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Development of a New Current Controlled Maximum Power Point Tracking Based on the Binary Search Algorithm

Ahmed Fhad Alrwaili[1], Richard Molyet[2]
[1,2]The University of Toledo, Dept. Electrical Engineering and Computer Science, OH, Toledo, USA
([1]Engr.Ahmed.f@gmail.com, [2]Richard.molyet@utoledo.edu)

Abstract- Extracting maximum energy from a photo-voltaic panel has presented a significant challenge due to the dependency on both solar irradiance and ambient temperature. Therefore, the development of maximum power point tracking (MPPT) algorithms is crucial for maintaining the operation of solar panels at maximum efficiency. Historically, two benchmarks have been utilized to evaluate the tracking speed and accuracy of any MPPT algorithm. This paper introduces a novel MPPT method based on controlling the panel current to track the MPP. A Binary search-based MPPT technique has been utilized to reduce the convergence time, steady-state error, and ripple. By comparing the proposed method with the state-of-the-art linear search-based methods such as the P&O technique under different scenarios, the results demonstrate a significant advancement in terms of tracking speed and accuracy. In addition, the ripple has been significantly diminished.

Keywords- *Maximum Power Point Tracking, Photo-Voltaic, Binary Search, Current Control, Solar Energy*

I. INTRODUCTION

The efficiency of energy conversion from PV panels is very low. Therefore, extracting the maximum power of PV panels is very crucial to reducing the total cost and the occupied space for mounting PV panels [1]. There are two main remarks by noticing the power to voltage and the current to voltage characteristic curves. The first is shown in Fig.1. It shows that there is only one point at which the power is maximum for specific temperature and irradiance value. The other issue is that the current to voltage and power to voltage are non-linear relations [2].

Consequently, the MPP can be determined only by utilizing searching techniques. Many search algorithms have been introduced in the literature for determining the MPP. These methods vary in the convergence time, cost of implementation, number of control variables, and accuracy. Figure 2 depicts the most MPPT methods in the literature alongside the control variables [3]. It shows three categories which are the conventional methods that are divided into direct and indirect search methods. The most used direct methods are the perturb and observe (P&O) and incremental conductance (IC) methods. The fractional open-circuit voltage (FOCV) and Fractional short circuit current are two examples of conventional indirect methods. In addition, the novel or most recent techniques are based on artificial intelligence (AI), Fuzzy logic (FLC), and heuristic search algorithms like a genetic algorithm (GA) and Particle swarm optimization (PSO) [4].

Surveying these methods comprehensively is not one of the purposes of this paper. However, many articles have intensely analyzed all these methods with a comprehensive and comparative review. Table 1 lists the main parameters and deep performance comparison between some of the most used MPPT in the literature. Studying the summarized data in table 1 clearly shows that the main issues in the most current methods are the low efficiency, steady-state oscillation, complexity, and implementation cost. Therefore, there is still a knowledge gap that needs some research to solve such issues and increase the efficiency of tracking.

This paper presents a new tracking method based on controlling the current of the PV panel based on a binary search algorithm. The P&O method has been taken as a baseline method to validate the proposed algorithm and compare the results to show the enhancements that have been achieved by utilizing the new methods in terms of efficiency, accuracy, and tracking speed. The paper has been implemented by using MATLAB Simulink and validated with methods in the literature.

The article is organized as follows: Section 2 presents the logic and design of the new algorithm; section 3 introduces the results and discussion; section 4 validates the obtained results, and section 5 concludes the work.

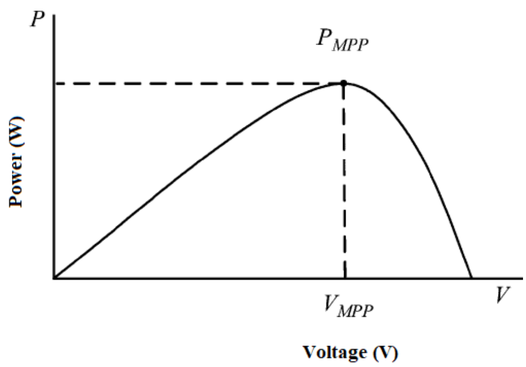


Figure 1. The power to voltage curve of PV panel [3]

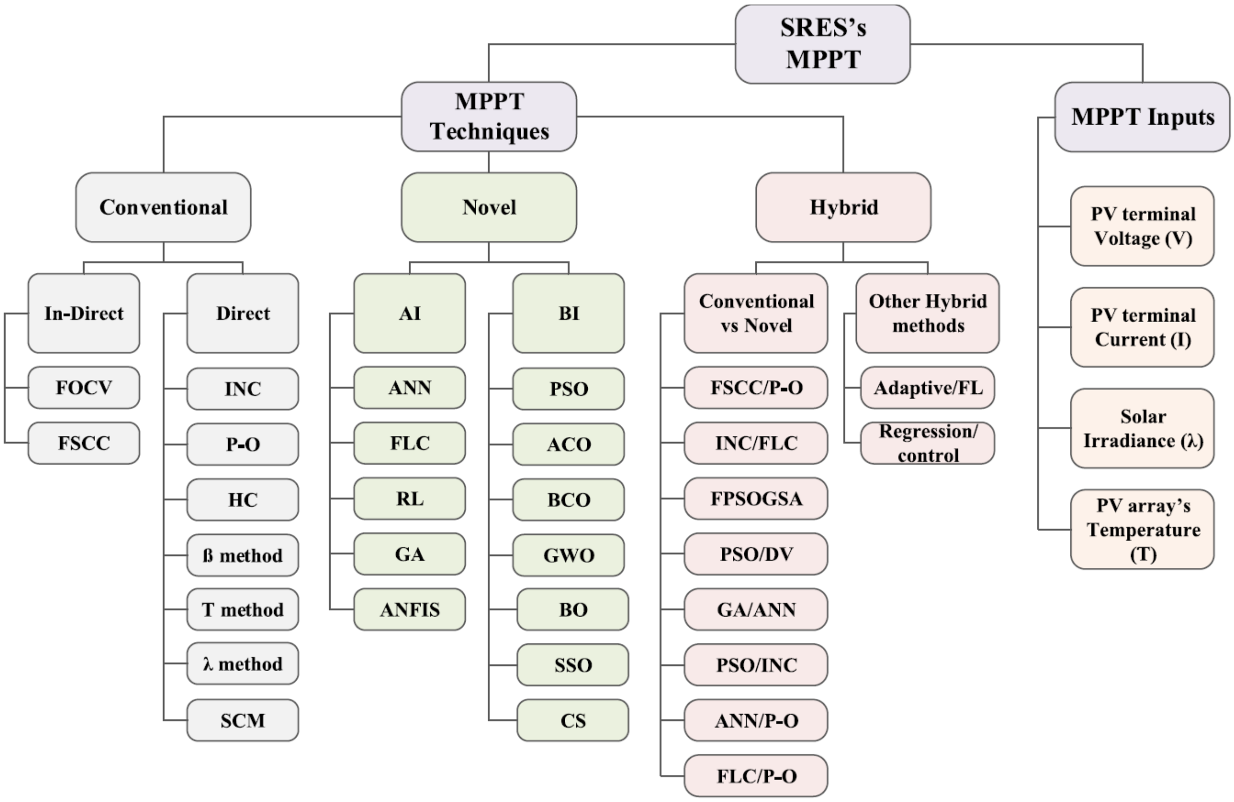


Figure 2. The most MPPT in literature and the control variables [3]

TABLE I. A COMPARISON OF THE MOST COMMON MPPT METHODS

Reference	MPPT Method	Efficiency	Convergence Speed	Complexity	Steady State Oscillation	Implementation Cost	Sensors
[2]	FVOC	Low	Medium	Low	High	Low	V
[3,4]	FSCC	Low	Medium	Medium	High	Low	I
[3,5]	P&O	Medium	Varies	Low	High	Low	I&V
[3]	INC	Medium	Varies	Medium	Medium	Medium	V&I
[6]	Modified P&O	High	High	Medium	Medium	Low	V&I
[7]	Computation Method	Low	Medium	Medium	Medium	Low	T and G
[8,9,10]	PSO	High	Medium	Medium	Varies	Medium	V&I
[11,12]	FLC	Medium	Medium	Medium	Varies	Medium	V&I
[13]	ANN	High	Medium	High	Varies	Medium	V&I
[14]	Simulating Annealing	High	Varies	Medium	Low	Low	V&I
[12]	Genetic Algorithm	High	High	High	Low	Medium	V&I
[9]	FLC/P&O	High	High	Medium	Low	Medium	V&I
[15]	Ant Colony (ACO)/P&O	High	High	Medium	Low	Medium	V&I
[16]	GA/ANN	High	High	High	Low	High	V, T, G

II. METHODS

A. PV Cell Model

The system is composed of the PV module on which the proposed algorithm is tested to track the MPP and the current based controller which is modeled based on a single diode PV model as shown in fig. 3. [20]. Based on a single diode model of the solar cell shown in fig. 3, the current to voltage (I-V) of a solar cell can be modeled as series and parallel resistance alongside the diode. In this equivalent circuit of a solar cell, the load current can be determined as in equation 1. In addition, there are three versions of algorithms that have been coded to represent the new method, the P&O method, and one additional method from literature to be utilized and validated with the proposed method.

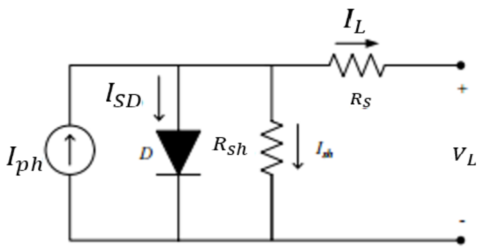


Figure 3. A single diode PV model

$$I_L = I_{ph} - I_{SD}\left(e^{\left(\frac{q(V_L + I_L R_S)}{nKT}\right)-1}\right) - \left(\frac{V_L + I_L R_S}{R_{sh}}\right) \qquad (1)$$

where

I_L : The terminal current (A).

I_{ph} : The solar cell photocurrent (A).

I_{SD} : The diffusion and saturation current (A).

V_L: The terminal voltage (V).

R_s: The series resistance (Ω).

R_{sh}: The shunt resistance (Ω).

n : The ideality factors.

K : Boltzmann's constant ($J.K^{-1}$).

q : The electronic charge (e)

T : Solar cell temperature in kelvin (K)

III. Proposed Method

The new method is developed based on a binary search algorithm of the fastest search technique with a big O complexity speed of O (log n), while the traditional P&O search speed is based on a linear search with a big O complexity of O(n). Moreover, n is the number of values that are being searched to determine the target MPP. As a numerical example for searching in (n=1000) points, the P&O, which is a linear searching method requires at least 1000 iterations, while the proposed method which is based on binary research, needs only 10 iteration at most.

The complexity of binary search can be described as follows [21]:

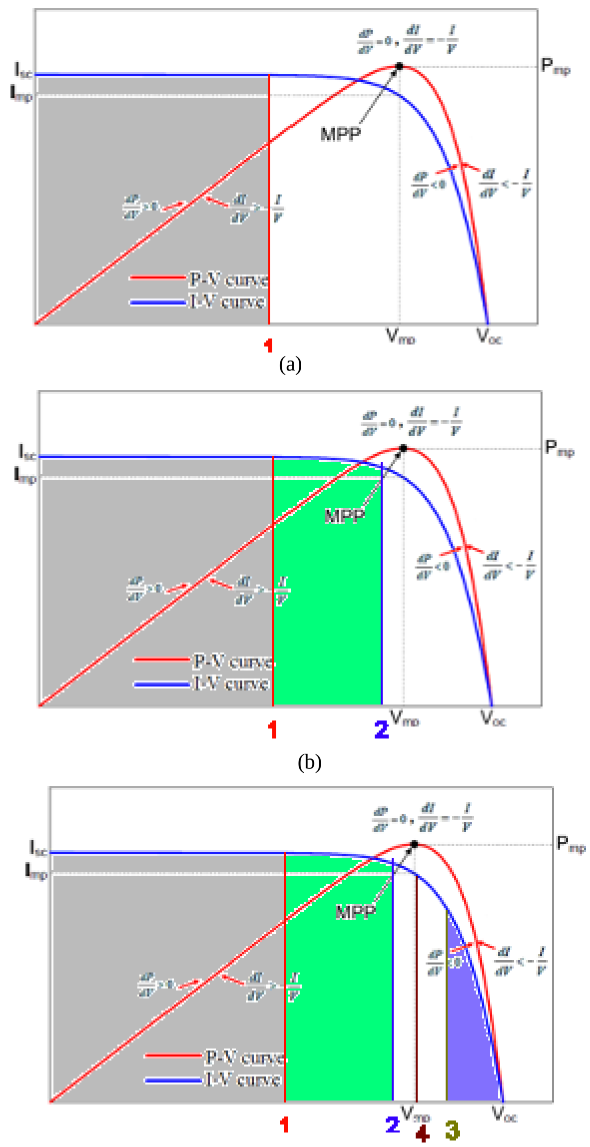
k = log (base 2) (n)

where n is the number of searched items and K is the number of iterations to reach the target point. So for searching 1000 items based on binary search, there could be only 10 iterations.

Pseudocode:

1. Set the left boundary (L) to 0 and the right boundary (R) to the short circuit current (Ish).
2. If L>R, the search terminates as unsuccessful.
3. Set the position of the middle element (b) to the greater integer less than or equal to (L+R)/2.
4. If the current power value (Pm) < the maximum power sofar (Pmpp) set L to m+1 and go to step 2.
5. If Pm>Pmpp set R to m-1 and go to step 2.
6. Now Pm = MPP, the search is done; return.

Figure 4 depicts the searching flowchart logic of the proposed method. According to the scenario depicted in Fig. 4, the method starts by initializing all parameters and setting the start and end searching points of the search range. It then checks the points at the middle of the search domain which is located at (1) and marked by the red line. This point is determined to be located at Isc/2 according to equation 2.



(a)

(b)

(c)

Figure 4. The operating scenario of the proposed method (VOC: the open-circuit voltage, ISC: the short circuit current)

The search point=$(I_{end} - I_{start})/2 = (I_{sc} - 0)/2 = \frac{I_{sc}}{2}$ (2)

It then checks the change in power with respect to the change in current. If it is positive, it discards the left side of the search domain and updates the search region as follows:

$$I_{end} = I_{sc} \tag{3}$$

$$I_{start} = I_{sc}/2 \tag{4}$$

The new search point = $\frac{I_{sc}}{2} + (\, I_{sc} - \frac{I_{sc}}{2})\, /2 = \, 3I_{sc}/4$ (5)

The search domain is updated from Isc/2 to Isc & checks the middle point once again is located at $3I_{sc}/4$ & marked by the blue line located at point 2. If it is positive, it discards the left side of the search domain & so on point 3, & finally point 4, which is the MPP. The example shows that the method fetched the target in only four iterations, and every check discards half of the search space & updates the search domain.

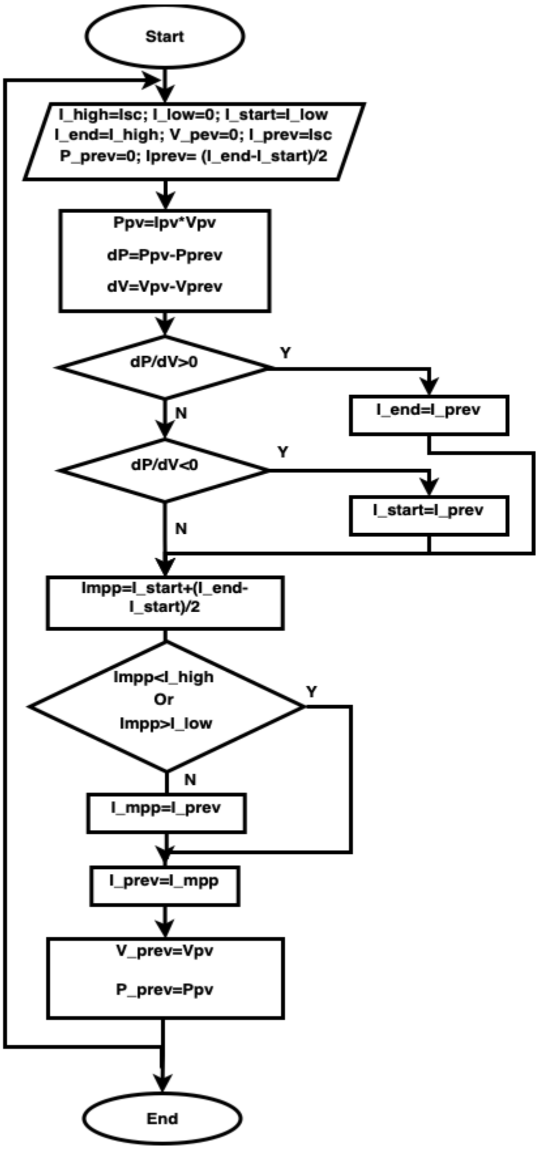


Figure 5. The flowchart of the proposed technique

In addition, the Simulink model in Fig. 6, shows the PV module model on the left. In addition, it shows three blocks of code. The block on the top represents the traditional P&O method. The block in the middle represents the new method (Binary search method). And the one at the bottom represents Modified P&O method in the literature that is used for validating the proposed algorithm [19]. Table 2 shows the design parameters of PV module of power 84 watt based on the datasheet parameters of the simulated PV module.

TABLE II. THE PV MODULE DESIGN PARAMETERS

Short-circuit current	5.45
Open-circuit voltage	22.2
Current at Pmax	4.96
Voltage at Pmax	17.1
Maximum Output(Pmax)	84.82

IV. RESULTS AND DISCUSSION

A. *Overview*

For testing the proposed method and the implemented model, a variable irradiance profile has been designed by a signal builder in MATLAB, as shown in Fig. 7. The profile shows the case of an increase in the irradiance from 500 w/m2 to 1000 w/m2. By testing with this irradiance profile, most cases are imitated, including the sudden changes in operating conditions, and this is applied to the three algorithms in the implemented model. The results of the new algorithm, the P&O, and the validated method are compared to validate the new method's properness and compare the new algorithm's performance with the traditional P&O tracking method.

B. *Oscillation and Accuracy test case*

Figure 8 shows the output power of the proposed algorithm and that of the traditional P&O method. The new method shows higher efficiency thanks to minimizing the steady-state oscillations. By zooming in the output as shown in Fig. 9, the new method offers a higher power output with a minimum o near to zero oscillation output. In addition, Fig. 10 compares the output current from the new algorithm and the conventional method. The new method provides a current of minimized oscillation compared with that generated by the traditional MPPT method.

C. *Tracking speed test case*

Figure 10 pictures zoom in on the current of the new method and the traditional method. It shows the new method reaches the targeted MPP significantly earlier than the traditional method.

By comparing measurements, table 4 lists the time taken to reach the MPP for the new method and the conventional method as well.

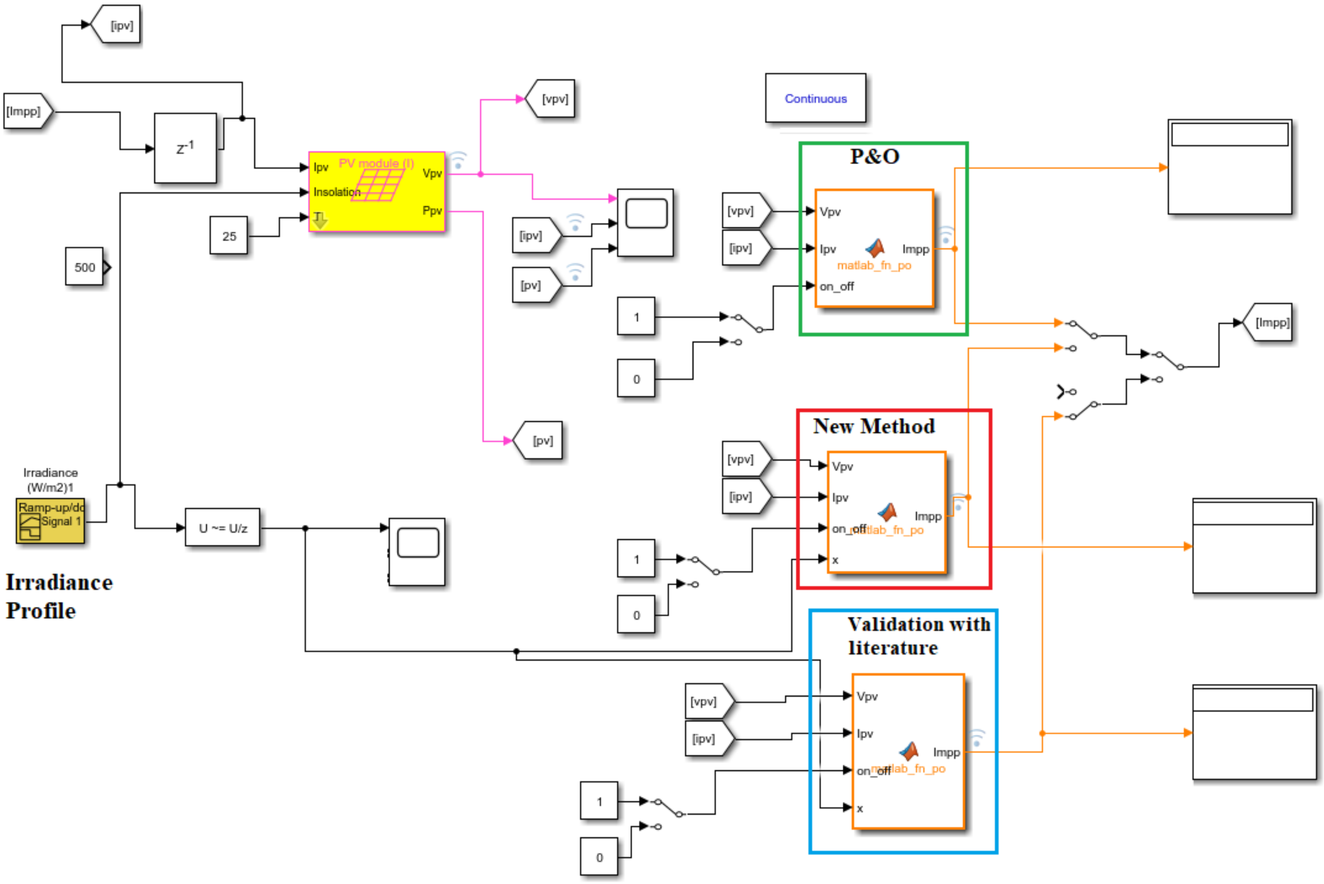


Figure 6. The Simulink model for testing the new algorithm

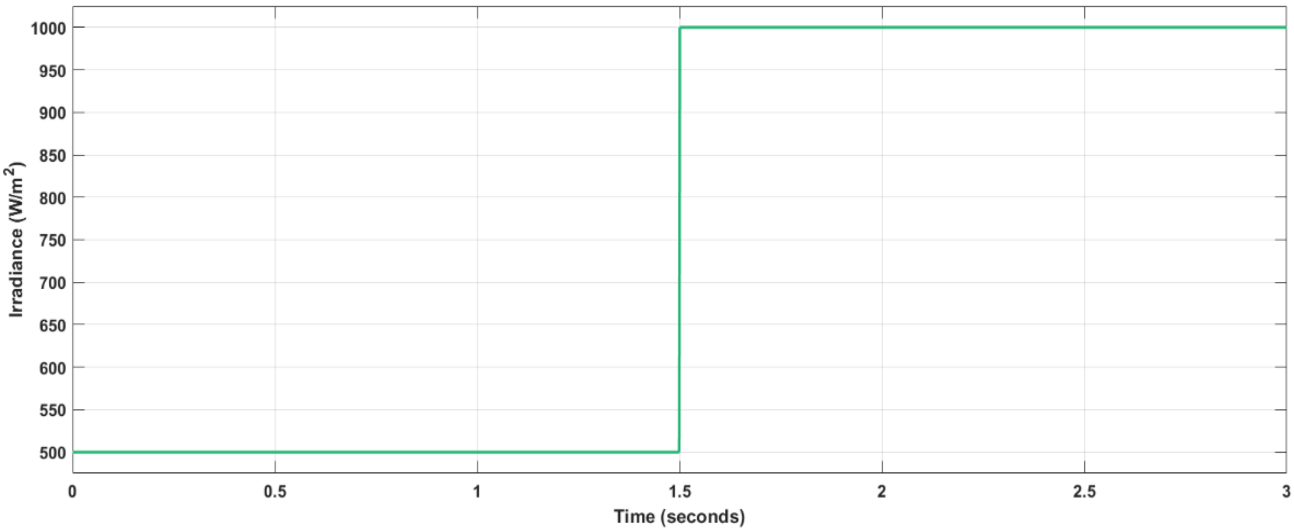


Figure 7. The irradiance profile

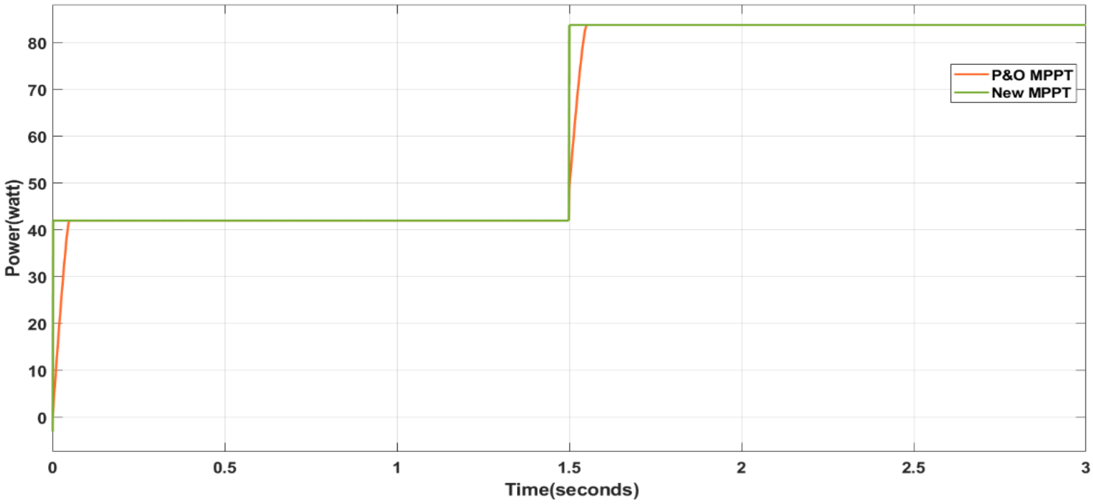


Figure 8. The output power of the new method and the traditional method

Figure 9. Zooming in of the output power of the new algorithm and the traditional method

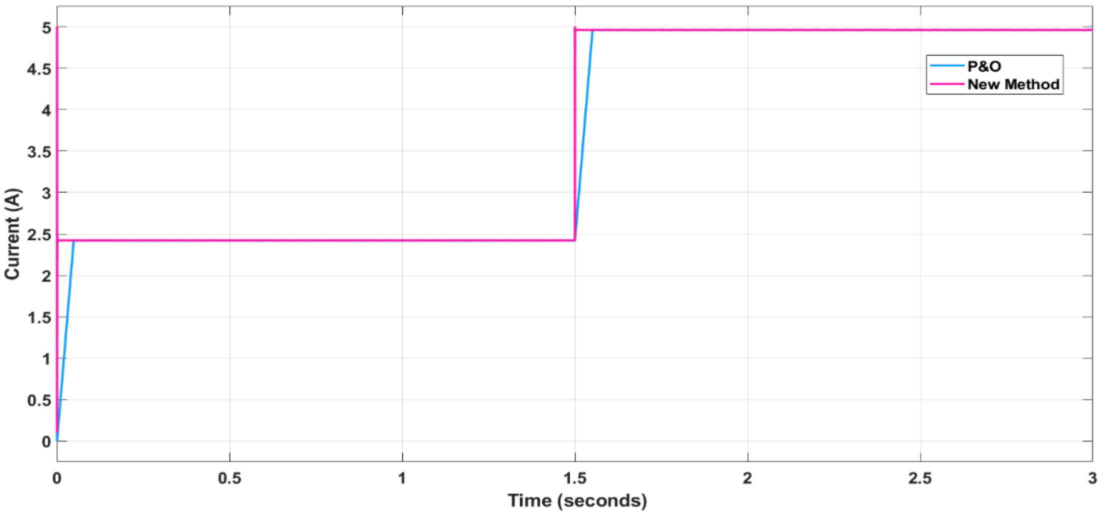


Figure 10. The output current of the new algorithm and the traditional algorithm

TABLE III. POWER AND EFFICIENCY COMPARISON BETWEEN THE NEW AND CONVENTIONAL METHODS

Measurements	PV power (watt)	New method	Conventional P&O method
Power (at irradiance 1000 w/m^2)	84.816	83.7836	83.7832
Ripple	-	No ripple	High
Efficiency (round to thousandth)	-	98.783	98.782

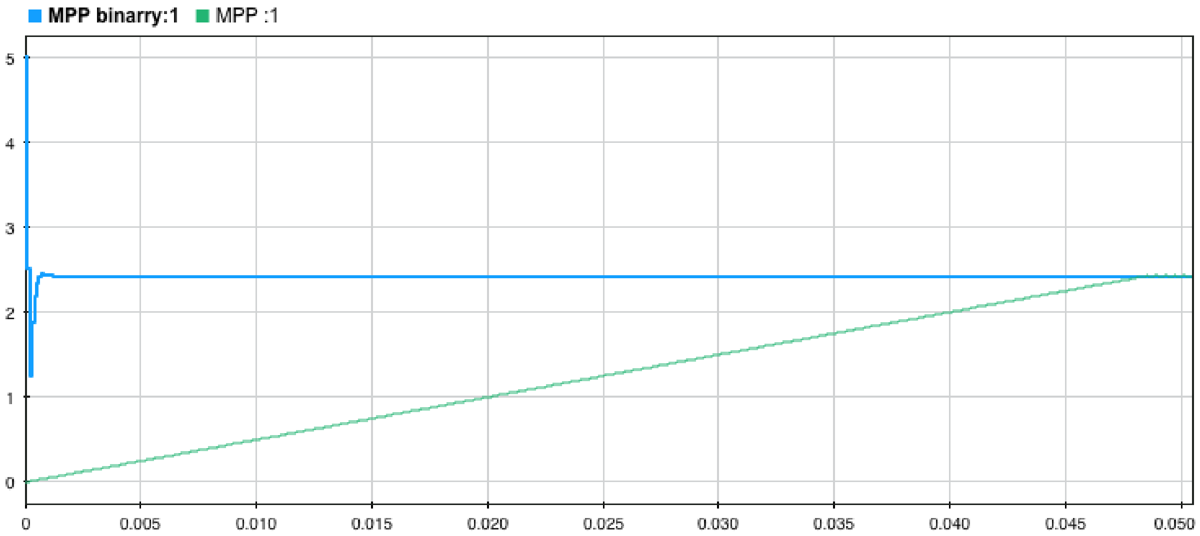


Figure 11. The convergence speed of the new method and the conventional method

TABLE IV. THE CONVERGENCE AND TRACKING SPEED COMPARISON BETWEEN THE NEW AND CONVENTIONAL METHOD

Measurements	New method	Conventional P&O method
Time reaching MPP(at irradiance 500 w/m^2)	0.0011 sec	0.0483 sec

D. Validation

In addition to the classic P&O method which is compared above, there are many modified versions of the P&O algorithm. For validating the new algorithm, one method (Modified P&O) in the literature has been selected and implemented to be compared with the new method [19]. Figure 11 shows one of these methods which ensure the reduction of both steady-state oscillation and the deviation from the target value. By applying some perturbations, the operating point finally starts reaching the MPP. At that moment, the oscillation at the MPP will appear. This oscillation phenomenon is detected by a smart test, and they are minimized by reducing the perturbation size. Thus, the oscillation dilemma is fixed. Afterward, the tracking direction defectivity is addressed as follows. Figure 12 compares the output power of the new method and the method used for validation. The new method provides accurate results and shows a significant improvement in terms of the tracking speed and accuracy with minimum steady-state oscillations.

By comparing in values measured for the new methods and the validated method, the tracking speed and the power and efficiency of the new method are listed in table 5.

TABLE V. COMPARISON BETWEEN THE NEW METHOD AND THE VALIDATED METHOD (MODIFIED P&O)

Measurements	PV module	New method	Validated method [19]
Time reaching MPP (at irradiance 500 w/m^2)		0.001 sec	0.0174 sec
Power ((at irradiance 500 w/m^2))	42.408 Watt	42	41.93
Efficiency		99.03	98.87

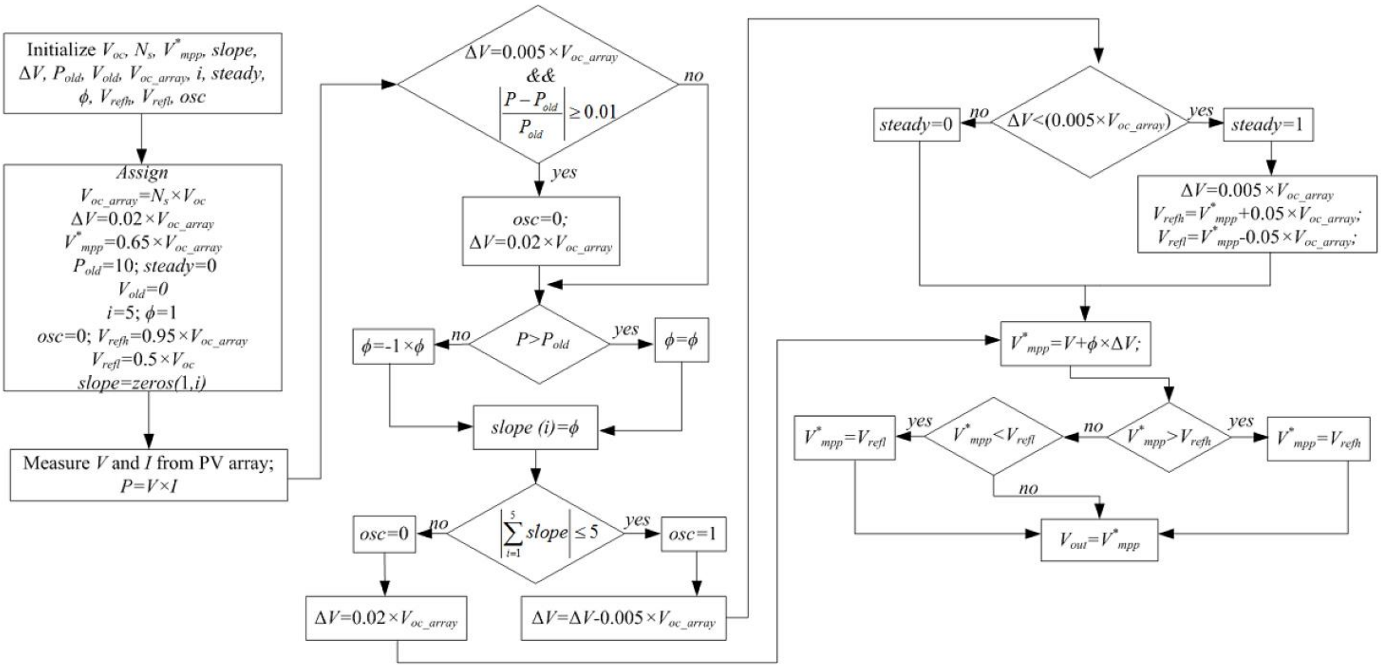


Figure 12. Modified P&O algorithm from [19]

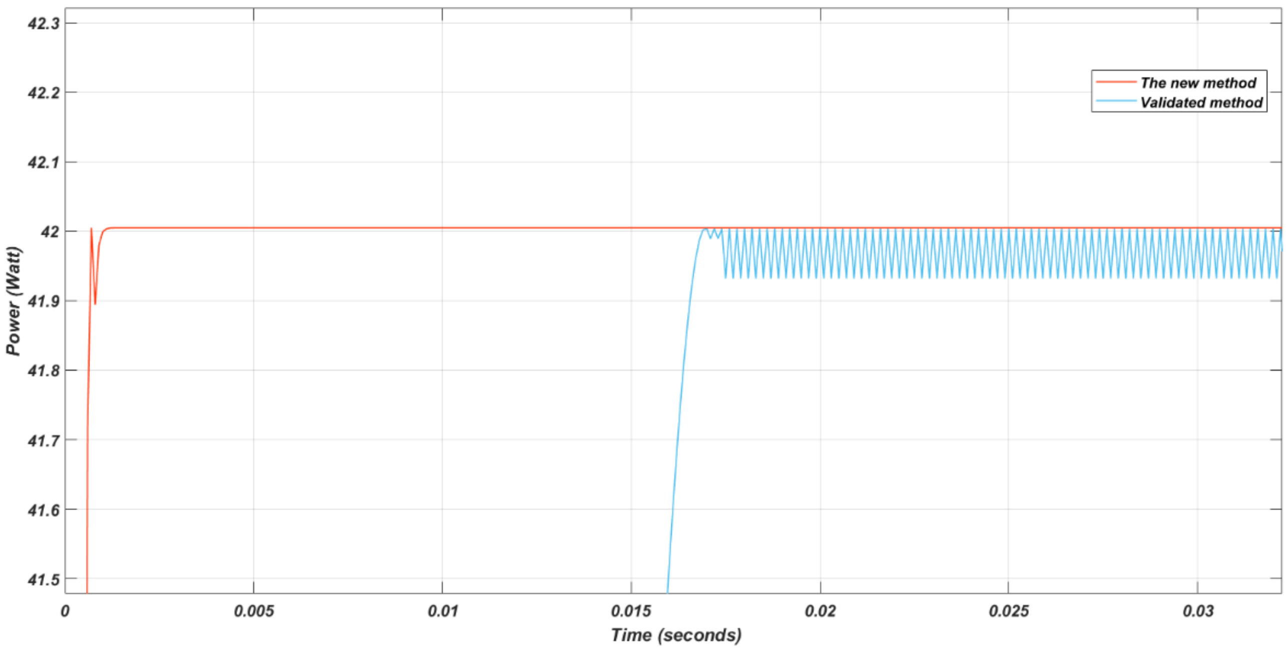


Figure 13. The validation between the new method and one that in literature [19]

V. Conclusion

This paper presents a new MPPT method based on controlling the current based on a binary search algorithm. The new method has been implemented alongside the traditional P&O methods by using MATLAB Simulink. The results have been compared and showed significant improvement of the new method in terms of tracking speed and accuracy. The new method can determine the MPP in a few iterations, while the traditional techniques take hundreds of thousands of iterations to reach the target MPP. In addition, the new method can minimize the steady-state oscillations, which increase the efficiency of the tracking process and increase the output power.

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Ahmed Alrwaili received the B.S. degree in electrical engineering from Indiana University–Purdue University Indianapolis, Indianapolis, IN, USA in 2012 and received the M.S. degree in electrical and computer engineering from Gannon University, Erie, PA, USA, in 2014. He is working in the Department of Electrical Engineering, Northern Border University, as Lecturer, Arar, Saudi Arabia. Also, He is currently Ph.D. candidate in Electrical Engineering and Computer Science Department at University of Toledo, Toledo, OH, USA, since 2016. His research interests are Smart Grid, Maximum Power Point Tracking (MPPT) in photovoltaic system, and Solar Energy.

Senior Professor Richard Molyet received his B.S. and M.S. degrees in electrical engineering, and his Ph.D. degree in engineering science from the University of Toledo, Toledo, OH, USA in 1973, 1977, and 1981, respectively. In 1981, he joined the Department of Electrical Engineering and Computer Science at the University of Toledo. His research interest is automatic control. He has received awards for excellence in teaching at the departmental, college and university levels. Dr. Molyet is a Life Member of the Institute of Electrical and Electronics Engineers, and has served on the board of the Toledo Section of IEEE for 38 years.

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