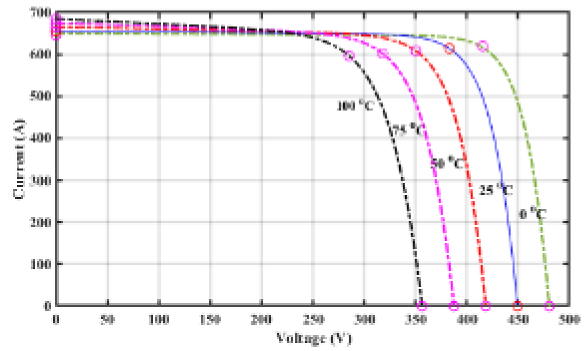
Result and Discussion:

In this paper, a photovoltaic solar energy system is modeled using Matlab/Simulink. The system comprises PV modules, a boost converter, an MPPT controller, and a load. The first component of the system is the PV array, which consists of seven (7) series-connected modules per string, with parallel strings. The module type used is SunPower SPR-305-WHT. The parameters of the solar modules utilized in this study are listed in Table 1.

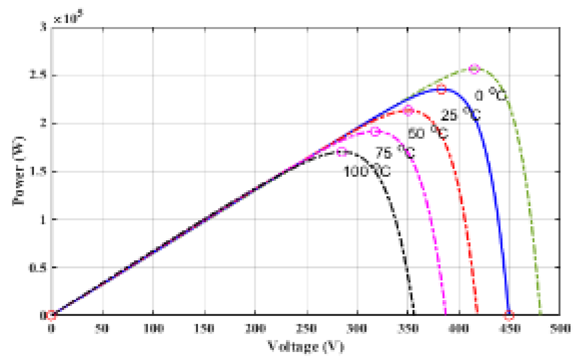
Table (1) PV Module parameter

Number of cells per modules	96
Open circuit voltage V_{OC} (V)	64.2
Short circuit current I_{SC} (A)	5.96
Voltage at maximum power point Imp (A)	5.58
Current at maximum power point Imp (A):	5.58
Temperature coefficient of Voc (V/deg.C)	-0.177
Temperature coefficient of Isc (A/deg.C)	0.003516
Temperature coefficient of Vmp (V/deg.C)	-0.186
Temperature coefficient of Imp (A/deg.C	-0.00212

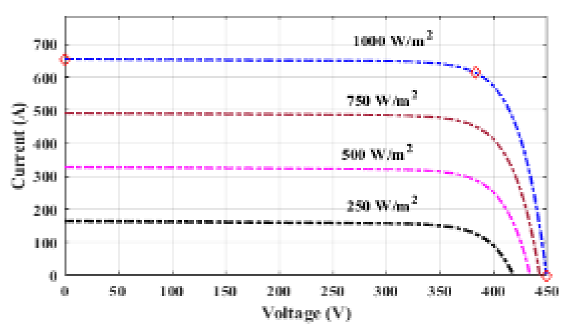
The power generated by solar cells is influenced by the surrounding climate conditions, including temperature and solar radiation. Therefore, PV modules have two primary inputs: solar radiation and temperature. The I-V and P-V characteristics for various cell temperatures at a radiation level of 1000 W/m² for the PV array are shown in Figures 8 and 9, respectively. Additionally, the impact of changing solar radiation on the I-V and P-V characteristics at 25°C is illustrated in Figures 10 and 11, respectively.



Fig(8) I-V Characteristic of the array at 1000 w/m2



Fig(9) P-V Characteristic of the array at 1000 w/m2



Fig(10) I-V Characteristic of the array at 25oc

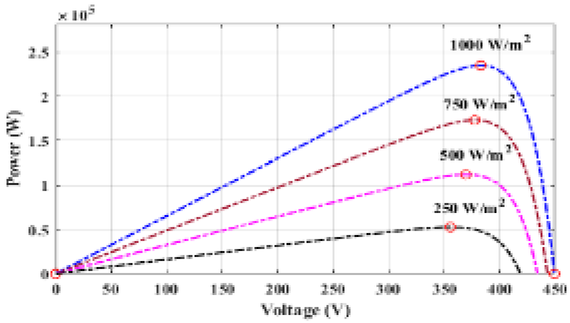


Fig (11) P-V Characteristic of the array at 25oc

Simulink model of Perturb and Observe algorithm is shown in fig. (12)

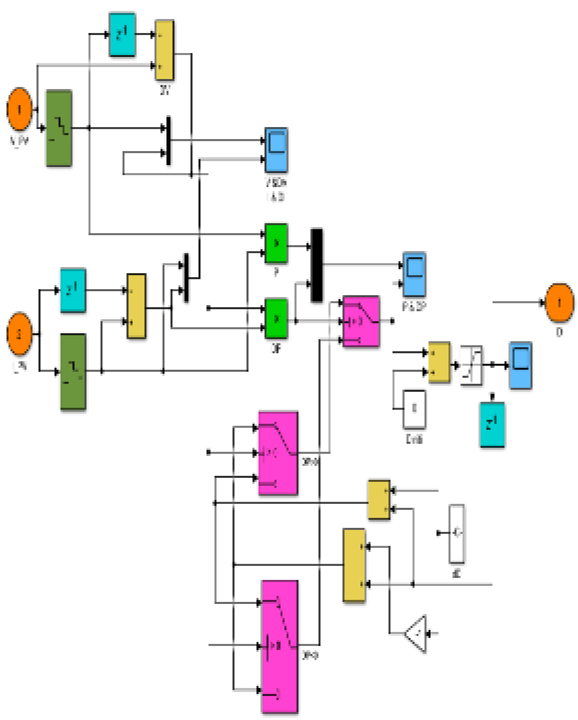


Fig (12) Simulink model of Maximum power point tracking by Perturb and Observe method

In this paper, three cases are analyzed to assess the effectiveness of the Perturb and Observe algorithm in tracking the maximum power point, which will be discussed later. Regarding variations in solar radiation, it is well-known that these changes are nonlinear, unpredictable, and fluctuate throughout the day. For the purposes of this study, it is assumed that solar radiation changes randomly, and as such, it is modeled using the Signal Builder block.

Case 1:

The variation in solar irradiance was modeled to analyze the system's performance. First, the impact of fluctuations and changes in solar radiation intensity on the system is examined. The temperature is set at 30°C, and the solar irradiance levels are varied across three different levels. The first irradiance level is set at 1000 W/m². At 0.3 seconds, the solar irradiance drops to 750 W/m². Finally, the irradiance stabilizes at 600 W/m² between 0.6 and 1 second. Figures (13 - 16) illustrate the resulting output power, voltage, and current for this case study.

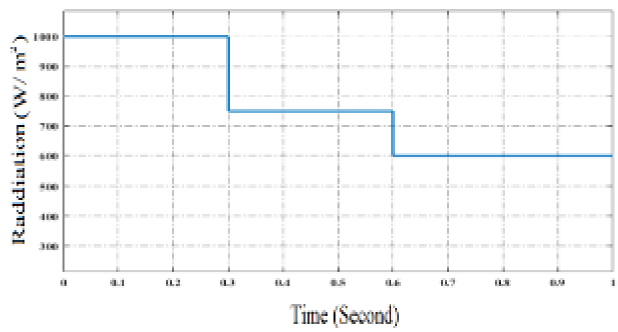


Fig. (13) Variation of sun radiation for first case study

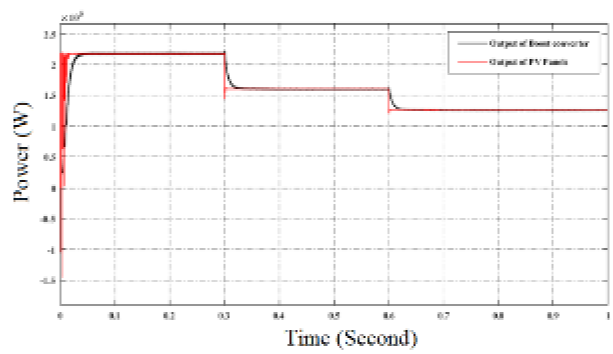


Fig (14) Output power of the Boost converter and output voltage of the PV panel

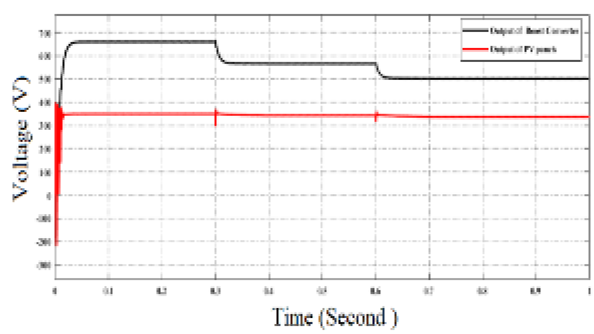


Fig (15) Output voltage of the Boost converter and output voltage of the PV panel

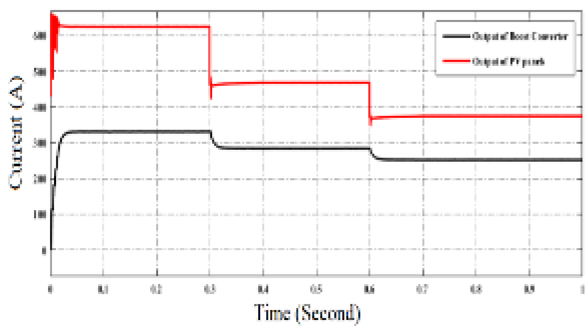


Fig (16) Output current of the Boost converter and output current of the PV panel

Case2 : The effect of temperature on the system is investigated. The solar radiation is set to 1000 W/m², and the analysis is conducted for three different .)17(temperature values, as shown in Figure

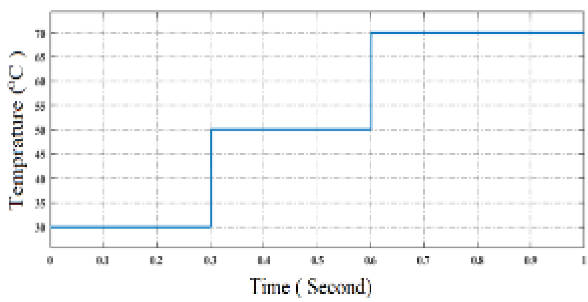


Fig (17) Variation of temperature for second case study

Figures (18–20) present the simulation results of the output power, voltage, and current corresponding to this case study.

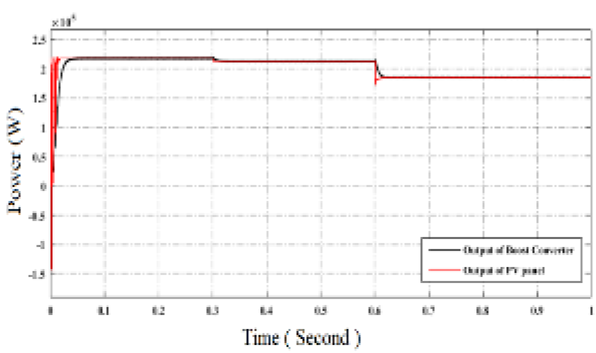


Fig (18) Output power of the Boost converter and output voltage of the PV panel

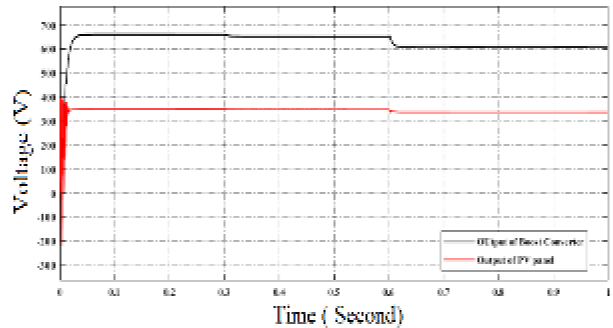


Fig (19) Output voltage of the Boost converter and output voltage of the PV panel

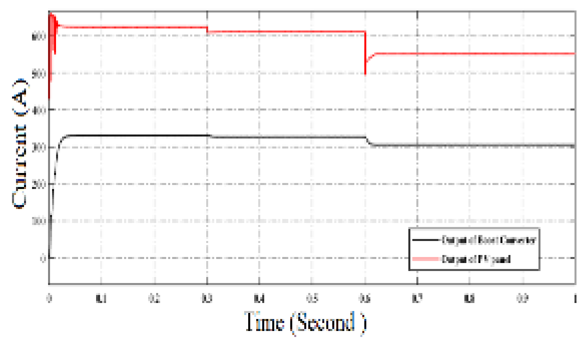


Fig (20) Output current of the Boost converter and output current of the PV panel

Case 3: In this scenario, the system's dynamic behavior was examined by applying simultaneous variations in solar radiation and temperature (Figure 21). The resulting output power, voltage, and current responses are depicted in Figures 22–24.

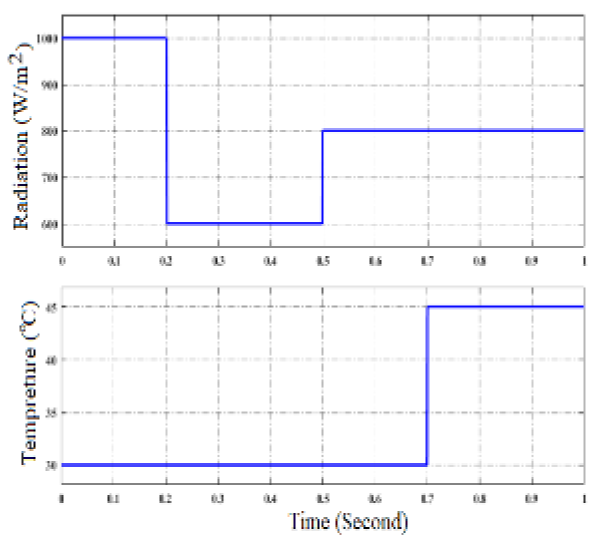


Fig. (21) solar radiation and temperature for third case study

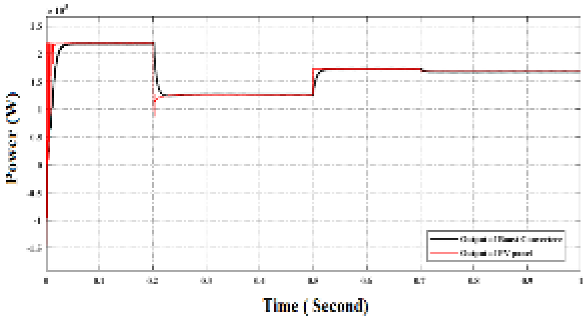


Fig (22) Output power of the Boost converter and output voltage of the PV panel

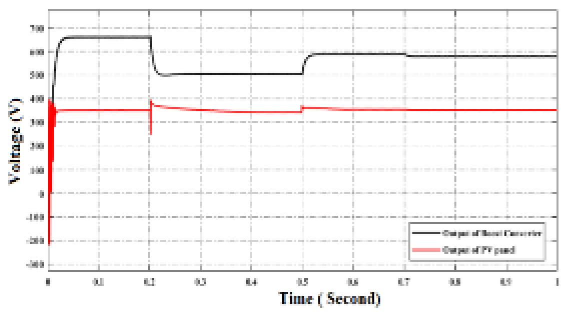


Fig (23) Output voltage of the Boost converter and output voltage of the P

A comparison between the Incremental Conductance (INC) method, which the authors previously studied [9], and the Perturb and Observe (P&O) algorithm, which was employed in this work, has been included to further support the analysis. Because of its low computing needs, simplicity, and ease of implementation, the P&O approach is frequently used and appealing for PV applications that are cost-effective.

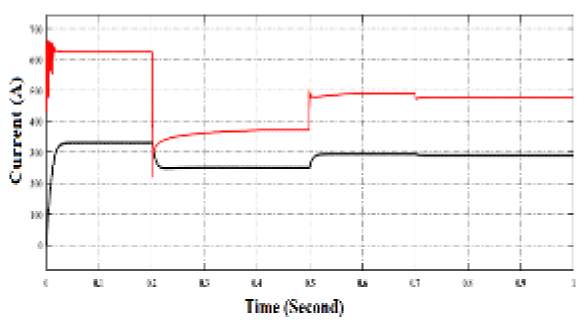


Fig (24) Output current of the Boost converter and output current of the PV panel

It may, however, experience diminished efficiency in situations with rapidly fluctuating irradiance and oscillations near the maximum power point. However, by directly calculating the power-voltage curve's] 9slope, our previous work on the INC algorithm [showed that it achieves higher accuracy and faster dynamic reaction. However, INC calls for more intricate computations and extra sensing units, which could raise the complexity and cost of implementation. Consequently, INC is more suited for applications needing high tracking precision and resilience under rapid environmental variations, even though P&O is still a viable option for straightforward and inexpensive PV systems.

To give a better understanding, Table (2) compares the Incremental Conductance (INC) approach that the authors previously investigated with the Perturb and]. 9Observe (P&O) algorithm utilized in this work [Higher precision in quickly changing conditions is provided by INC, albeit at the expense of greater complexity and hardware requirements, whereas P&O offers simplicity and inexpensive implementation costs.

Table 2. Comparative analysis between P&O and INC algorithms

Feature / Criterion	Perturb and Observe (P&O)	Incremental Conductance (INC)
Implementation Complexity	Simple, easy to implement	Involves greater complexity, necessitating slope computation.
Hardware Requirements	Voltage & current sensors	Voltage & current sensors + higher processing capability
Response under Fast Irradiance Changes	Slower, may cause mis-tracking	Faster, more accurate
Steady-State Performance	Oscillations around MPP	Stable operation at MPP
Computational Burden	Low	Higher
Suitability	Low-cost PV systems, educational purposes	High-precision PV applications

Conclusion:

The Perturb and Observe (P&O) algorithm has proven to be highly effective at accurately and quickly tracking the Maximum Power Point (MPP), which enhances the efficiency of energy extraction in photovoltaic (PV) systems. The P&O technique works well in stable environmental conditions, according to simulation results. But it might have problems when the amount of sunlight changes quickly, which could affect how well it tracks and how efficiently it converts. The Boost Converter has been shown to work well at raising the output voltage of the PV system, which improves the overall efficiency and performance of the solar energy system. To improve system stability and accuracy in tracking the MPP, it is suggested to make the algorithm more adaptable to sudden changes in the environment by combining it with advanced control methods like fuzzy logic or artificial neural networks.

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