Comparative analysis of perturb & observe and fuzzy logic maximum power point tracking techniques for a photovoltaic array under partial shading conditions

T. MURALI MOHAN*, V.S. VAKULA

Department of Electrical and Electronics Engineering, University College of Engineering Vizayanagaram, Jawaharlal Nehru Technological University Kakinada, Andhrapradesh, India.
E-mails: tmmohan2009@gmail.com; drvakulavs@gmail.com
* Corresponding author, phone: 91-7416430767

Abstract

The interfacing of maximum power point tracking (MPPT) controller is more concern as it contributes significantly to the power output of photovoltaic systems. The perturb and observe (P&O) and fuzzy logic based P&O are two most promising MPPT techniques in wide range of irradiance conditions which include fully shaded condition to no shading, uniform and non uniform shadings among the strings. This paper analyzes the implementation of those two MPPT techniques to a photovoltaic (PV) array in MATLAB/SIMULINK environment. Basically the power verses voltage curve of a PV array is highly non linear which contains single peak in the curve under uniform irradiance but the non uniform irradiance leaves multiple peaks in the curve. The MPPT normally controls the boost converter duty cycle to track the global peak power point of the PV array. When multiple peaks are present, the P&O has the probability of capturing a local maximum point rather than a global maximum. It is observed that under normal shadings both MPPTs are performed well but under partial shadings Fuzzy logic based P&O MPPT outperform over P&O MPPT.

Keywords

Photovoltaic System; Perturb & Observe Maximum Power Point Tracking;

Fuzzy logic MPPT; Boost converter

Introduction

Solar photovoltaic system is one of the best alternatives for the energy sources among the renewable energy sources. Though it was an old concept the generation of power is eventully increasing as the advances in power electronics and technology in manufacturing of PV cells are growing rapidly. However, the power output from the PV modules and consequently the efficiency is less which is about 19% which is very low. This generates the motivation for research into the extraction of maximum power from PV array by adopting a control technique called maximum power point technique (MPPT) [1-3].

There are different MPPT techniques came into the application such as perturb and observe MPPT, incremental conductance MPPT etc. The basic function of these techniques is to extract maximum power from PV array by virtually making the load impedance equal to the source impedance of the PV array. This is done by switching appropriately the power electronic switch used in the boost converter which is connected next to the PV array. These two techniques suffer from the draw back that under partial shadings they fail to extract the maximum power [4-8].

The partial shadings are mainly created by formation of dust upon the cells in a module, shadows which are produced by surrounding objects (trees, antennas, buildings), and passage of clouds which leads to non-uniform (partial shadings) irradiance and temperature upon the PV modules [9]. Under partial shadings the above MPPT techniques are fail to extract the maximum power because multiple peaks are present in the power verses voltage curve of a PV array [10]. The novel technique called fuzzy logic based P&O MPPT which overcomes the difficulty of locating the global peak among the multiple peaks [11].

The fuzzy logic based P&O MPPT technique is used in this paper which is equally good at normal and partial shadings as it possess fuzzy rules in the fuzzy inference engine. For an array consists of number of strings connected in parallel. In the subsequent sections the modules such as PV cell and array modeling and MPPT technique is implemented and analyzed its performance under different types of irradiance conditions [12-15]. The modeling and analysis of MPPT is done in MATLAB/SIMULINK environment.

PV System Structure

Figure 1 shows the equivalent circuit of a PV cell used in a PV module. To get a required rating of voltage and current such cells are connected in series and parallel respectively. This enhances the power output of the array.

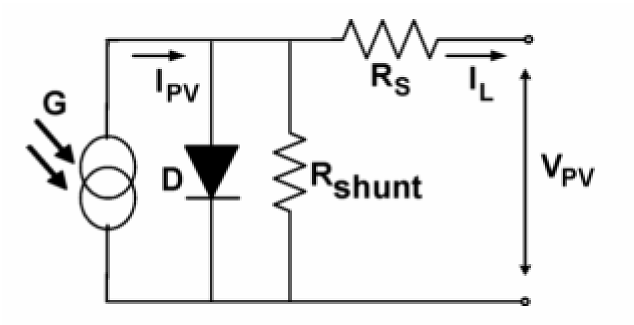

Figure 1. *Equivalent circuit of a PV cell*

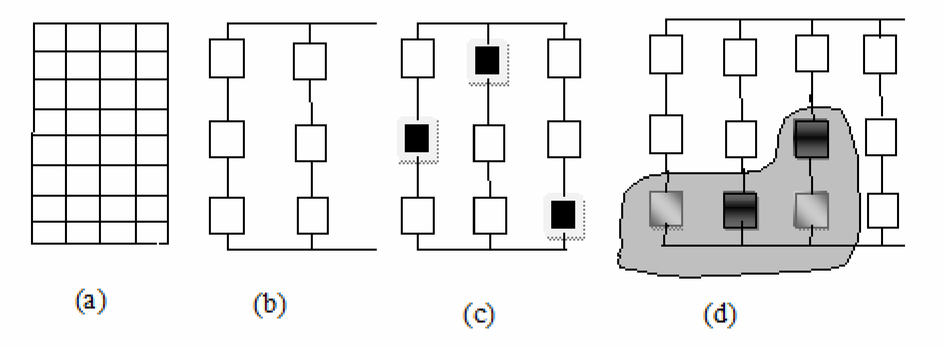

Figure 2. *PV array terminologies. (a) PV module. (b)Two strings in parallel (c)Individual Module shading (d) PV array with group partial shading*

In Figure 2, the figure (a) shows the PV module, where number of cells are connected in series and parallel. The dark color on the module shows more shading or completely shaded. These shadings are two types such as partial and full shading. The partial shadings on the modules shall be simulated by setting irradiance less than the standard value 1000 w/m2 and full shading by 0 w/m2 shown in figure 2 (c) and figure 2 (d) respectively.

Perturb and observe MPPT algorithm

One of the mostly used MPPT method is the perturb & observe. In this method the voltage is perturbed and change in power is measured and used for analysis. If the change in power is positive for a change in voltage (dP/dV > 0) a further perturbation in voltage is made because the operating point lies on the left of the power verses voltage curve of the PV system. This requires a further perturbation in PV voltage. This process repeats until the change in power is zero (dP/dV =0) which occurs at maximum point (MP) on the P-V curve shown in figure 3. If the operating point is on right side of the curve the change in power will be negative (dP/dV > 0) which requires moving the operating point towards the MP. In Figure 3 MPP is the maximum power point (Pmp) which occurs at the point where maximum voltage (Vmp) and maximum current (Imp) occur in the system (where Isc is the short circuit current of the PV array normally higher than the maximum current).

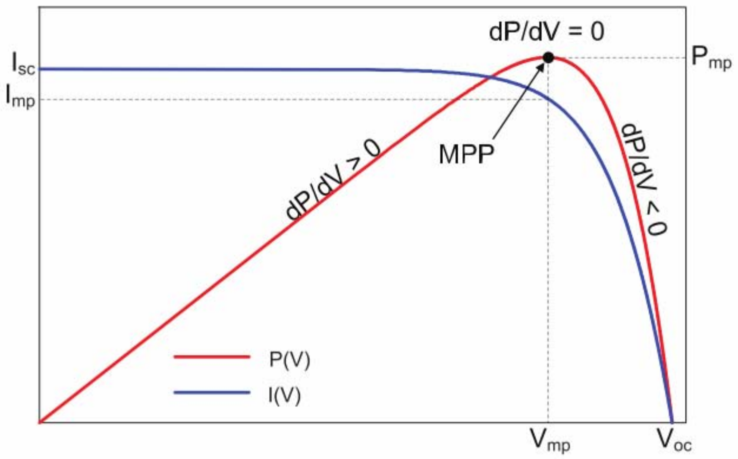

Figure 3. *Power characteristic of a PV module*

The implementation P&O algorithm is shown in the flow chart form in Figure 4, where primarily the voltage and current signals are sampled at k^{th} interval as Vk and Ik respectively and use them for calculating the power at k^{th} interval Pk. Find the difference between the powers obtained from the previous and the present intervals (Pk-Pk-1). If the difference in powers is zero then no need to change the reference voltage Vref used in the direct current to direct current (DC to DC) boost converter which is used to adjust the output voltage of the converter. If (Pk-Pk-1) > 0 then it checks for voltage difference of present and previous intervals (Vk-Vk-1), if it is positive that needs to increase the reference voltage otherwise it decreases the reference voltage. If (Pk-Pk-1) < 0 then it checks for (Vk-Vk-1), if it is positive that needs to decrease the reference voltage otherwise it increases the reference voltage. This process continues throughout the operation of the PV system.

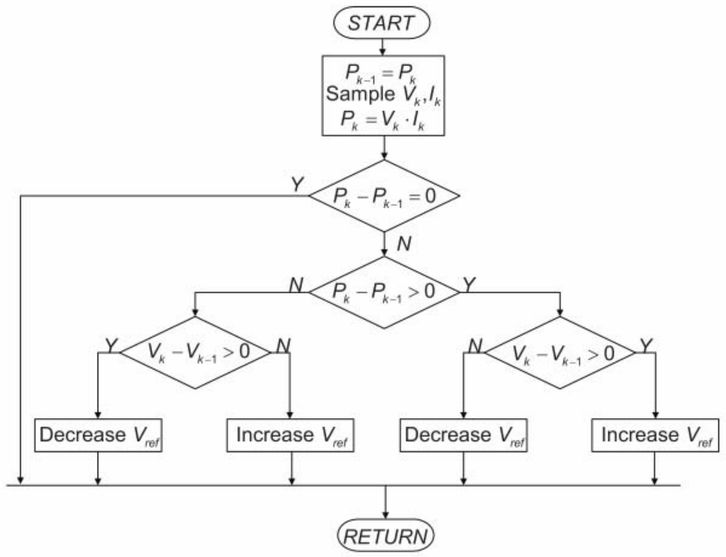

Figure 4. *Flow chart of P&O algorithm*

The main advantage of the P&O method is that it is easy to implement, it has low computational demand, and it is very generic, i.e. applicable for most systems, as it does not require any information about the PV array, but only the measured voltage and current. Because of this the P&O is most commonly used method of MPPT method. The two main disadvantages of the method mentioned in the literature, are oscillations around maximum power point in steady state and poor tracking in rapidly changing atmospheric conditions. This method suffers too to extract maximum power under partial shadings on the PV panels.

Materials and Methods

Figure 5 shows the flowchart of the proposed method, where Vpv and Ipv are the PV output voltage and current, respectively, D is the duty cycle, Pm is the global MPP, and ΔPm is a constant which represents the allowable difference between the global maximum point and the operating power point. In the proposed method a large perturbation is made to identify a global maximum power point over a wide range on the PV locus. Whenever the global maximum point exceeds during tracking the duty cycle must return to minimum value.

Scanning and storing the PV power are accomplished during perturbation and observation. A fuzzy logic based MPPT is preferred with the proposed method; because the tracking speed is not constant. During initial or varying weather conditions, the initial tracking speed should be fast enough to make a wide range of scan and store the global maximum. However, the tacking speed should decreases once the global maximum point is reached to minimize any oscillation around the global maximum point. The proposed controller with a PV system is shown in Figure 6.

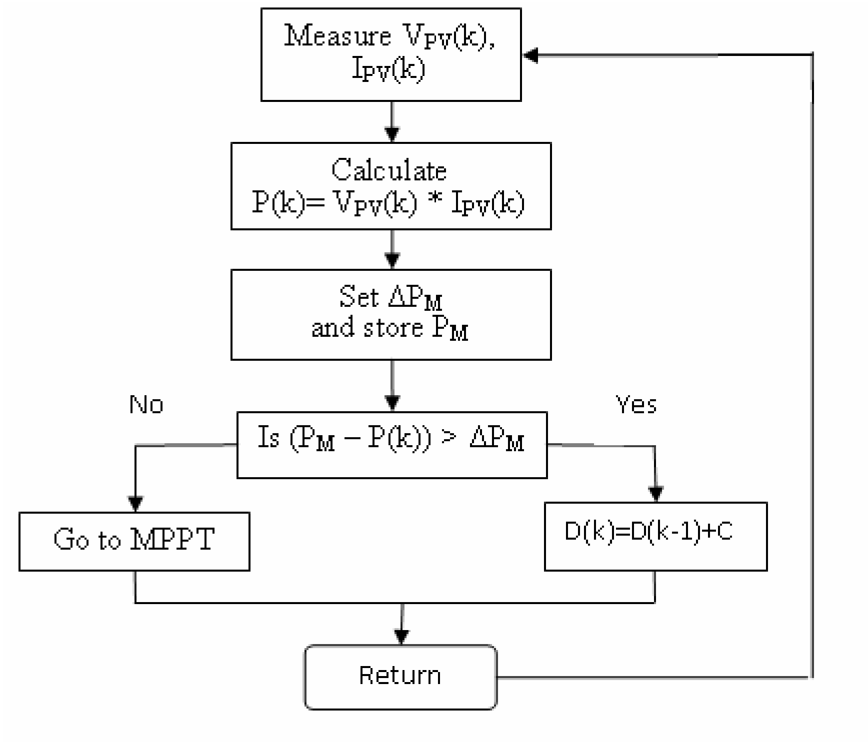

Figure 5. *Proposed method flow chart*

The inputs to the fuzzy logic controller are and the output equation is:

(i) Change in power from k^{th} and $(k-1)^{th}$ time interval.

$$\Delta P=P(k)-P(k-1) \quad (1)$$

(ii) Change in current from k^{th} and $(k-1)^{th}$ time interval.

$$\Delta I=I(k)-I(k-1) \quad (2)$$

(iii) Change in power between the global maximum power and the power at k^{th} interval.

$$\Delta P_M=P_m(k)-P(k) \quad (3)$$

and the output of the fuzzy logic controller is

(i) Change in boost converter duty cycle between present and previous time interval.

$$\Delta D=D(k)-D(k-1) \quad (4)$$

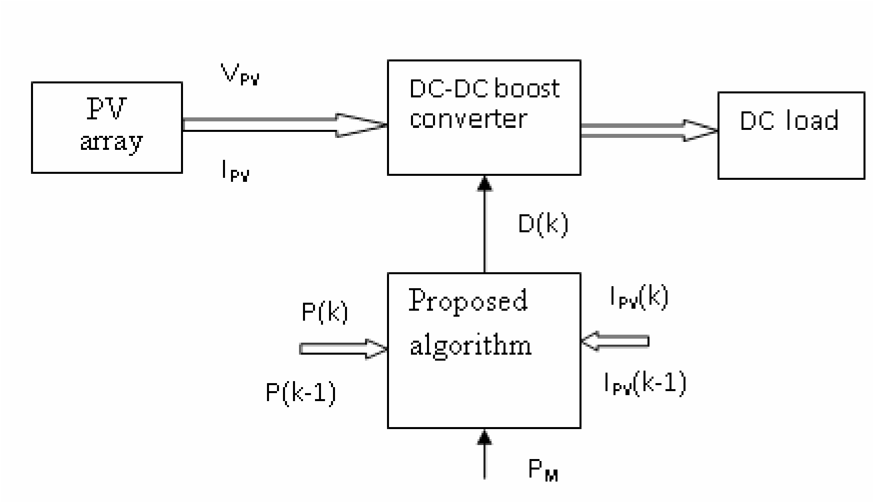

Figure 6. *PV array with proposed MPPT controller*

Equations (1)-(4) are used for forming the fuzzy logic rule table which is used in fuzzy inference engine shown in Table 1.

Table 1. Fuzzy logic rules

ΔI / **ΔP**	**NB**	**NS**	**PS**	**PB**	**ΔPM**
NB	PM	PM	NM	NM	PS
NS	PS	PS	NS	NS	
PS	NS	NS	PS	PS	
PB	NM	NM	PM	PM	
NB	PB	PB	PB	PB	PB
NS	PB	PB	PB	PB	
PS	PB	PB	PB	PB	
PB	PB	PB	PB	PB	

The variable inputs ΔP and ΔI are divided into four fuzzy subsets: positive big (PB), positive small (PS), negative big (NB), and negative small (NS). The variable input ΔP_M is divided into two fuzzy sub sets: PB and PS. The output variable ΔD is divided into six fuzzy subsets: PB, PM, PS, NB, NM, and NS. Therefore, the fuzzy algorithm requires 32 fuzzy control rules; these rules are based on the regulation of a hill climbing algorithm along with the reference power. To operate the fuzzy combination, Mamdani's method with max–min is used.

The shapes and fuzzy subset partitions of the membership function in both of the inputs and output are shown in Figure 7. The last fuzzy controller stage is defuzzification where the centre-of-the-area algorithm is used to convert the fuzzy subset duty cycle changes to real numbers.

$$\Delta D = [\sum_1^n \mu(D_i)D_i]/[\sum_1^n \mu(D_i)] \quad (5)$$

where ΔD is the fuzzy controller output and D_i is the centre of the max–min composition at the output membership function

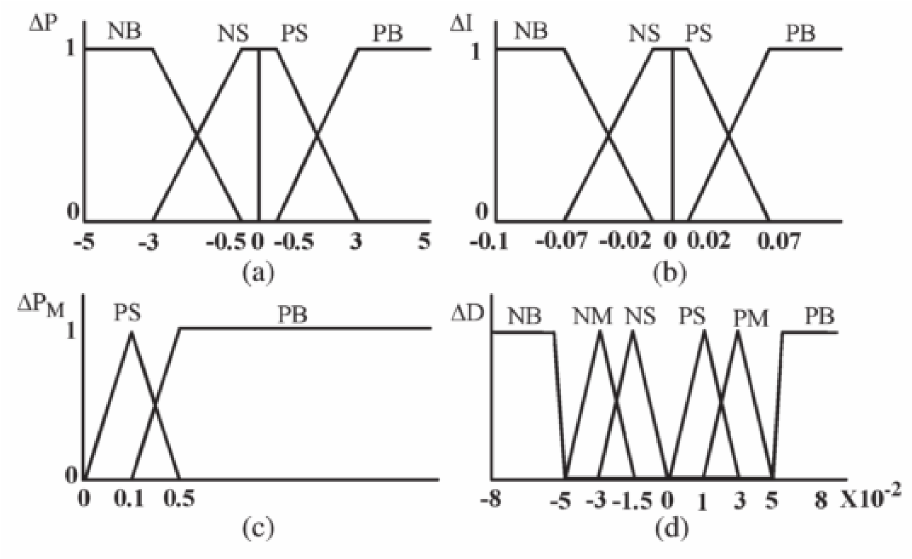

Figure 7. *Membership functions:*
(a) Input ΔP, (b) Input ΔI, (c) Input ΔP_M, and (d) Output ΔD

Equation (5) gives the change in duty cycle.

Simulation of proposed system

An array consists of three strings of PV modules connected in parallel and each string consists of three modules is considered for analysis. The PV module used in simulation is having the following specifications shown in Table 2.

Table 2. Specifications of a PV module

S.No	Name of the parameter	Value
1.	Open circuit voltage	43.4 V
2.	Maximum voltage	36.0 V
3.	Short circuit current	4.4 A
4.	Maximum current	4.235 A

Case A: In normal shading mode all the modules are assumed the standard temperature 25°C and standard irradiance of 1000 w/m^2. This is an ideal case but it is different in practical situation.

Case B: In this case all the modules are not given an equal amount of irradiance but of different values such as 500, 200, 50 w/m^2 in module 1, module 2 and module 3 respectively in each string. However, the temperature is kept constant over all the modules at 25°C.

Case C: In case C pulse type of irradiance is considered at all modules. The pulse irradiance is defined as follows: 400 w/m^2 during 0 to 0.3 sec, 1000 w/m^2 during 0.3 to 0.6 sec, and 200 w/m^2 during 0.6 to 1 sec. A uniform temperature of 25°C is considered across all the modules.

Case D: In this case the partial shadings are considered as follows: In first row the modules are given irradiance 1000 w/m^2, in second row the modules are set equally with a stepped pulse irradiance which is characterized by 0 to 0.3 sec, 200 w/m^2, 0.3 to 0.6 sec, 600 w/m^2, and 0.6 to 1 sec, 1000 w/m^2. In third row each module is given irradiance as 0 to 0.3 sec, 1000w/m^2, 0.3 to 0.6 sec, 600 w/m^2, and 0.6 to 1 sec, 200 w/m^2.

Results and discussion

Case A: No partial shadings

The comparative results of P&O MPPT and fuzzy logic based P&O MPPT are presented in Figures 8-10 for the four different cases of the PV system described in the system analysis section. This is one practical case where irradiance and temperature is assumed as constant across the modules. This is an ideal case normally would not prevail in the system all the time but happens at some of the times during the day.

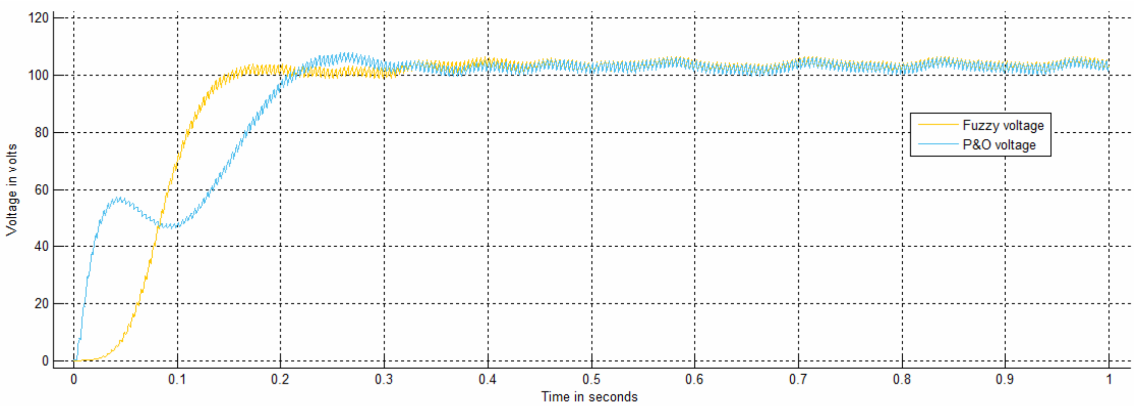

Figure 8. *Load voltage waveforms*

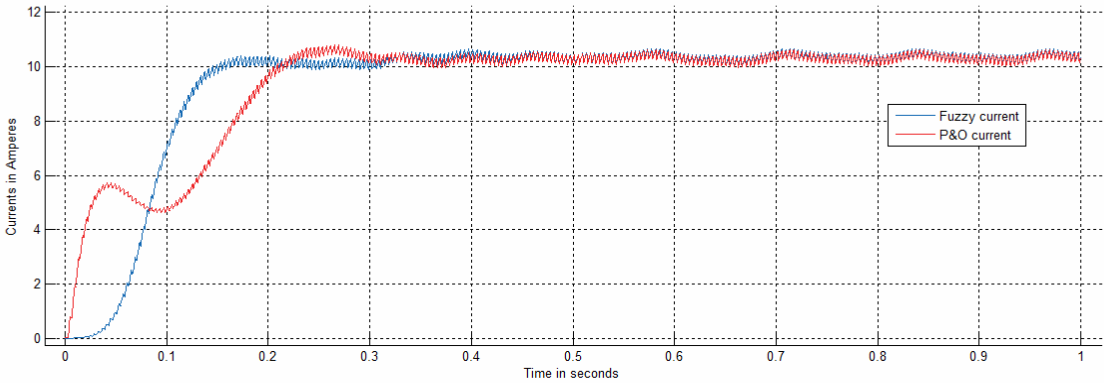

Figure 9. *Load current waveforms*

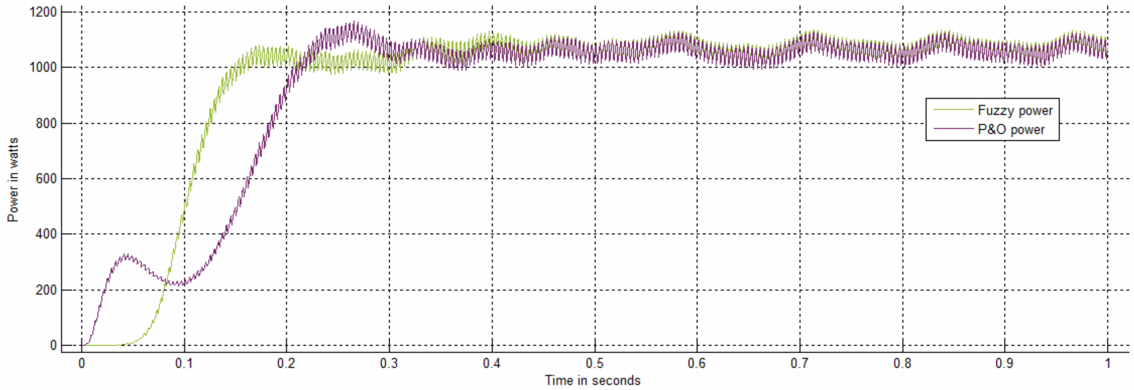

Figure 10. *Load power waveforms*

Figures 8-10 depict that the PV voltage, current, and power at the load terminals are approximately 100 V, 10 A, and 1000 W respectively. These are nominal values obtained without any shadings applied across the modules which are close to the peak values. It is evident that both MPPT methods are giving same results in steady state across the load when there is no shading. Nevertheless the fuzzy MPPT is giving a faster response than P&O MPPT.

Case B: Partial shadings type-1

In this case the modules are given different shadings of constant values with respect to time. The temperature of the modules is assumed as constant 25°C which is one of the practical situations where analysis needs to be done.

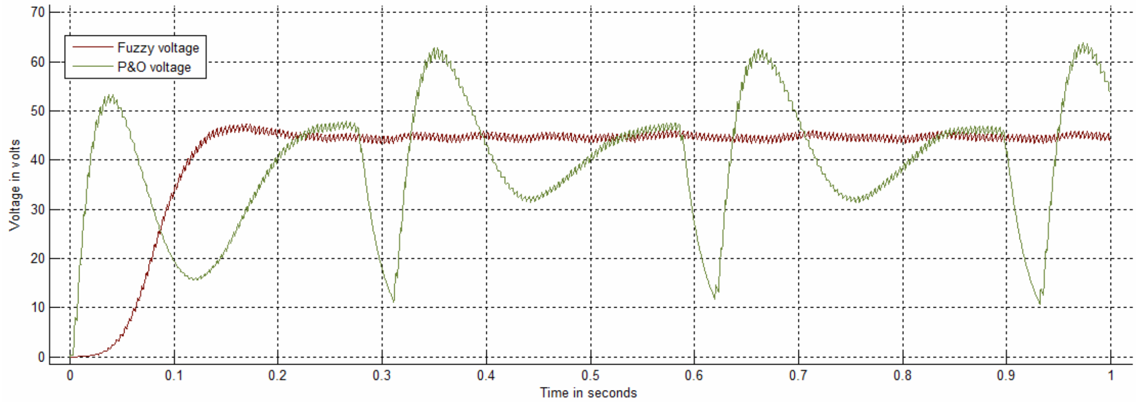

Figure 11. *Load voltage wavefoms under shadings type-1*

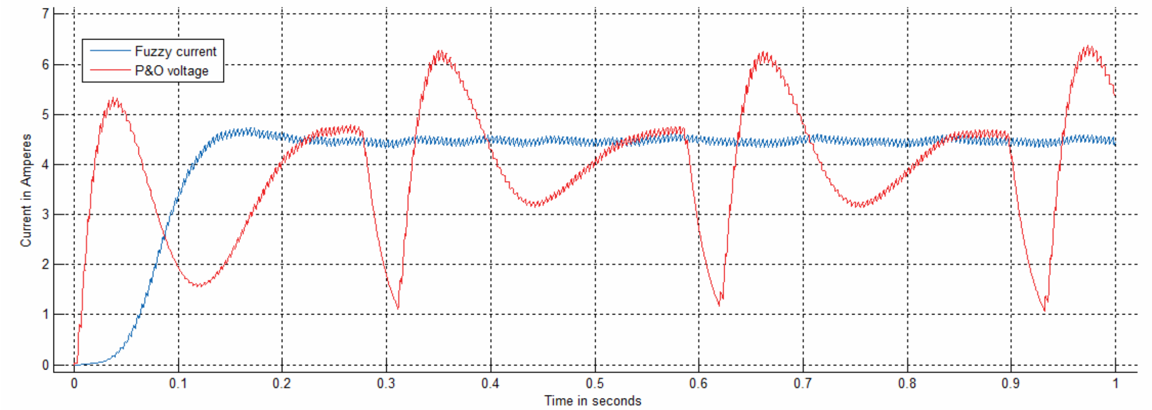

Figure 12. *Load current waveforms under shadings type-1*

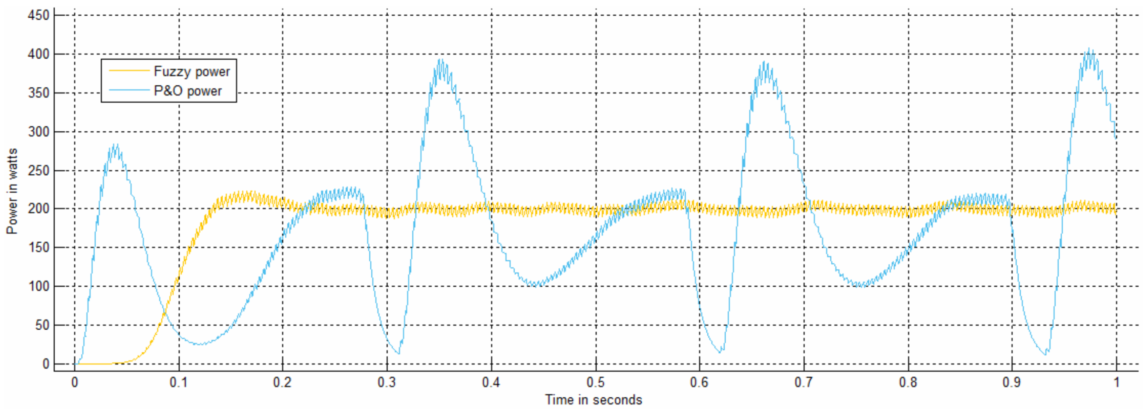

Figure 13. *Load power waveforms under shadings type-1*

Figures 11-13 depict the voltage, current, and power of PV array in partial shadings mentioned above. It is observed that P&O MPPT produces oscillating power with peaks continuously which are highly undesirable to the power system. However, the fuzzy MPPT produced the power without any variation or oscillations despite of the partial shadings persists cross the modules.

Case C: Partial shadings type-2 (pulse type of irradiance)

Sometimes the irradiance across the PV array can vary with respect to time at a faster rate. This is true due to the passage of clouds in rainy season; as a result of that pulse type of irradiance is simulated and analyzed the system behavior.

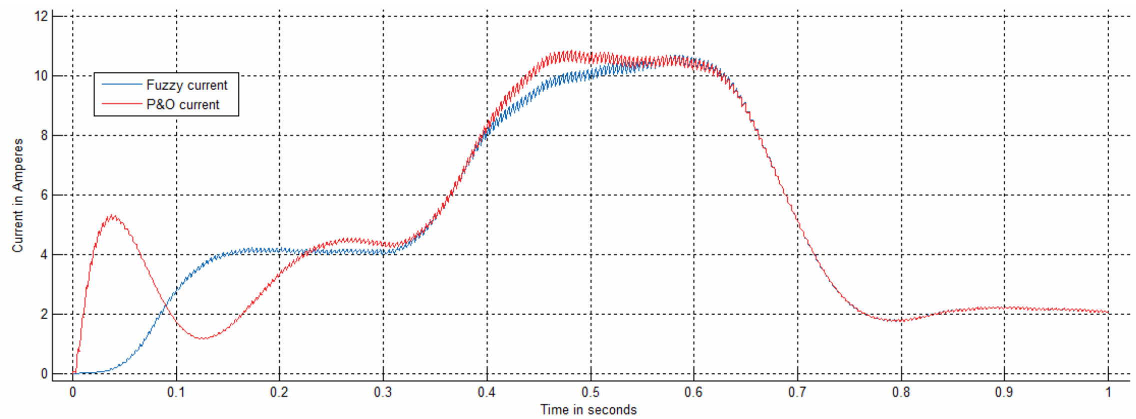

Figure 14. *PV current characteristics for shadings type-2*

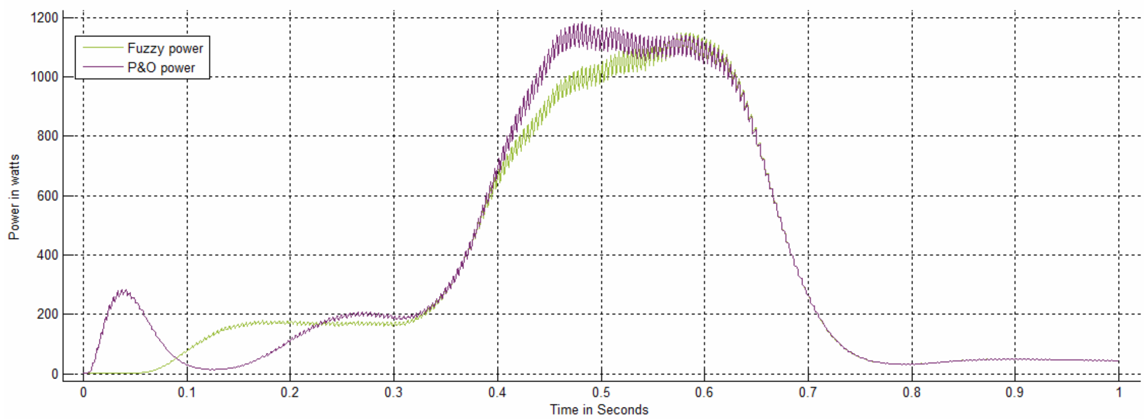

Figure 15. *PV powers for shadings type-2*

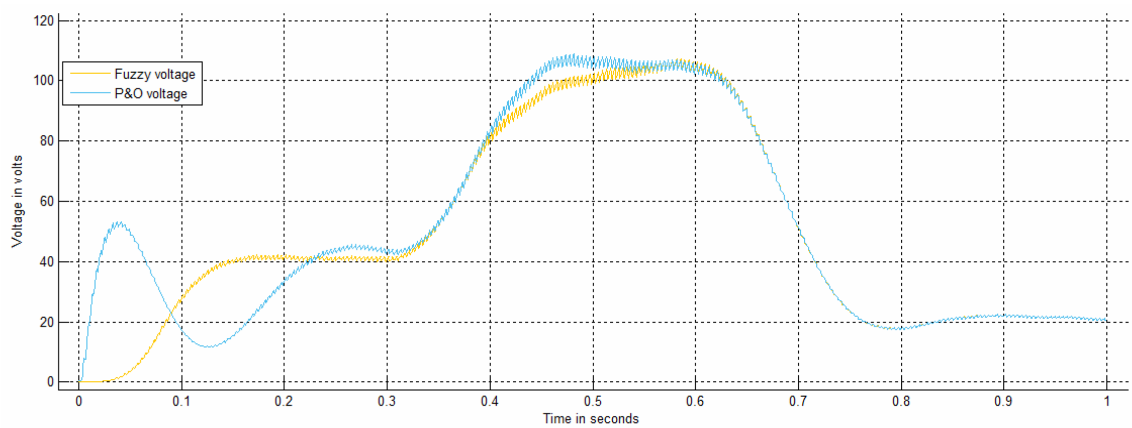

Figure 16. *PV voltages for shadings type-2*

Issue 27, July-December 2015
p. 1-16

Figures 14 to 16 illustrate the curves for pulse type of irradiance described above. It shows that the output current, voltage and power also resemble pulse form. This type of results comprises peaks at the time of transition of irradiance.

Case D: Partial shadings type-3

In this case a combination of constant irradiance at some modules and pulse type of irradiance at some other modules is considered. Because, this is one more practical situation where a combination of irradiances can exist cross modules.

Despite of the combination of different irradiances across the modules, the Figures 17 to 19 shows that the voltage, current and power respectively are less oscillatory from the proposed method.

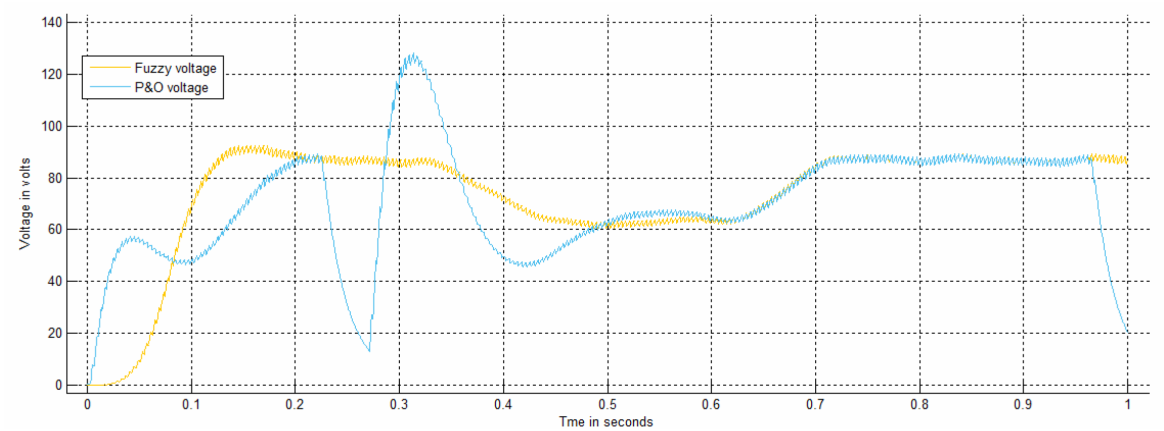

Figure 17. *PV voltages for shadings type-3*

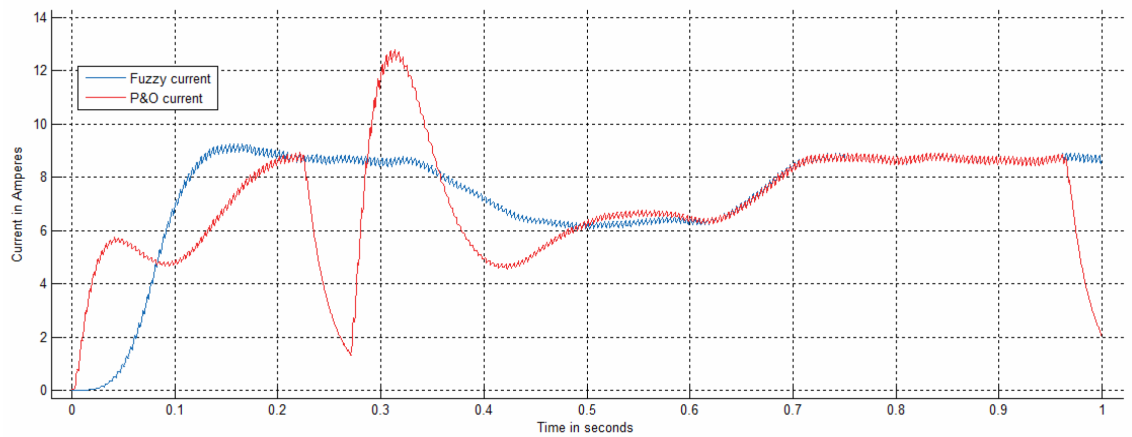

Figure 18. *PV currents for shadings type-3*

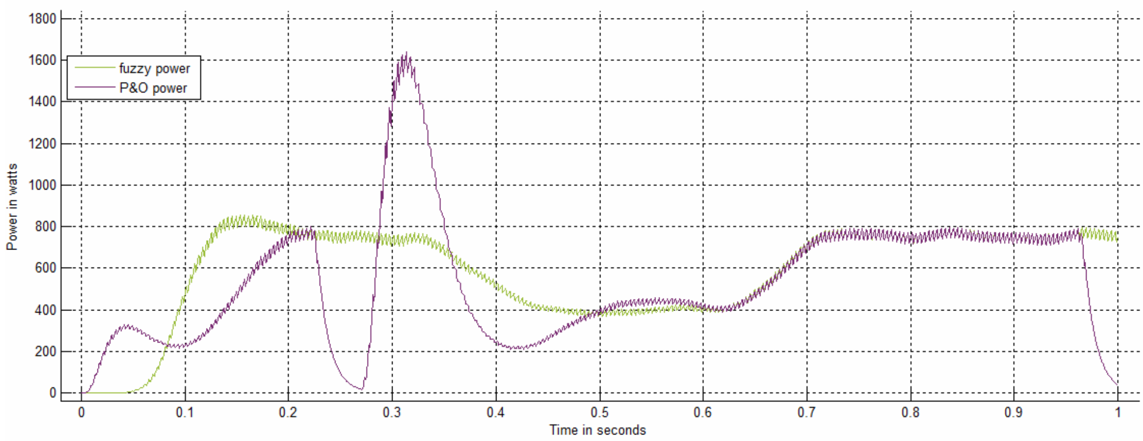

Figure 19. *PV powers for shadings type-3*

Conclusion

It is observed that the partial shading array produces highly fluctuating output power. It is found that output power is in proportion to the solar irradiance but due to non uniform irradiance across the modules output power appears non uniform. Under partial shadings the P&O MPPT fails to identify global maximum point and as a result the output power is less than the global maximum. The fuzzy logic MPPT extracted the maximum power in majority of the partial shading conditions.

References

1. Hohm D., Ropp M., *Comparative study of maximum power point tracking algorithms using an experimental, programmable, maximum power point tracking test,* Photovoltaic Specialists Conference Record of the Twenty-Eighth IEEE, 2000, p. 1699–1702.
2. Femia N., Petrone G., Spagnuolo G., Vitelli M, *Optimization of Perturb and Observe MPPT method*, IEEE trans. Power Electron., 2005, 20(4), p. 963-973.
3. Roman E., Alonso R., Ibanez P., Elorduiza Patarietxe S., Goitia D., *Intelligent PV module for grid-connected PV systems,* IEEE Transactions on Industrial Electronics, 2006, 53(4), p. 1066-1073.

4. Brambilla A. G. A. R. F., Gambarara M., *New approach to photovoltaic arrays maximum power point tracking*, Proceedings of Power Electronics Specialists Conference, 2004.
5. Esram T., Chapman P.L., *Comparison of photovoltaic array maximum power point techniques*, IEEE Trans. Energy Convers., 2007, 22(2), p. 439-449.
6. Femia N., Granozio D., Petrone G., Spagnuolo G., Vitelli M., *Predictive & adaptive MPPT Perturb and Observe Method*, IEEE Transactions on Aerospace and Electronic Systems, 2007, 43(3), p. 934-950.
7. Esram T., Chapman P., *Comparison of photovoltaic array maximum power point tracking techniques*, IEEE Transaction on Energy Conversion, 2007, 22(2), p. 439-449.
8. Kjaer S, *Evaluation of the hill climbing and incremental conductance maximum power point trackers for photovoltaic power systems*, IEEE Trans. Energy Convers., 2012, 27(4), p. 922-929.
9. Patel H., Agarwal V., *MATLAB-Based Modeling to Study the Effects of Partial Shading on PV Array Characteristics*, IEEE Transactions on Energy Conversion, 2008, 23(1), p. 302-310.
10. Ding K., Bian X.G., Liu H.H., Peng T., *A MATLAB Simulink Based PV Module Model and its Application Under Conditions of Nonuniform Irradiance*, IEEE Transactions on Energy Conversion, 2012, 27(4), p. 864-872.
11. Chaouachi A., Kamel R.M., Nagasaka K., *MPPT Operation for PV Grid-connected System using RBFNN and Fuzzy Classification*, World Academy of Science, Engineering and Technology, 2010, 4, p. 5-25.
12. Alajmi B., Ahmed K., Finney S., Williams B., *Fuzzy logic controlled approach of a modified hill climbing method for maximum power point in micro grid stand-alone photovoltaic system*, IEEE Trans. Power Electron., 2011, 26(4), p. 1022-1030.
13. Koutroulis E., Blaabjerg F., *A New Technique for Tracking the Global Maximum PowerPoint of PV Arrays Operating Under Partial Shading Conditions*, IEEE Journal of Photovoltaics, 2012, 2(2), p. 184-190.
14. Ji Y.-H., Jung D.-Y., Kim J.-G., Kim J.-H., Lee T.-W., Won C.-Y., *A Real Maximum Power Point Tracking Method for Mismatching Compensation in PV Array Under Partially Shaded Conditions*, IEEE Transactions on Power Electronics, 2011, 26(4), p. 1001-1009.

15. Alajmi v, Ahmed K. H., Finney S. J., Williams B. W., *A Maximum Power Point Tracking Technique for Partially Shaded Photovoltaic Systems in Microgrids*, IEEE Transactions on Industrial Electronics, 2013, 60(4), p. 1596-1606.