Novel TPPO Based Maximum Power Point Method for Photovoltaic System

Muhammad Awais ABBASI, Muhammad Fahad ZIA
School of Systems and Technology, University of Management and Technology, 54000, Pakistan
awais.abbasi@umt.edu.pk

***Abstract*—Photovoltaic (PV) system has a great potential and it is installed more when compared with other renewable energy sources nowadays. However, the PV system cannot perform optimally due to its solid reliance on climate conditions. Due to this dependency, PV system does not operate at its maximum power point (MPP). Many MPP tracking methods have been proposed for this purpose. One of these is the Perturb and Observe Method (P&O) which is the most famous due to its simplicity, less cost and fast track. But it deviates from MPP in continuously changing weather conditions, especially in rapidly changing irradiance conditions. A new Maximum Power Point Tracking (MPPT) method, Tetra Point Perturb and Observe (TPPO), has been proposed to improve PV system performance in changing irradiance conditions and the effects on characteristic curves of PV array module due to varying irradiance are delineated. The Proposed MPPT method has shown better results in increasing the efficiency of a PV system.**

***Index Terms*—DC-DC power converters, maximum power point trackers, photovoltaic cells, solar energy, solar power generation.**

I. INTRODUCTION

Solar photovoltaic technology offers an environmental friendly source of electricity. Without pollution, or depletion of the natural resources, the world can harvest enormous amount of energy. Unfortunately, the PV system is somewhat costly and inefficient. We can decrease the cost by increasing the total power output from the solar panels or increasing the efficiency of any circuit connected to the solar panel. This can be done by using an efficient controller, which is accurate and provides speedy calculations to track the maximum power point of the PV cell.

The solar irradiance and the temperature affect the power-voltage curve of PV arrays. Due to the non-linearity of the PV I-V curve as shown in Fig. 1, Power curve and maximum power point (MPP) are shifted whenever the temperature or the irradiance factors are changed [1]. In such conditions, maximum power point tracking in an effective way is critical to produce maximum achievable power.

There are many approaches to get the maximum output using MPPT and the choice of MPP Tracker depends on various factors which include Implementation complexity, cost, response time, and ability to detect local and global MPP, etc. In the seeking algorithms, there are some indirect control or "quasi seeking methods" such as the look-up table method [2], the constant voltage (CV) method [3-5], the short-circuit current (SC) method [6, 7], temperature method [8] and the direct control or "true seeking methods". True seeking methods include the Perturb & Observe (P&O) [9-13], the Incremental Conductance (IC) [14, 15], and finally artificial intelligence methods such as fuzzy logic control (FLC) MPPT technique [16-18], and the neural network method [19-22]. However, the realization of artificial intelligence methods is overwhelmingly complex in the software and hardware construction of the solar panel. The indirect control methods can be characterized by the fact that the MPP is estimated either from measurements of the voltage and current of the solar panel, the irradiance, or by the use of empirical data through numerical approximations. These methods are therefore not appropriate when changes occur in irradiance or temperature [23]. In contrast, the true seeking methods are able to obtain actual maximum power when variations occur in weather conditions. One or two variables may be used in the seeking process. P&O and IC are two-variable methods because they require the measurement of two variables to calculate the maximum power, and PV output voltage and current while SC and CV methods use only one variable to control either PV output current or voltage respectively.

The P&O algorithm, widely used in PV systems, continuously perturbs the terminal voltage and compares the output power with the previous perturbation. Once the maximum point is determined, the algorithm will keep oscillating around the MPP.

In this paper, Tetra Point Perturb and Observe based MPPT method has been proposed to improve PV system performance in changing irradiance conditions and the effects on characteristic curves of PV array module due to varying irradiance are delineated. The Proposed MPPT method has shown good results in increasing the performance of a PV system.

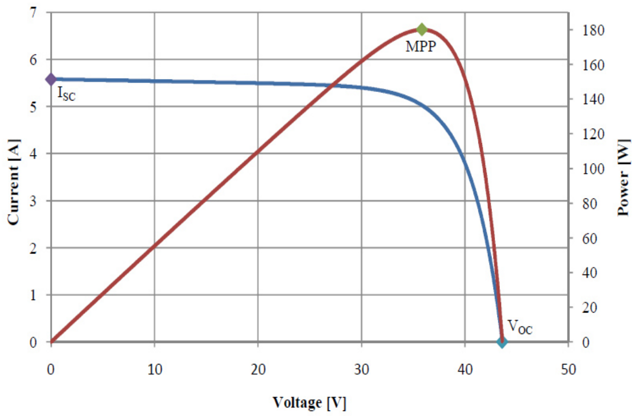

Figure 1. Characteristic curve of a PV cell

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II. Equivalent Circuit of a Solar Cell

PV cells convert light energy into electric energy. Some of the photons emitted by the sun are absorbed by the semiconductor layers, causing the electrons to be freed. These free electrons move to the positive layer of the p-n junction causing a voltage drop. In case of load, a current is produced. The variation of the intensity of the sunlight throughout the day is inconsistent, thus resulting in changing the output of the PV module. The change in the output of a PV module is resulting from changes in temperature and solar irradiance. To maximize the efficiency of the solar cell, it is important to extract the maximum power output. The DC-DC converter is used to track the maximum power point coming out of the PV module.

Mathematical models are used to model the behaviour of the PV cell in terms of open circuit voltage, short circuit current and maximum power point voltage and current. The most common approximate model is the single diode model (SDM) shown in Fig. 2. The mathematical of model PV array is represented in (1) [24].

$$I = N_{SH}\left(I_{ph} - I_o\left[\exp\left(\frac{q(V+IR_s)}{N_s AKT}\right)-1\right]-\frac{(V+IR_s)}{N_s N_{SH}}\right) \quad (1)$$

where, I and V represent the output current and voltage of PV array respectively. NS and NSH are series and parallel connected PV cells respectively. q is the electronic charge and Iph is the light current that is proportional to solar irradiance. Io is the saturation current and A is the diode ideality factor. K is the Boltzmann’s constant and T is the temperature of PV cells (in Kelvin).

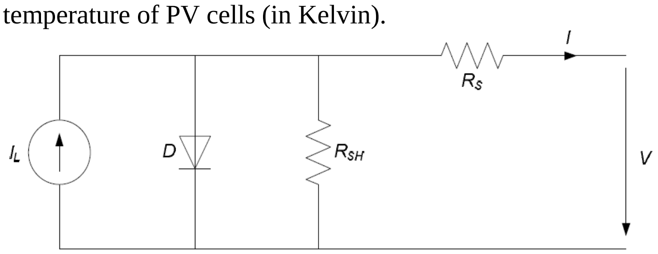

Figure 2. Equivalent circuit of a solar cell

III. Effects of Irradiance and Temperature

The output power of a solar PV panel changes in accordance with change in solar radiation and temperature level. This makes it impossible to use the direct coupled method to automatically track the MPP. These changes in weather conditions are shown by the P-V curves displayed in Fig. 3 and 4 respectively.

An MPPT system needs to be implemented to extract maximum power during the operation of solar panel and to be able to track the changes in power due to changes in atmospheric conditions. The position of the MPP on the I-V characteristic is not known a priori and varies in an unpredictable manner according to changes in atmospheric conditions. It therefore needs to be located. An MPPT search algorithm or calculation model is often necessary for this purpose. In the literature, MPPT efficiency is used to quantify an algorithm’s performance in comparison with other algorithms [25].

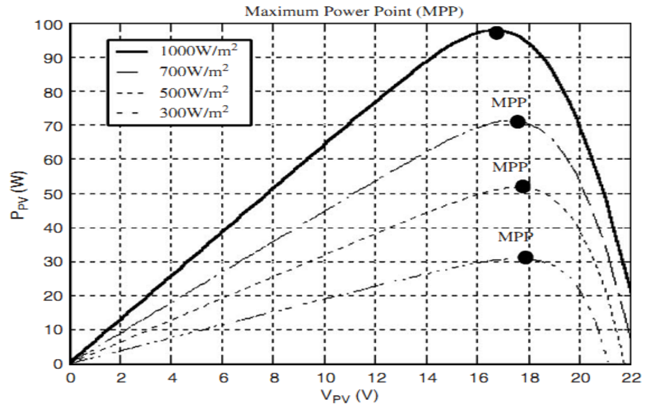

Figure 3. Characteristic curves at four different irradiances

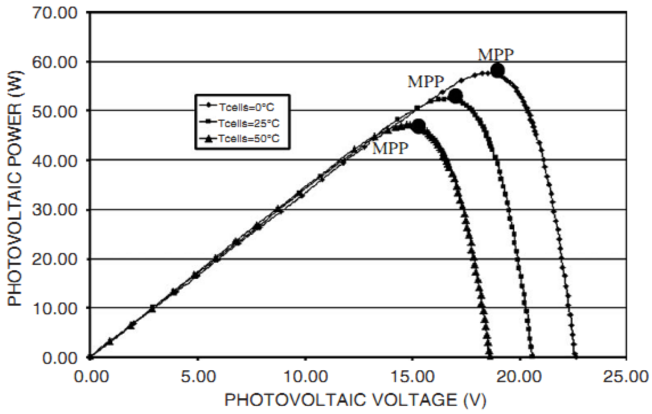

Figure 4. Characteristic curves at different temperatures

IV. Perturb & Observe (P&O) Algorithm

Perturb and Observe is the most commonly used Hill-climbing method to track the maximum power point. The simplicity and less cost make it an attractive method to use. The aim of the algorithm is to continuously perturb the PV terminal voltage and compare the corresponding power with the power from the previous perturbation. The direction of the movement of the reference voltage stays the same as long as the output power increases or decreases with the perturbation.

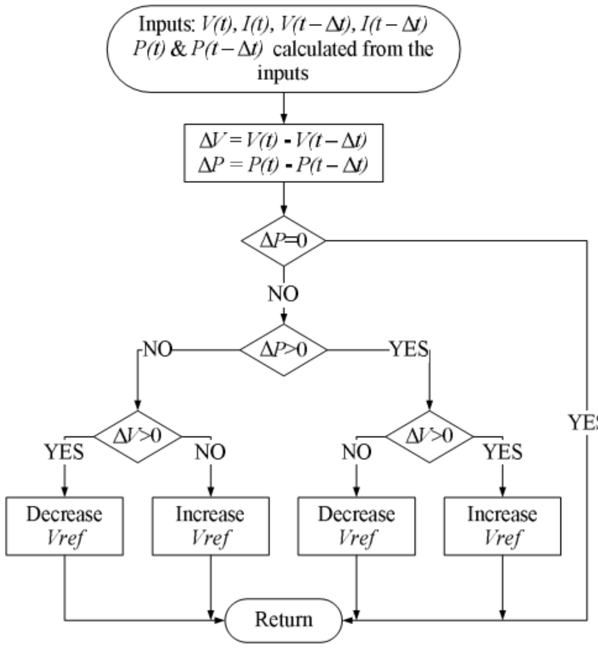

Figure 5. Perturb and Observe Algorithm Flowchart

The PV model is perturbed by a small increment which changes the output power. If the change in power is positive, the direction of the perturbation is effectively moving towards the MPP. Otherwise, the direction should be reversed. Flow Chart in Fig. 5 elaborates Perturbation & Observance Algorithm. P&O algorithm is proven to be an efficient MPPT technique and is widely used because of its simplicity.

There are some limitations of P&O algorithm. Firstly, there is oscillation around the maximum power point and it depends on the step size of the perturbation. If the step size is reduced oscillation can be reduced, but the MPPT will slow down. Secondly, a rapidly changing irradiance condition also strongly affects the current of PV panel. This changing current also brings a rapid change in P-V curve of PV panel and, as a result, the algorithm deviates from its right path towards MPP as shown in Fig. 6.

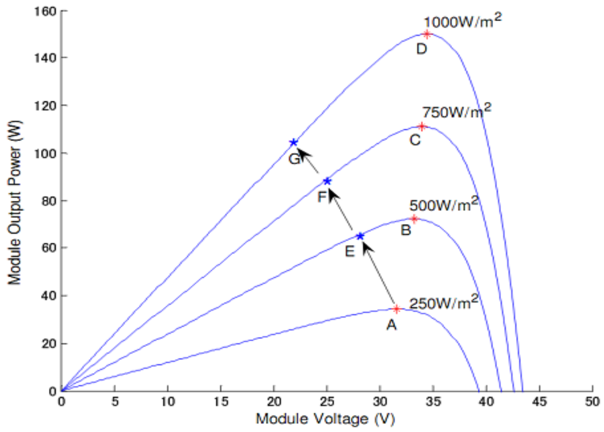

Figure 6. P&O moving away from MPP under rapidly changing irradiance conditions

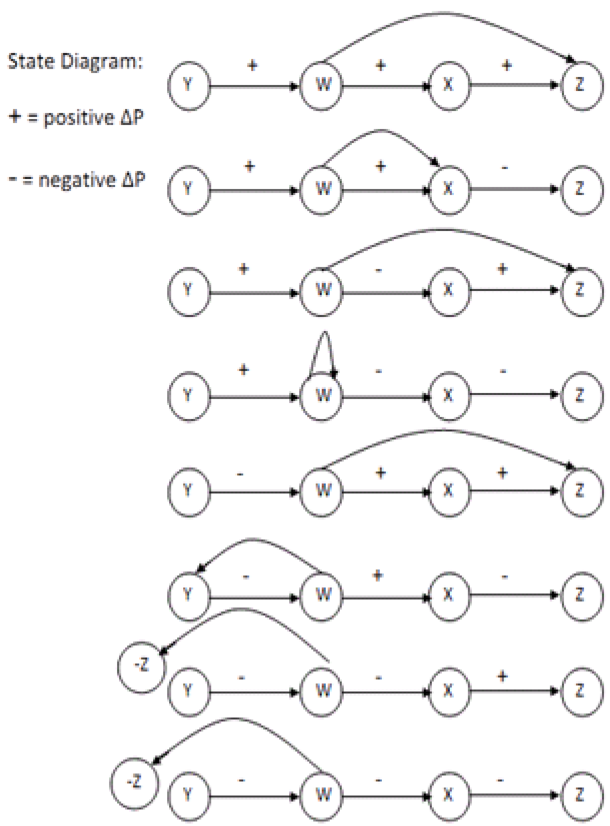

Figure 7. State Diagram of proposed TPPO method

V. Tetra Point Perturb and Observe Algorithm

To overcome the limitations of P&O algorithm under varying weather conditions, a new algorithm, Tetra Point Perturb and Observe (TPPO), has been proposed. This algorithm minimizes the power loss in changing irradiance conditions. The convergence speed of this method towards MPP is higher and it produces low oscillations, therefore, less power loss occurs.

This proposed algorithm works periodically by making perturbations in the selected range of operating voltage of the PV panel for three different points. After that, it calculates the respective powers at all these four points, including the reference operating point. These four points are; current operating point (W) of PV panel which is taken as a reference point, point(X) perturbed forward from point (W), then the point (Y) is taken by making perturbation backward from point (W), and finally, the point (Z) is doubly forward perturbed from point (W). After obtaining all the perturbed voltages, voltage at each point is multiplied with the corresponding current, to calculate the power at each respective point. Now the new operating point is selected based on the comparison of these power values. In other words, the decision of change in duty cycle of DC/DC converter, connected between PV panel and system load, is made by the comparison of these powers at all points. A Buck-Boost converter has been used in this research work.

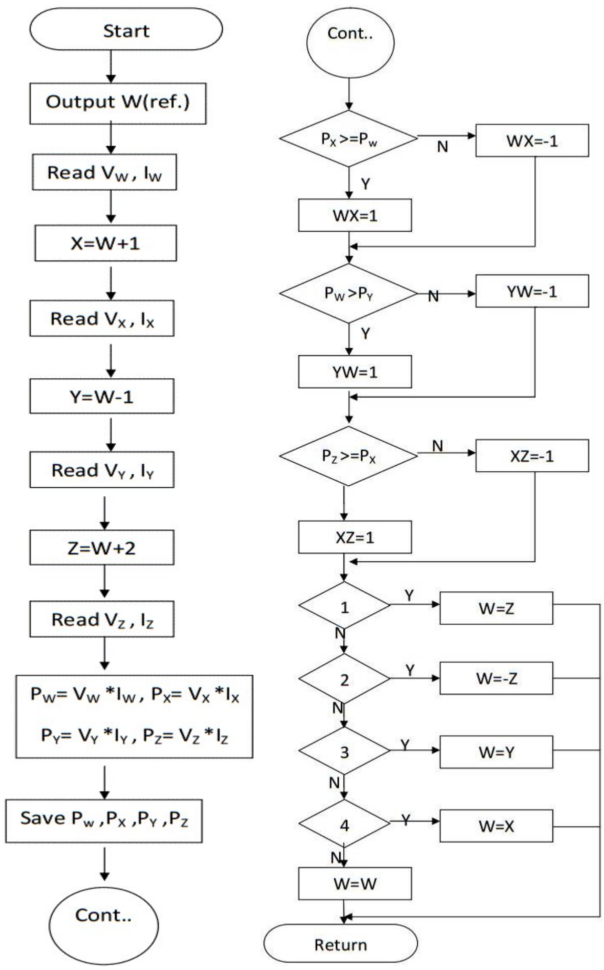

Figure 8. Flowchart of proposed P&O algorithm of Tetra Point Perturb and Observe (TPPO) Algorithm

The following three comparisons are made between these points:

1:Power (P_W) of point (W) with power (P_X) of point (X)
2:Power (P_W) of point (W) with power (P_Y) of point (Y)
3:Power (P_X) of point (X) with power (P_Z) of point (Z)

In case of points W and X, positive sign is assigned if P_X is greater or equal to P_W and a negative sign otherwise. In comparison of points X and Z, a positive sign is assigned to the state if P_Z is greater than P_X and a negative sign otherwise. Similarly, in case of points Y and W, state gets a positive sign if P_Y is less then P_W and a negative otherwise. A state diagram with all possible eight cases between these four points is shown in Fig. 7. The flow chart of the algorithm is shown in Fig. 8 and conditions in Fig. 9.

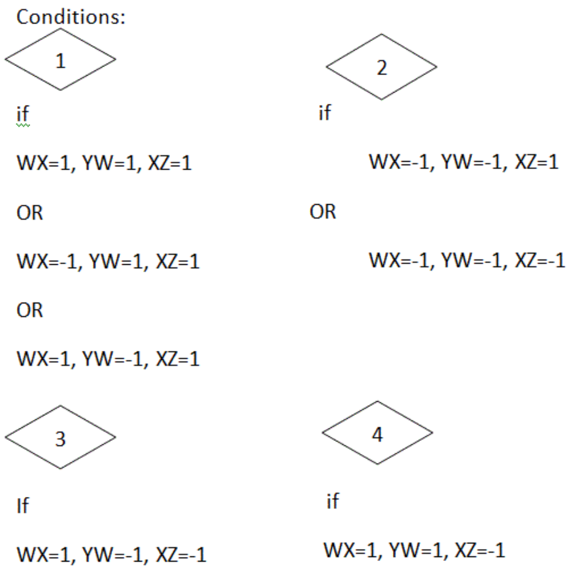

Figure 9. Conditions used in Flowchart of proposed TPPO

VI. DC/DC Converter

As operating voltage of PV panel is changed to operate it at the maximum power point, but the load always requires a constant voltage as well as power at output. Therefore, a DC-to-DC converter is connected between the PV panel and load to fulfill this requirement. The buck-boost converter is used in this work because it can step up and step down the voltage in accordance with the load and keeps the power constant. The converter is operated in continuous conduction mode.

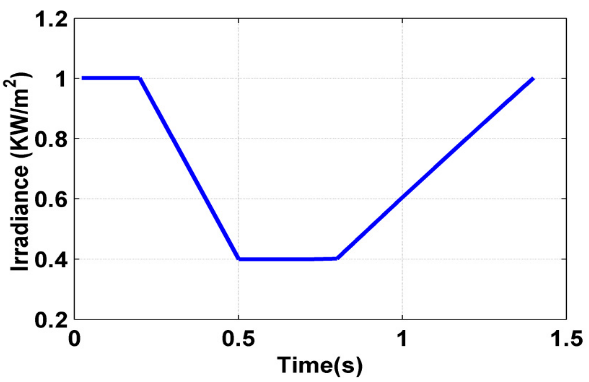

Figure 10. Irradiance input curve

VII. Experimental Set-Up

The proposed algorithm implementation on PV module is realized in Matlab simulation platform. A varying irradiance input is used to test the effectiveness of proposed algorithm. The irradiance varies from 1KW/m^2 to 0.4KW/m^2, remains at 0.4KW/m^2 for 0.3 seconds, and then increases from 0.4KW/m^2 to 1KW/m^2 gradually as shown in figure 10.

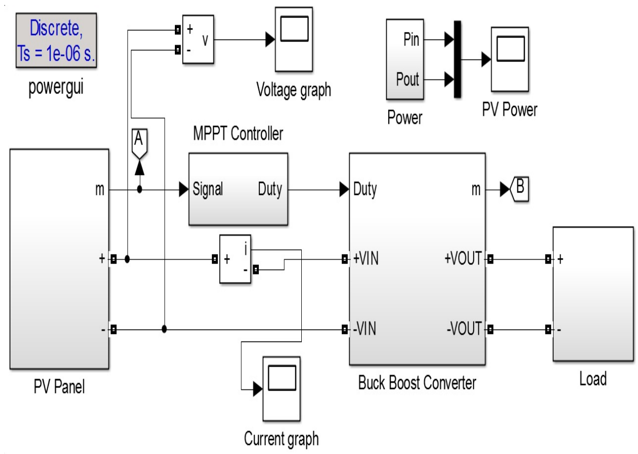

Figure 11. Matlab model of PV system with Tetra Point Perturb and Observe (TPPO) Algorithm

Table 1. Parameters of used Standalone PV Panel

Parameter	Value
No of cells	72
Maximum module power P_{max}	327.6W
Voltage at P_{max}	38.2v
Current at P_{max}	8.57A
Open Circuit Voltage (V_{oc})	43.2v
Short Circuit Current (I_{sc})	10.1A

The Matlab model of the new proposed TPPO Method is shown in Fig. 11. The temperature (T) and irradiance (G) are the inputs of the PV module. The output voltage (V) of the module is used as feedback to the module to track the maximum power point. The parameters used for PV panel are shown in Table 1.

VIII. Results

The results for voltage, current and power of the PV module in absence of any MPPT controller can be seen in Fig. 12, 13 and 14 respectively. The power output results are clearly showing that maximum power approached is around 176.8 W at full irradiance, which is much lesser than the theoretical maximum power of 327.6 W as mentioned in Table 1. Hence, it is clear from these results that it is necessary to use MPPT controller to get maximum possible power.

The simulated time variations of the voltage, current and power of the PV panel by using the MPPT controller are shown in Figs. 15, 16 and 17, respectively. In this case, the MPPT controller is having the Perturb and Observe algorithm to track the maximum power point.

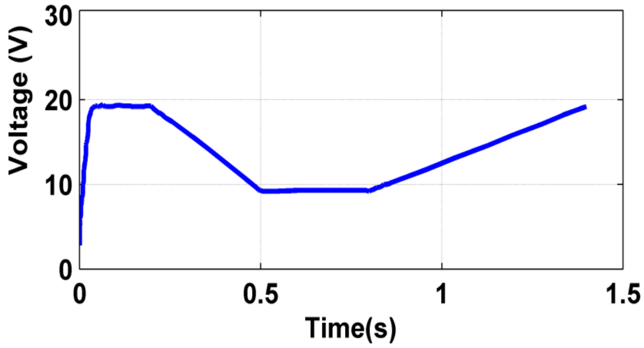

Figure 12. PV panel Voltage without MPP Tracker

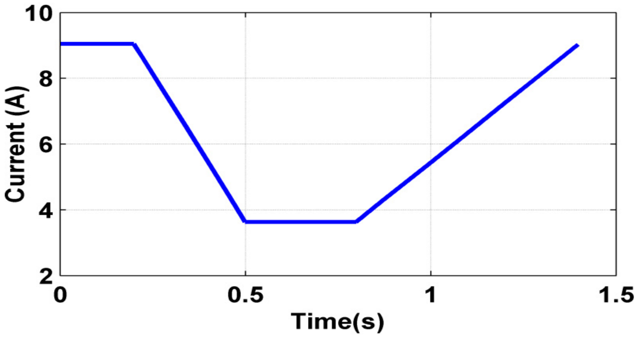

Figure 13. PV panel Current without MPP Tracker

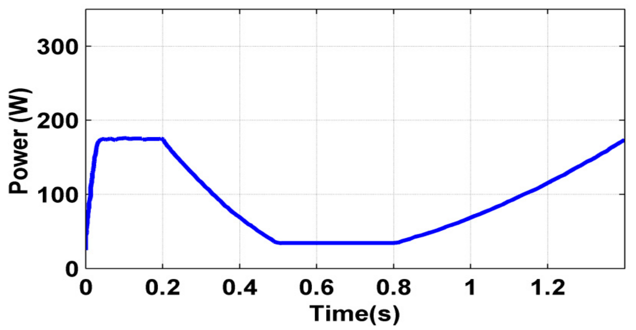

Figure 14. PV panel Power without MPP Tracker

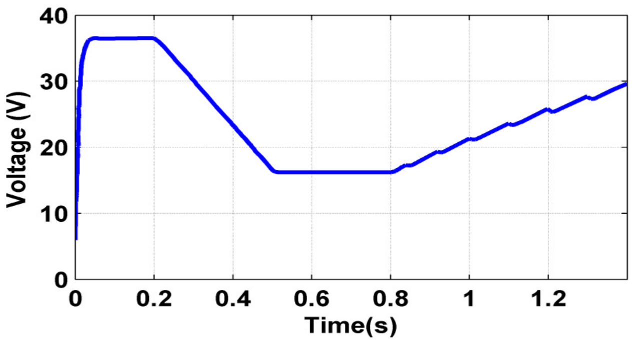

Figure 15. PV panel Voltage with P&O

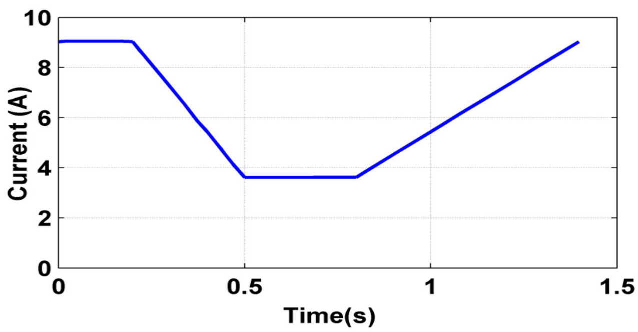

Figure 16. PV panel Current with P&O

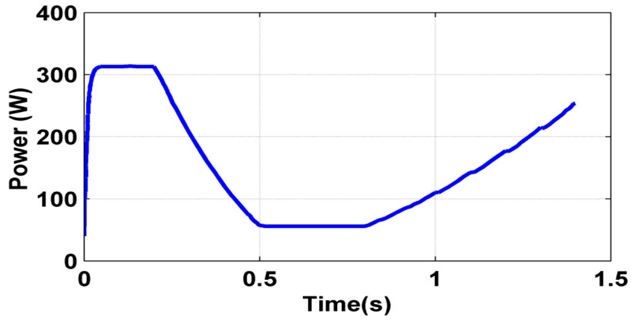

Figure 17. PV panel Power with traditional P&O

Above results are clearly showing that the power of the PV panel, with MPPT controller having traditional P&O algorithm, is much improved as compared to without it.

Finally the simulated time variations of the voltage, current and power of PV panel, by using the controller having proposed TPPO algorithm, are shown in Fig. 18, 19 and 20 respectively. These results are prominently showing that the PV panel delivered much better power output in case of TPPO as compared to the P&O algorithm. Particularly, during varying irradiance, the outputs are enhanced remarkably in the presence of TPPO algorithm. Moreover PV panel power output without any MPPT controller is at lowest level comparatively, which shows that a MPPT controller plays an important role to get maximum power from PV panel.

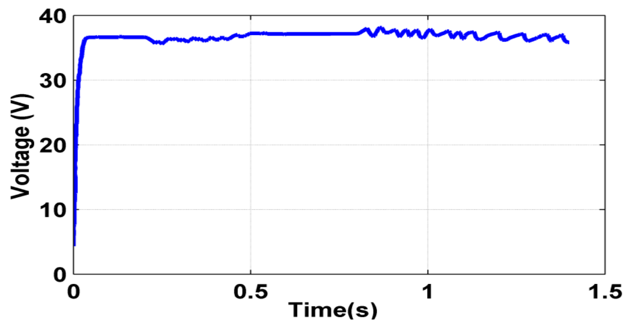

Figure 18. PV panel Voltage with proposed TPPO algorithm

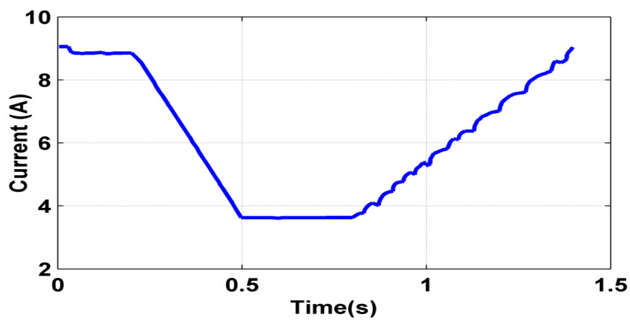

Figure 19. PV panel Current with proposed TPPO algorithm

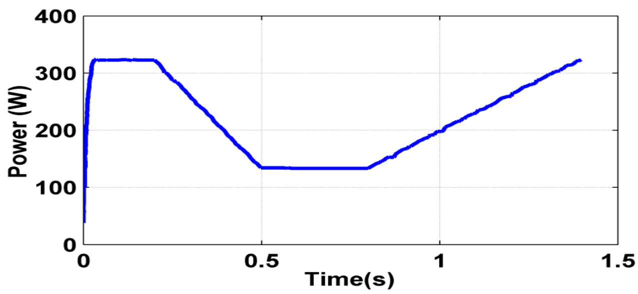

Figure 20. PV panel Power with proposed TPPO algorithm

A comparison of all three power outputs, without MPP Tracker, with traditional P&O algorithm and with proposed TPPO algorithm, is shown in Fig. 21. Table 2 compares the performance of the proposed TPPO method with other MPPT methods. The comparison verifies the excellent performance of the proposed TPPO based MPPT method.

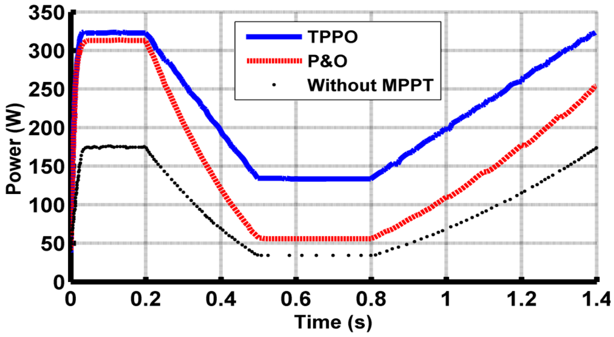

Figure 21. PV panel Power results Comparison

TABLE 2. COMPARISON OF MAXIMUM EFFICIENCY BASED ON MPPT TECHNIQUES

MPPT Technique	Efficiency (%)
Open circuit voltage (OCV) [4]	86
Short circuit current (SCC) [6,7]	89
Temperature method [8]	89
Perturb and observe fixed (P&O fixed) [10]	88
Perturb and observe variable (P&O variable) [10]	96
Three-point weighted [11]	96
Incremental conductance (IC) [14,15]	95
Fuzzy logic [16,17]	96
Proposed TPPO	98.8

IX. CONCLUSION

A new robust MPPT method, Tetra Point Perturb and Observe, has been proposed to efficiently track the changes in output power of PV system due to changes in irradiance. The proposed MPPT method gets maximum power under varying irradiance conditions and provides efficient results in reduced power loss. The performance of the TPPO method is compared to the existing MPPT methods and it performs better by enhancing the efficiency to 98.6%. This method also avoids or minimizes the oscillations at MPP. Thus it can be envisaged that this algorithm will magnetize research and industry professionals in designing a new MPPT algorithm for PV system.

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