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Original Article

Real Time Implementation of Maximum Power Point and Insolation Tracking Under Normal and Partial Shading Conditions for Standalone PV System

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***Abstract** - Due to various environmental conditions, the solar photovoltaic (PV) modules' output power is not always the maximum power they can produce. It becomes inexorable to track the maximum power point by adopting suitable techniques. Various methods are available to perform this tracking process, and perturb and observe (P&O) method is widely used due to its ease of implementation and simplicity. Although this method can track the maximum power point effectively, it has some limitations, like oscillation near the local maximum, thus preventing it from reaching the global maximum during partial shading conditions and increasing the time response. The power extracted will not be the actual maximum power that can be produced by the PV modules. To vanquish these impediments, a method that combines the P&O method with isolation tracking is proposed in this literature. The proposed method is more efficient than the traditional P&O method in extracting the maximum power under normal and partial shading conditions. The robustness of the proposed method is demonstrated by simulating the developed system, and the results are validated by the prototype developed.*

***Keywords** - Isolation tracking, Maximum power point tracking, Perturb and Observe method, Solar photovoltaic systems.*

1. Introduction

The daily increase in power demand engenders the need to increase power generation. Concurrently, environmental factors must be considered when generating electricity. Renewable energy resources, particularly solar photovoltaics, can effectively address this. The output power of a solar PV module depends on various environmental factors; extracting the maximum power from the modules is challenging. Some methods, called Maximum Power Point Tracking Methods (MPPT), can track the maximum power effectively. One of the simplest and most widely used methods is the Perturb and Observe (P&O) method, which can track the maximum power. The P&O method has some drawbacks, like oscillation around the maximum power point under steady state conditions and confusion between local and global maximum under dynamic changes in environmental conditions. The local maximum represents the maximum value of power that occurs locally during partial shading conditions. Its value will be less than the real maximum value of power, called the global maximum. These drawbacks are overcome by customizing the MPPT parameters according to the dynamic behaviour of the converter [1]. However, the results presented here do not explicitly address the improvement in efficiency. The tendency of the algorithm to oscillate near MPP is eliminated by adopting a variable step length [2]. Experimental results demonstrate that the proposed method is better than the classical P&O algorithm under steady state and dynamic change in climatic conditions, but the improvement in efficiency is not up to the mark. The performance of the P&O method is enhanced by evaluating the amplitude and frequency of the perturbations by online evaluation using the correlation method [3]. The results prove that the method is suitable for real-time implementation. However, no considerable improvement in efficiency is mentioned in the results. In [4], the P&O algorithm with some modifications is adopted to track the maximum power. This method scans the power and voltage characteristics, and the P&O algorithm is activated near the maximum power point. It is mentioned that the false detection of the global maximum power point is avoided. Even though it is mentioned that there is a considerable increase in efficiency, it is not very high. The problem of oscillations at steady state and delayed time response is reduced by adaptive step size [5]. However, there is a need for switching and a loss during the switching process. An improved adaptive P&O method is implemented in [6], which incorporates an additional PI controller with an algorithm to determine the Maximum Power Point (MPP) at steady state. This method proves to minimize the oscillations around MPP, but the percentage of increase in efficiency is not explicitly mentioned in the literature. In [7], the adaptive P&O method is proposed, in which the current is perturbed instead of the voltage. Simulation studies prove this method is superior to the conventional P&O method. However, the increase in efficiency is not mentioned here.

Moreover, it has not been validated by hardware results. A multiple-step size-zero oscillation P&O method is proposed to improve the tracking efficiency of the photovoltaic module [8]. This method is more efficient than the traditional P&O method, and the oscillations around MPP are nullified, which is one of the advantages of this method. This literature lacks hardware results to support the performance of the proposed method, and the percentage increase in efficiency is also not mentioned.

A variable step size P&O method implemented by using fuzzy logic method is proposed in [9] to overcome the drawbacks of the traditional P&O method. The simulation results show that the output power is higher when the proposed method is implemented, compared with the ordinary P&O method, but the percentage increase in efficiency is not mentioned in this literature. The traditional P&O and Incremental Conductance (IC) methods are investigated in tracking the MPP under normal and partial shading conditions in [10]. It is observed that the methods perform well during normal conditions but fail to track the MPP during partial shading conditions, which is justified by simulation results. The performance of the P&O algorithm under various operating conditions is examined in [11] and presented.

The study reveals that the algorithm oscillates more under high perturbation frequency operation and does not reach a steady state. Also, the system loses stability under this condition, but the transient response is fast. Handling a proper criterion for selection parameters makes it possible to achieve slightly higher efficiency under stable weather conditions. But there is confusion due to noise and system dynamics.

Moreover, the implementation cost is also high. From the literature analyzed, it is identified that most of the analysis that uses some form of modified P&O method have improved performance but fail to address the improvement in efficiency percentage and do not focus on tracking the isolation. This is overcome by the proposed method, in which the P&O algorithm with isolation tracking is used to overcome these issues.

2. MPPT Methods - An Overview

2.1. Evolution of MPPT Methods

The initial stage of development of MPPT methods comprises tracking the maximum power. Traditional methods like the P&O method and IC method belong to this category. However, they possess some limitations, like delay in convergence and oscillations near MPP. It is also cumbersome for the methods to track the maximum power under dynamic conditions. With the advancements in optimization techniques and emerging technologies like fuzzy logic, neural networks, adaptive neuro fuzzy and genetic algorithms, various new MPPT methods like Particle Swarm Optimization, Ant Colony Search and Grey Wolf Optimization algorithms were developed.

These algorithms perform well under changing environmental conditions but with increased computational complexity. In the later stage, hybrid methods evolved to establish a balance between accuracy and complexity.

2.2. Perturb & Observe Method

The perturb and observe method works by creating a disturbance in the voltage or current, and the changes in power corresponding to this new value will be tracked. The new value of power will be compared with the previous value to identify whether or not there is an increment in power.

If the value of power increases, the perturbation is continued in the same direction; otherwise, the perturbation direction is reversed. The operation of the P&O algorithm is elaborated in Figure 1.

3. Materials and Methods

3.1. Proposed MPPT Method

The proposed method incorporates the isolation tracking process with the conventional P&O method. The tilt angle of the PV module will be changed according to the preset program stored in a controller.

The tilt angle is physically changed with the help of a servo motor, which is controlled by the controller. The change in tilt angle is based on time settings so that the PV module receives maximum insolation. This control will work in parallel with the P&O algorithm, making it more efficient in tracking the maximum power.

The procedural step of the proposed methodology is given in detailed steps below:

1. Initialize the measurement of voltage and current.
2. Calculate the value of power and change in power.
3. Compare the new value of power generated with the previous value.
4. If the new power is more than the previous value, then continue perturbation in the same direction. If not, reverse the direction.
5. Measure the new isolation value and compare it with the previous one. If there is no change in isolation value, continue the process. If not, measure the value of voltage and current again and repeat the process.
6. Update the voltage and current values and return.

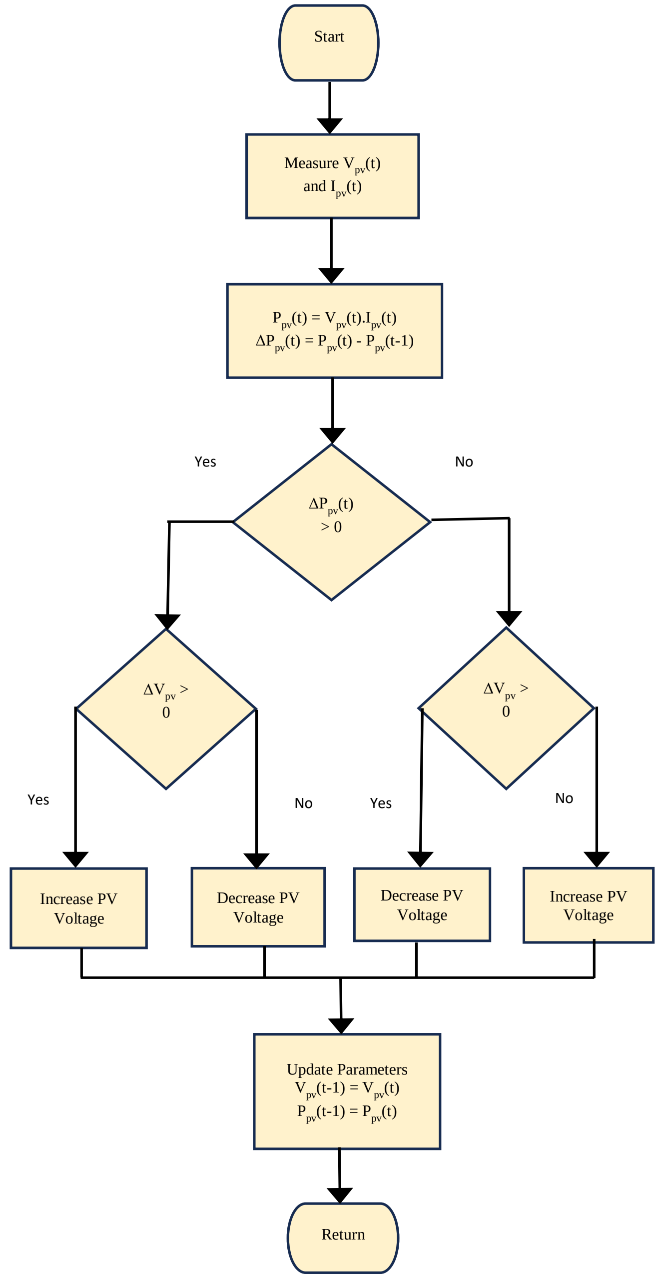

Fig. 1 Flowchart of P&O algorithm

3.2. System Development for Implementation of the Proposed Method

A photovoltaic system with a DC-DC boost converter is developed to validate the proposed MPPT method, which is shown in Figure 2. The voltage and current measured from the PV module are fed into the MPPT algorithm to generate the required duty cycle, which is the gate pulse to the MOSFET switch used in the boost converter.

The system is first simulated in MATLAB/SIMULINK to analyse the performance of the proposed method. A user-defined block is used to incorporate the P&O algorithm, which controls the duty cycle of the MOSFET switch.

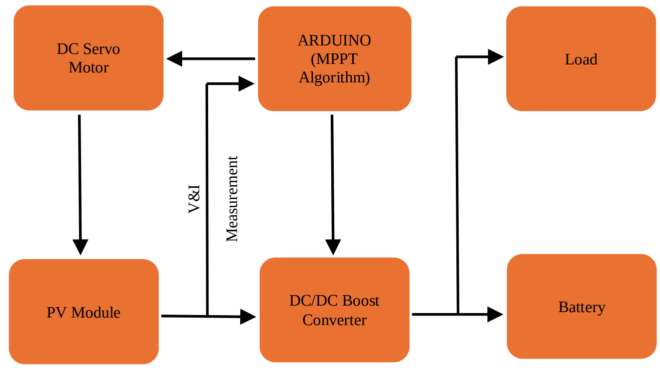

Fig. 2 Block diagram of the developed system

The model of the photovoltaic cell used in the developed system is given by Figure 3 [12]. The specifications of the solar PV module used in the simulation are mentioned in Table 1. In MATLAB/SIMULINK, the change in tilt angle for isolation tracking is replicated by using a signal generator block, which acts as one of the inputs to the solar PV module.

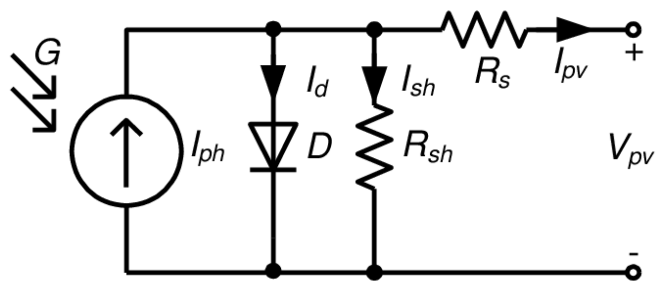

Fig. 3 Model of solar PV cell

The model of the boost converter circuit used in the system is shown in Figure 4 [13]. The specifications of the boost converter circuit are mentioned in Table 2. The temperature is maintained at 25 °C during the entire time of simulation.

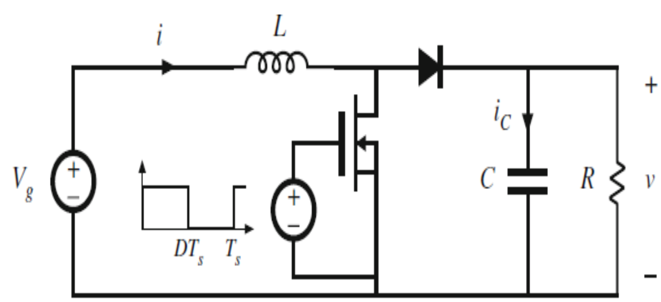

Fig. 4 DC-DC Boost converter model

Table 1. Parameters of the PV module used in the simulation

Parameter	Values
V_{OC}	21.5 V
I_{SC}	4.98 A
Maximum Power	97.99 W
V_{MP}	20.5 V
I_{MP}	4.78 A

Table 2. Parameters of the boost converter used in the simulation

Parameter	Values
L	3 mH
C_{PV}	1000 µF
C_{dc}	6500 µF
Switching Frequency	50 kHz
Load	20 Ω

The prototype developed to validate the results obtained through simulation is shown in Figure 5. The P&O MPPT algorithm is programmed into the ARDUINO controller. The voltage and current from the solar PV module are continuously monitored and sent to the ARDUINO by an INA219 current sensor. Taking this as input, the MPPT algorithm in the ARDUINO controller produces a duty cycle that is given as a gate signal to the MOSFET in the boost converter. A 20 Ω resistor is used as a load in the developed system. The control circuit used in the prototype is shown in Figure 6. The parameters of the solar PV module and boost converter used in the prototype are mentioned in Tables 3 and 4, respectively. The hardware results were taken from 7 am to 5 pm, and the corresponding results are presented here. The value of power and voltage is measured by a built-in LCD display specially programmed for measurement. The prototype has a reset button to switch the operation from the ordinary MPPT method to the proposed method.

Table 3. Parameters of the PV module used in the prototype

Parameter	Values
V_{OC}	13.6 V
I_{SC}	1.7 A
Maximum Power	20 W
Size	30*14.5 cm
Weight	138 g

Table 4. Parameters of the boost converter used in the prototype

Parameter	Values
L	312.5 mH
C_{PV}	10 µF
C_{dc}	62.5 µF
Switching Frequency	20 kHz
Load	20 Ω

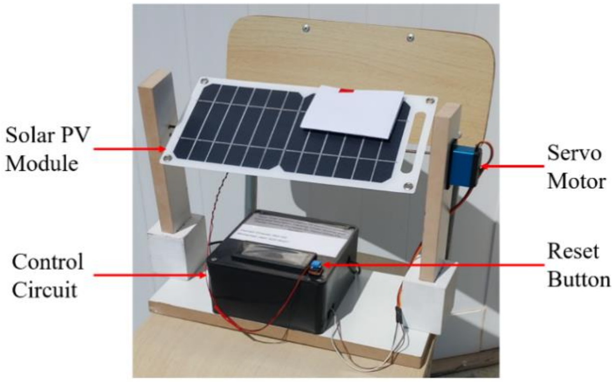

Fig. 5 Developed prototype showing partial shading condition

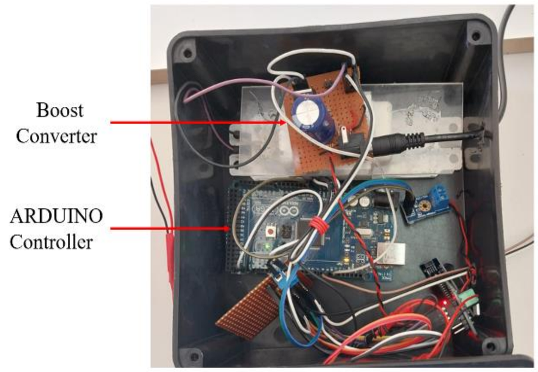

Fig. 6 Control circuit of the prototype

4. Results and Discussion

The developed system is simulated under a MATLAB environment to test the effectiveness of the proposed tracking method. The developed system with a single PV module is first simulated under normal operating conditions without and with the implementation of MPPT at various irradiance levels. The simulation results show a considerable increase in output power when P&O with the isolation tracking method is used compared to the conventional P&O method, as shown in Figure 7.

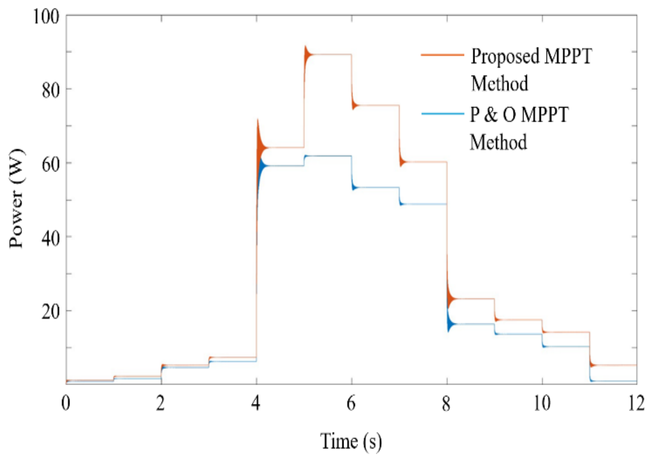

Fig. 7 Comparison of output power under normal operating conditions

Figure 7 shows that the proposed method can effectively track the maximum power under various environmental conditions. Moreover, the power extracted by this method is greater than that of the traditional P&O method. The entire simulation time is taken as twelve seconds to replicate the twelve-hour duration from morning six to evening six. It is observed that the difference in output power between the proposed method and the P&O method during dawn and dusk is less. However, there is a considerable difference in output power during the sunny times of the day, especially during noon time, around 87 W is generated when the proposed method is implemented. In contrast, the conventional P&O method gives only around 62 W. This contributes to a sizeable increase in output power.

The simulation is now extended to two PV modules in series to observe their performance under partial shading conditions. The irradiance level of modules 1 and 2 are kept at 1000 W/m2 and 800 W/m2, respectively, in the simulation with a constant temperature of 25 °C. The proposed method seems to be effective in tracking the maximum power even under the partial shading condition. The output power obtained during this scenario is shown in Figure 8. The comparison of output power between the proposed method and the P&O method under partial shading conditions is represented in Figure 9. This figure shows that the power obtained by the proposed method is about 56 W, while the power obtained by the P&O method is around 47 W.

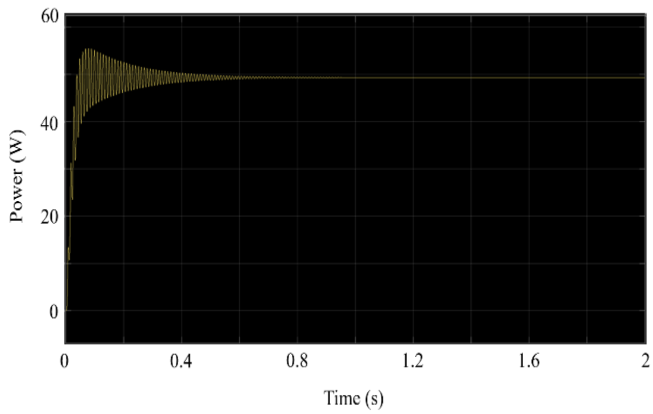

Fig. 8 Output power obtained during the partial shading condition

The experimental study is now conducted on the developed prototype under normal and partial shading conditions. The voltage waveform under normal operating conditions with P&O and with proposed MPPT (combination of P&O and insolation tracking) is depicted in Figure 10. This shows that the proposed method achieves 9.92 V at its peak, whereas the P&O method achieves only 7.26 V and performs well in a real-time environment. Figure 11 shows the power waveform for the same scenario. It clearly exposes that the power extracted while using the proposed method is 6.42 W, which is more than the conventional P&O method, where the power is only 5.24 W.

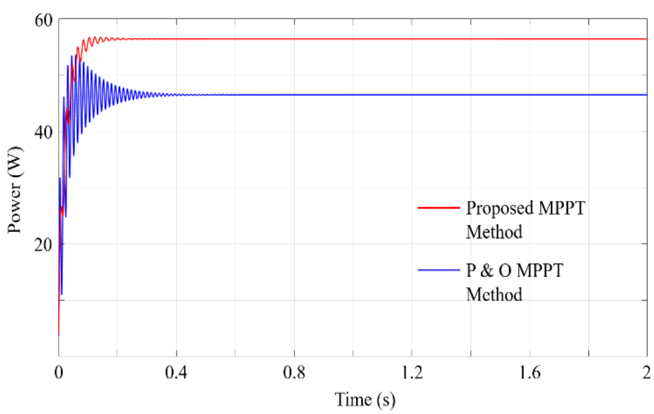

Fig. 9 Comparison of output power under partial shading conditions

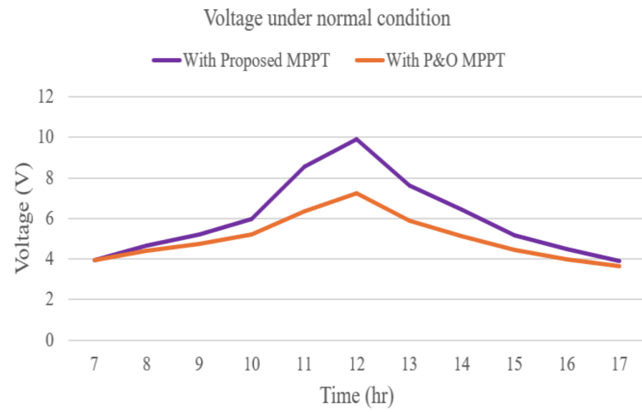

Fig. 10 Voltage waveform under normal operating conditions

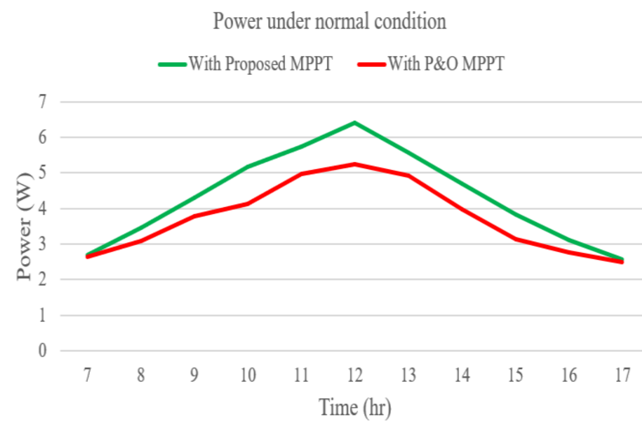

Fig. 11 Power waveform under normal operating conditions

A partial shading condition is created as shown in Figure 5 to observe the performance of the proposed algorithm. Experimental results confirm that the proposed method outperforms the traditional P&O method in partial shading conditions. The voltage and power waveforms under partial shading conditions with the P&O method and the proposed method are set forth in Figures 12 and 13, respectively. The peak value of voltage and power obtained by the proposed method is 9.51 V and 5.31 W, whereas the P&O method is 6.68 V and 4.12 W.

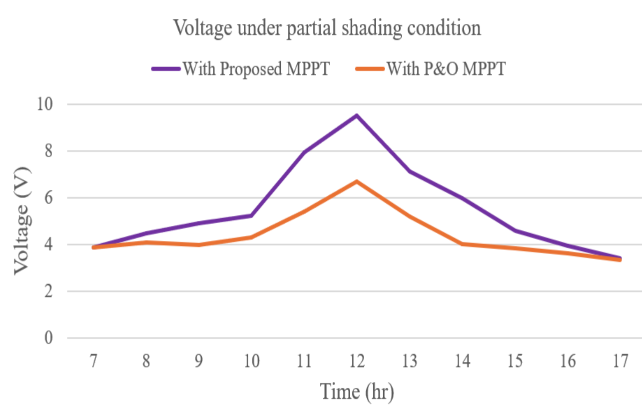

Fig. 12 Voltage waveform under partial shading condition

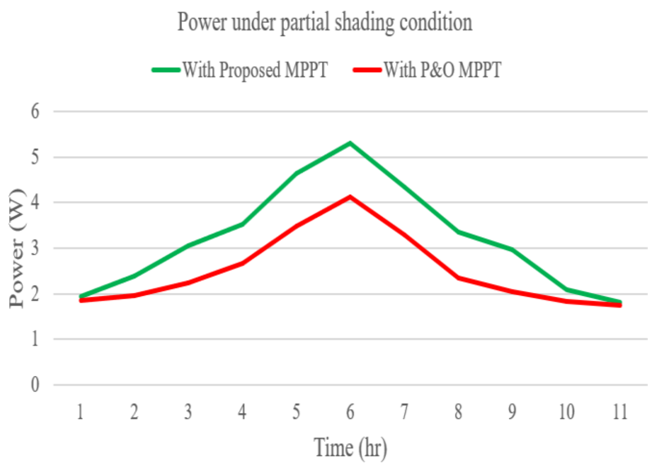

Fig. 13 Power waveform under partial shading condition

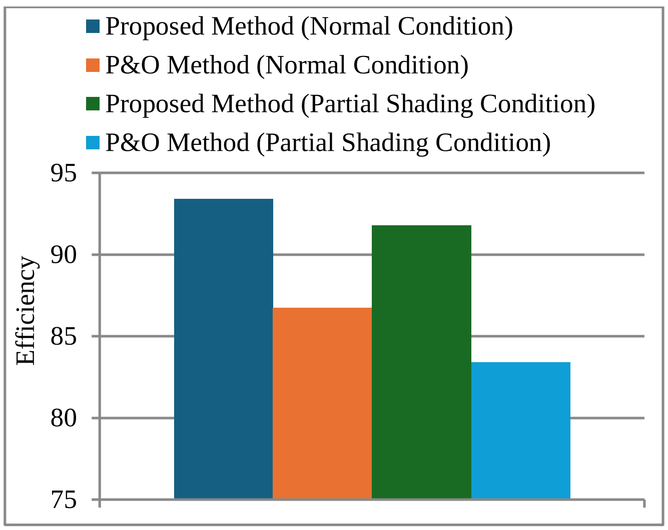

Fig. 14 Comparison of efficiency between the proposed method and the P&O method

The results obtained from the prototype clearly demonstrate that the power extracted when the proposed method is implemented is high when compared with the ordinary P&O method. The efficiency thus obtained also goes with the results, and the comparison of efficiency obtained by the ordinary P&O method and the proposed method under normal and partial shading conditions is presented in Figure 14. The efficiency of the proposed method under normal conditions is 93.4% while the traditional P&O method provides only 86.75% efficiency. The proposed method also outperforms the traditional P&O method under partial shading conditions, with an efficiency of 91.78% whereas the P&O method offers only 83.42% efficiency. The improvement in efficiency is mainly due to the incorporation of the tilt angle change with the conventional perturb and observe method. Moreover, it is achieved at a very low cost, and the complexity of the system is very low.

5. Conclusion

An MPPT algorithm is proposed in this literature, which combines the isolation tracking process with the P&O method. The primary objective of this method is to track the maximum power from the solar PV system under normal and partial shading conditions. A solar PV system is developed to test the robustness of the proposed method. The developed system is simulated in MATLAB/SIMULINK to test its performance, and it is compared with the conventional P&O method. Simulation results demonstrate that the proposed method is more efficient than the conventional P&O method. A prototype is developed to validate the results in a time environment. Experimental studies conducted in the prototype justify the simulation results. The proposed method can also be extended to grid-connected PV systems.

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All the authors contributed equally to this work.

References

[1] Nicola Femia et al., “Optimization of Perturb and Observe Maximum Power Point Tracking Method,” *IEEE Transactions on Power Electronics*, vol. 20, no. 4, pp. 963-973, 2005. [CrossRef] [Google Scholar] [Publisher Link]

[2] Ashish Pandey, Nivedita Dasgupta, and Ashok Kumar Mukerjee, “High-Performance Algorithms for Drift Avoidance and Fast Tracking in Solar MPPT System,” *IEEE Transactions on Energy Conversion,* vol. 23, no. 2, pp. 681-689, 2008. [CrossRef] [Google Scholar] [Publisher Link]

[3] Patrizio Manganiello et al., “Optimization of Perturbative PV MPPT Methods through Online System Identification,” *IEEE Transactions on Industrial Electronics*, vol. 61, no. 12, pp. 6812-6821, 2014. [CrossRef] [Google Scholar] [Publisher Link]

[4] Fathima Raziya et al., “MPPT Technique Based on Perturb and Observe Method for PV Systems Under Partial Shading Conditions,” *Proceedings of the Moratuwa Engineering Research Conference (MERCon)*, Moratuwa, Sri Lanka, pp. 474-479, 2019. [CrossRef] [Google Scholar] [Publisher Link]

[5] Andrew Vinícius Silva Moreira et al., “An Adaptive Perturb and Observe Method with Clustering for Photovoltaic Module with Smart Bypass Diode under Partial Shading,” *2019 IEEE PES Innovative Smart Grid Technologies Conference - Latin America (ISGT Latin America)*, Gramado, Brazil,pp. 1-6, 2019. [CrossRef] [Google Scholar] [Publisher Link]

[6] Shunlong Xiao, and Robert S. Balog, “An Improved Adaptive Perturb & Observe Maximum Power Point Tracking Technique,” *2018 IEEE Texas Power and Energy Conference (TPEC)*, College Station, TX, USA, pp. 1-6, 2018. [CrossRef] [Google Scholar] [Publisher Link]

[7] Sathish Kumar Kollimalla, and Mahesh Kumar Mishra, “Adaptive Perturb & Observe MPPT Algorithm for Photovoltaic System,” *2013 IEEE Power and Energy Conference at Illinois (PECI)*, Urbana, IL, USA, pp. 42-47, 2013. [CrossRef] [Google Scholar] [Publisher Link]

[8] Mohammed S Sheik, “Multiple Step Size Perturb and Observe Maximum Power Point Tracking Algorithm with Zero Oscillation for Solar PV Applications,” *2018 International Conference on Current Trends towards Converging Technologies (ICCTCT)*, Coimbatore, India, pp. 1-5, 2018. [CrossRef] [Google Scholar] [Publisher Link]

[9] F.A.O. Aashoor, and F.V.P. Robinson, “A Variable Step Size Perturb and Observe Algorithm for Photovoltaic Maximum Power Point Tracking,” *2012 47th International Universities Power Engineering Conference (UPEC)*, Uxbridge, UK, pp. 1-6, 2012. [CrossRef] [Google Scholar] [Publisher Link]

[10] Saptaparna Basu Roy Chowdhury, Alok Mukherjee, and Pritam Kumar Gayen, “Maximum Power Point Tracking of Photovoltaic System by Perturb & Observe and Incremental Conductance Methods under Normal and Partial Shading Conditions,” *2021 Innovations in Energy Management and Renewable Resources(52042)*, Kolkata, India, pp. 1-6, 2021. [CrossRef] [Google Scholar] [Publisher Link]

[11] Mohammed A. Elgendy, Bashar Zahawi, and David J. Atkinson, “Operating Characteristics of the P&O Algorithm at High Perturbation Frequencies for Standalone PV Systems,” *IEEE Transactions on Energy Conversion*, vol. 30, no. 1, pp. 189-198, 2015. [CrossRef] [Google Scholar] [Publisher Link]

[12] The ResearchGate website, 2025. [Online]. Available: https://www.researchgate.net/figure/PV-solar-cell-model-The-output-current-Ipv-of-the-PV-cell-model-can-be-defined-as-in_fig5_318860620

[13] Robert W. Erickson , and Dragan Maksimović, *Fundamentals of Power Electronics*, 3rd ed., Cham, Switzerland: Springer Nature, pp. 56, 2020. [CrossRef] [Google Scholar] [Publisher Link]