International Journal of Power Electronics and Drive System (IJPEDS)
Vol. 8, No. 3, September 2017, pp. 1327~1334
ISSN: 2088-8694, DOI: 10.11591/ijpeds.v8i3.pp1327-1334

Adaptive Neuro-fuzzy Inference System-based Improvement of Perturb and Observe Maximum Power Point Tracking Method for Photovoltaic Systems

Khaled Bataineh[1], Yazan Taamneh[2]
[1]Department of Mechanical Engineering, Jordan University of Science and Technology, Irbid, Jordan
[2]Department of Aeronautical, Jordan University of Science and Technology, Irbid, Jordan

Article Info

Article history:

Received Mar 26, 2017
Revised Jun 22, 2017
Accepted Aug 13, 2017

Keyword:

Adaptive neuro fuzzy
Maximum power point tracking
Partial shading second
Photovoltaic system

ABSTRACT

This paper presents a maximum power point (MPP) tracking method based on a hybrid combination between the fuzzy logic controller (FLC) and the conventional Perturb-and-Observe (P&O) method. The proposed algorithm utilizes the FLC to initialize P&O algorithm with an initial duty cycle. MATLAB/Simulink models consisting of, the photovoltaic system, boost converter and controllers, are built to evaluate the performance of the proposed algorithm. To accurately illustrate the performance of the proposed algorithm, comparisons with standalone FLC and P&O are carried out. The performance of the proposed algorithm is investigated difficult weather conditions including sudden changes and partial shading. The results showed that the proposed algorithm successfully reaches MPP in all scenarios.

Corresponding Author:

Khaled Bataineh,
Department of Mechanical Engineering,
Tel. +962 2 7201000 Ext. 22383; Fax. +962 2 7201074,
Jordan University of Science and Technology, Irbid, Jordan.
Email: k.bataineh@just.edu.jo

1. INTRODUCTION

Renewable energy sources provide the most promising solution to meet the increased in energy demand. Amongst them, solar energy is the most plentiful and permanent. The available solar power is larger than the global energy consumption rate [1]. The photovoltaic technology is considred efficient system in converting solar to electric energy [2]. The power generated from PV system depends on irradiance levels, temperature, shading, and other weather conditions [2]. The maximum power attained from PV system varies with the radiation, thus maximum power point MPP tracking algorithm is required to attain maximum power levels.

The tracking algorithms can be classified as direct and indirect methods. The indirect methods are considered as quasi seeking methods because they are based on empirically obtained databases. These methods are curve fitting, look-up tables, open-circuit voltage method, short circuit current method and the open-circuit voltage test cell method [3]. On the other hand, the direct methods are considered true seekers because they use true measurements of voltage and current. Examples of direct methods are Conductance incremental method, Differentiation methods, Perturbation and Observe method, Parasitic capacitance method, and the Artificial intelligent methods [3]. It has been observed that the conventional methods under severe weather conditions have failed to find MPP. Furthermore, several issues were reported such as, inaccuracy, large oscillations, and slow convergence and getting trapped in local peaks. To eliminate these disadvantages, several modifications were performed on these conventional methods [4-7].

The partial shading condition present a difficult challenge for MPPT algorithms. This mainly due to appearance of multiple peaks in the power curves. Conventional algorthims might get trapped in local maximum. Researchers have developed several algorthims to overcome this problem [7-9]. The artificial intelligent systems is becoming attractive approach for tracking the global MPP due to their capability of dealing with the prominent nonlinearities in the I-V characteristics of PV systems [15-19]. It has been shown that Fuzzy logic controller FLC has better tracking ability under the partial shading conditions, faster convergence and lower oscillation about the global maxima [21-22]. Furthermore, it is found that fuzzy logic controller can deliver more power than the neural network controller and can give more power than other different methods found in literature [19]. D'Souza et al. implemented variable size perturbations using fuzzy logic and non-switching zone schemes to improve transient and steady-state responses [20]. However, the performance of thier developed algorithms was not tested partial shading condition.

It is the objective of this study to develop a robust efficient MPPT algorithm that overcomes the problems with previous conventional methods under sudden changes and partial shading conditions. The main creteria for the desired algorithmare are; higher efficiency, faster convergence and lower oscillation about the global MPP under severe weather conditions. The main idea of the developed algorithm is using a hybrid combination between the fuzzy logic controller (FLC) and the conventional Perturb-and-Observe (P&O) method. It uses FLC algorithm to bring system near the MPP. Then, the P&O algorithm with a small step size is used to find accurately and efficiently the MPP. By rapidly brings the system to the vicinity of the MPP and P&O algorithm with small step size can be used for higher accuracy and lower oscillations. MATLAB/Simulink models consisting of the photovoltaic system, boost converter and controllers are built to investigate the performance of the proposed algorithm.

2. PV MODELING AND CHARACTERISTICS

Detialed description of the characteristic of PV cell is found in [2]. Typically, the generated voltage from one cell varies from 0.5 to 0.8 V depending on the manufacturing technology. To boost this low voltage and make it more useful, dozens of PV cells are connected in series forming the PV module [21]. The photovoltaic module current Ipvm is [18]:

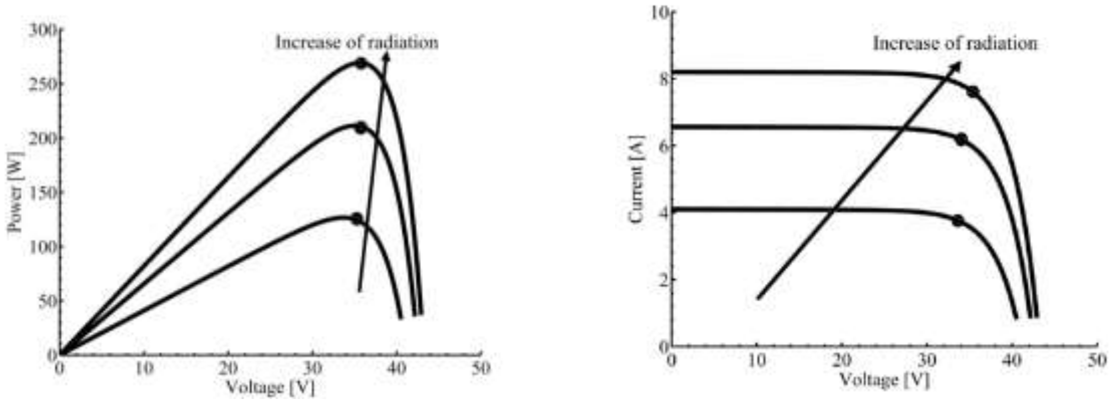
$$I_{PVM}=I_{ph}-I_{DS}\left[e^{\frac{q\left(I_{PV}R_s+V_{PV}\right)}{N_sK_bAT}}-1\right]-\frac{V_{pv}+I_{PV}R_sN_s}{R_{sh}N_s} \tag{1}$$

where, Ipv is the current generated by the cell, Iph is the solar generated current, Ish is the shunt resistance current and ID is the diode current, q is an electron charge (1.6 10 $\times 10^{-19}$ C), T is the cell's operating temperature, kb is the Boltzmann's constant (1.38 $\times 10^{-23}$ J/K), A is the diode ideality factor, Rs is the series resistance, Vpv and Ipv are the photovoltaic operating voltage and current respectively, IDS is the diode saturation current. Equation (1) is modeled in MATLAB/Simulink employing 72 cells connected in series based on the electrical specifications provided by SUNTECH STP270 - 24/Vd PV module datasheet shown in Table 1.

Table 1. Electrical specifications the STP 270-24/Vd PV module [22]

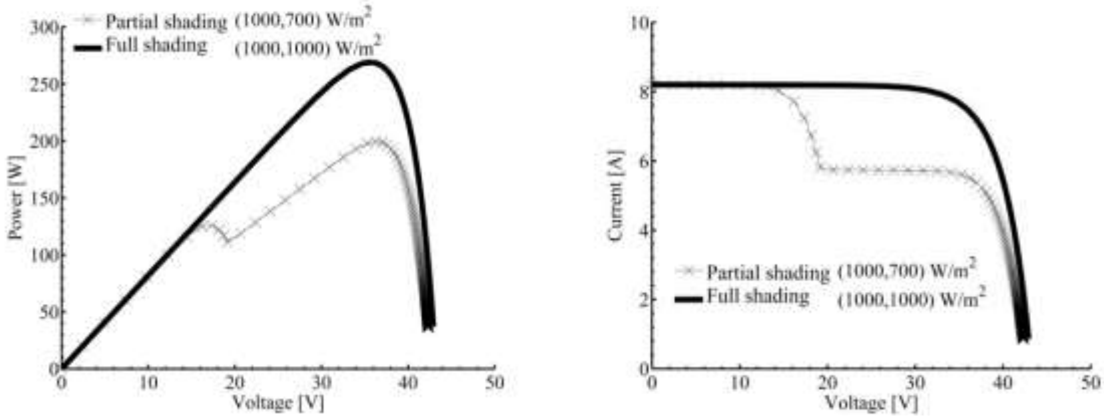
Electrical Characteristic	STP270 - 24/Vd
Optimum Operating Voltage (V_{mp})	35.0 V
Optimum Operating Current (I_{mp})	7.71 A
Open - Circuit Voltage (V_{oc})	44.5 V
Short - Circuit Current (I_{sc})	8.20A
Maximum Power at STC (P_{max})	270W
Temperature Coefficient of V_{oc}	-0.34 %/°C
Temperature Coefficient of I_{sc}	0.045 %/°C

The typical P-V and I-V nonlinear characteristics of the PV module are shown in Figure 1. As can be seen from the curves in Figure 1, maximum power occurs at a unique point called maximum power point MPP. MPPT is used to make the system operate at this specific point. The partial shading occurs when a part of the system experiences some shadowing. Multiple peaks appear in the PV characteristic when the system is subjected to partial shading conditions as shown in Figure 2. The existence of multiple peaks provides a real challenge for MPPT algorithms.



(a) (b)

Figure 1. Power curves of PV under different insulation levels, (a) P-V characteristics, (b) I-V characteristics



(a) (b)

Figure 2. Characteristics curves of PV under partial shading (a) P-V characteristics, (b) I-V characteristics

3. MPPT ALGORITHMS

The power produced by the PV module depends on the voltage delivered to the connected load. Boost convertors control the operating voltage of the module without the need of continuously changing the load [3]. This is achieved using a train of pulses with variable duty cycle produced by a pulse generator. Therefore, a MPPT algorithm is implemented to find the optimal duty cycle to maintain the maximum power levels.

3.1. Perturb and Observe (P&O) Algorithm

The detailed description of P&O can be found in [3]. The P&O algorithm steps can be summarized asfollows; after recording the present power levels produced by the system, the algorithm performs a perturbation to the operating point by means of changing the duty cycle and measures the resulting power accordingly. If there is an increase in the power levels, iteration is performed in the same direction. Otherwise, iteration in the reverse direction is carried out. The peak is detected when the power oscillates about a certain value, i.e., increasing and decreasing the duty cycle result in less power levels.

3.2. Fuzzy Logic Controller (FLC)

Unlike the traditional binary logic where variables can be either true or false, the fuzzy logic deals with partially true variables ranging between fully false and the fully true. The fuzzy based controllers can effectively deal with non-linearities and mimic the human expertise to form an approximation that maps input values to their predicted outputs based on IF-THEN rules.

The fuzzy controller proposed in this paper is built using adaptive neural network for Sugeno type fuzzy model. The Adaptive Neuro Fuzzy Inference System (ANFIS) generates rules and membership function parameters and tune them based on a given input–output data set. The inputs of the controller are the open circuit voltage (V_{oc}) and the short circuit current (I_{sc}), and the output is the desired duty cycle (D). In order to train the neural network and tune the fuzzy controller parameters, a set of input-output data is obtained manually using MATLAB/Simulink models. The parameters used to train the FLC using ANFIS are listed in Table 2.

Table 2. Anfis-Editor training parameters

Fuzzy logic type	Sugeno
Number of inputs	2
Number of membership function	10
No of TRAINING a epochs	3000
Input membership function type	Gaussian
output membership function type	Linear
Algorithm used	Grid partitioning
Optimization method	Hybrid

3.3. Proposed MPPT Algorithm

The idea of the proposed algorithm is inspired by using the benefits of both FLC and P&O algorithm in a single frame work. As mentioned previously, the FLC can work under severe weather conditions with limited accuracy, while P&O can be highly accurate when using small step size. An efficient algorithm can be constructed when utilizing the FLC to drive the system closer to the MPP, then using P&O to proceed the search to find the MPP. Hence, the proposed algorithm merges the swiftness of approximation from the fuzzy system with the accuracy of Perturb and observe method. Figure 3 shows the schematic diagram of PV system with hybrid MPPT used to build MATLAB\Simulink model.

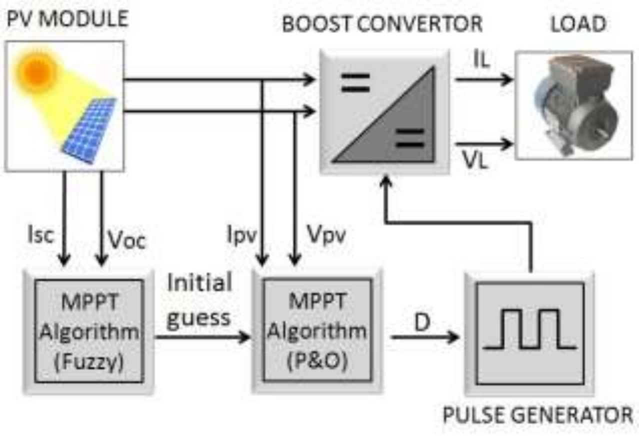


Figure 3. Schematic diagram of PV system with Hybrid MPPT

4. RESULTS AND DISCUSSION

4.1. Characteristics of Fuzzy Controller

The fuzzy controller developed in this study is generated using Adaptive Neuro Fuzzy Inference System (ANFIS) based on a training set of 110 data points. In order to assess the accuracy of the fuzzy controller, two scenarios are simulated; (1) Testing at the same training data points. (2) Testing far from training data points. Figure (4-a) and (4-b) show that the fuzzy controller reaches more than 97% of the available power when exposed to radiation conditions existed in the training data set. Figure (4-c) and (4-d) show that the efficiency of the fuzzy controller drops to less than 85% when exposed to radiation conditions differ from those used to train it. It's clear from Figure 4 that FLC is always capable of driving the system to the vicinity of the global maximum with limited accuracy that needs to be improved. Employing massive amount of data points to train the FLC requires large capacity of controller's memory and higher processing time. So, it's inefficient to enhance the accuracy of FLC by increasing training data points.

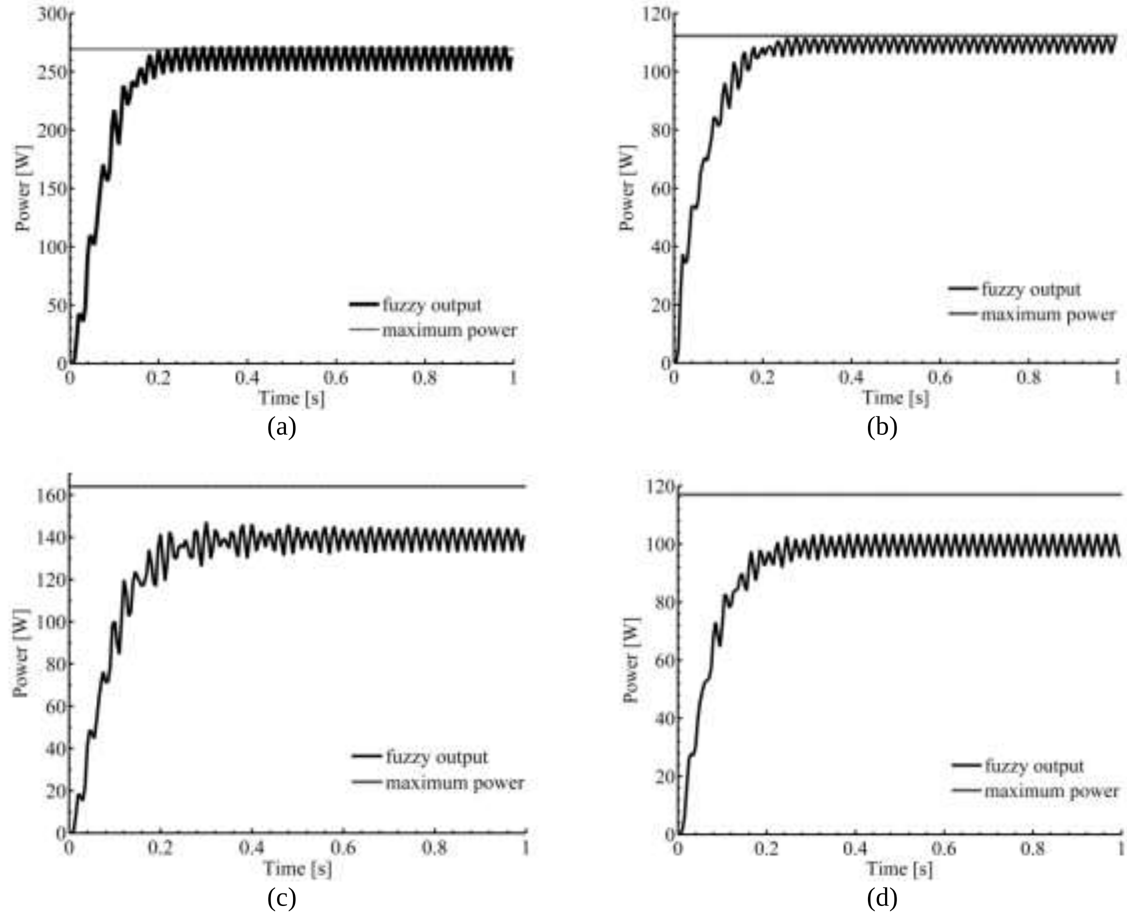


Figure 4. Fuzzy controller performance under different radiation conditions, (a) Uniform radiation of 1000 W/m^2 (b) partial shading of (800,400) W/m^2 (c) uniform radiation of 635 W/m^2 (d) partial shading of (985,317) W/m^2

4.2. Characteristics of Perturb and Observe Method

Perturb and observe method performance depends on the step size. To illustrate the effect of step size on the performance of P&O algorithm, two step sizes were simulated under uniform shading conditions. Figure 5 shows that using larger step size leads to faster convergence with wider oscillations. On the other hand, smaller step size leads to higher power with smaller oscillations. These observations can be explained as follows; using large step size might cause overstepping of the local maximum with wider oscillations, while using smaller step size, might cause oscillating of the power near the local maximum point.

When the module gets exposed to a partial shading condition, multiple peaks appear in the P-V characteristics. The P & O might get trapped in the local peak due to its seeking nature. In other words, the P & O continuously searches for the peak by changing the duty cycle and oscillates around the first peak found which is not necessarily the global. To illustrate this phenomenon, partial shading conditions are simulated by dividing the PV panel into two portions each with different radiation level. Figure 6 shows that P&O got trapped in a local maximum under partial shading conditions of (1000, 300) W/m^2.

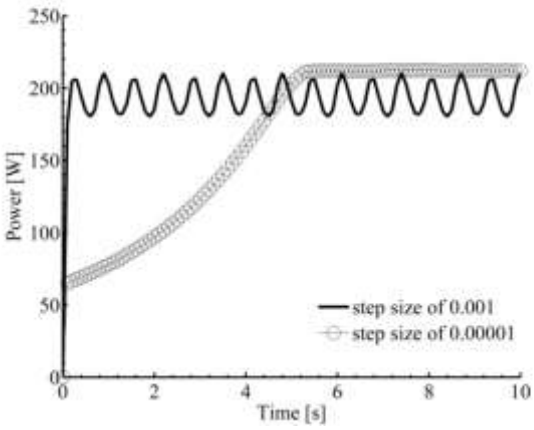


Figure 5. Effect of step size on the performance of P&O algorithm

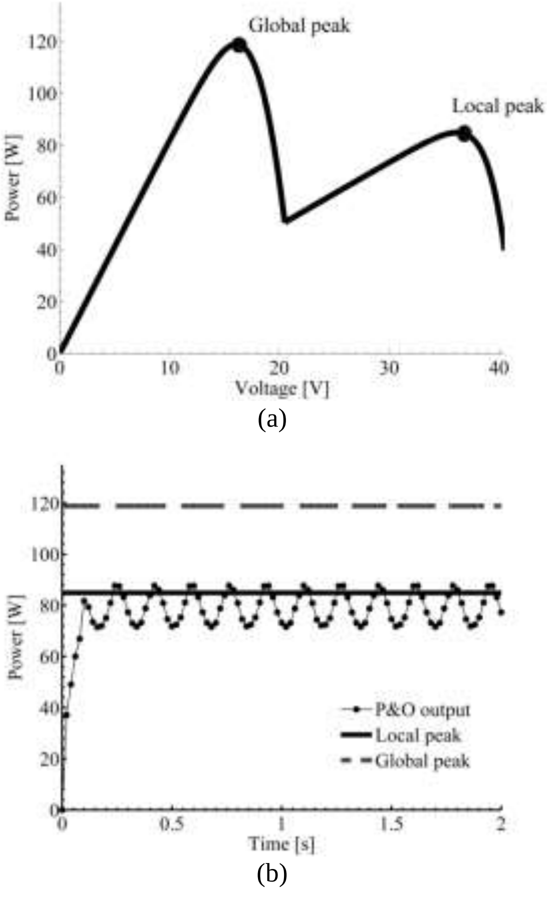


Figure 6. Performance of P&O under partial shading conditions, (a) P-V characteristics, (b) P&O controller performance

4.3. Performance of the Proposed Algorithm

In order to assess the performance of the proposed algorithm under uniform shading conditions, a comparison against P&O is carried out. It can be seen in Figure 7 that all algorithms approach MPP. The theoretical MPP under 800w/m^2 with convertor efficiency of 97.6% is 211.27 W. Figure 7(a) shows that the P&O controller with step size of 0.001 reaches 95% of the available power while the hybrid controller reaches 100%. It is worth mentioning that obtaining 100% of the available power using standalone P&O, the step size has to be decreased to 0.00001. However, with this step size it requires 4.8 s to reach the MPP while the proposed controller needs less than 0.3s.

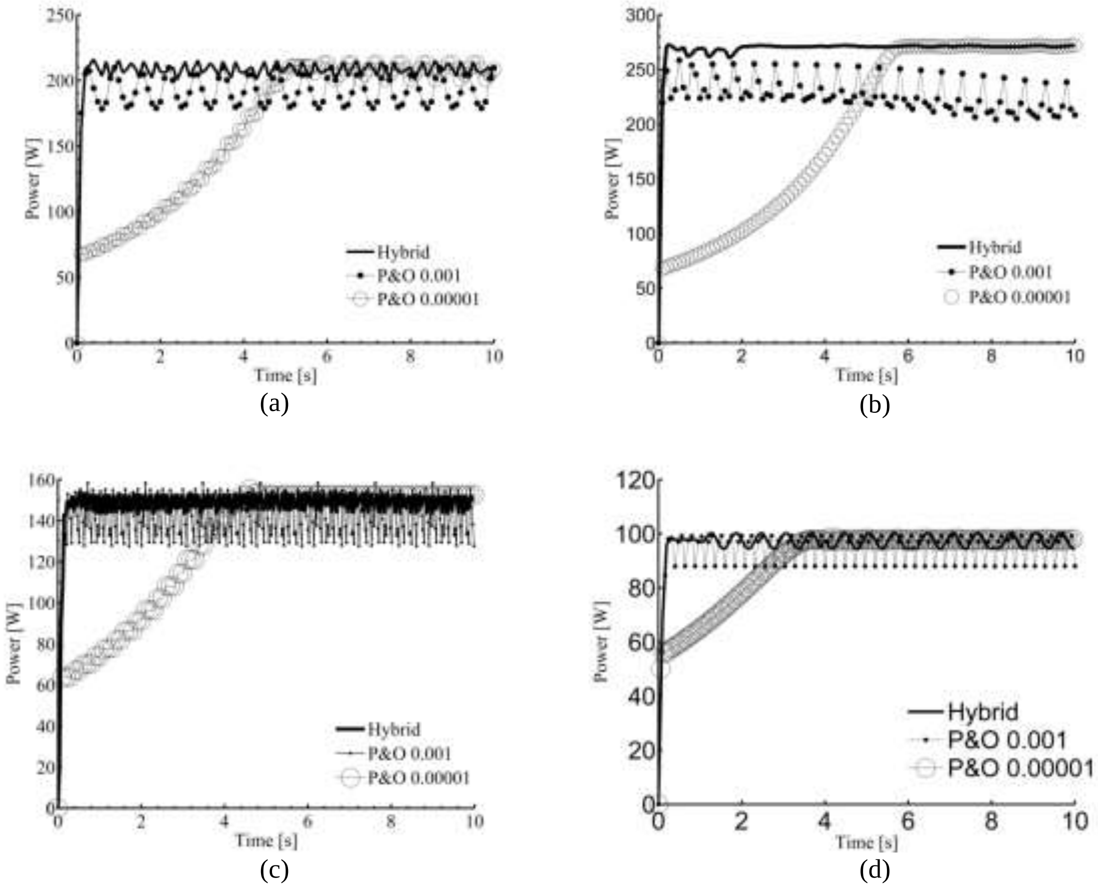


Figure 7. Simulation results under uniform shading conditions, (a) insulation level of 800 W/m^2, (b) insulation level of 1000 W/m^2, (c) insulation level of 600 W/m^2, (d) insulation level of 400 W/m^2

5. CONCLUSION

A hybrid algorithm combing both the strength of conventional P&O and FLC is developed. MATLAB/Simulink models are developed to investigate the performance of the proposed algorithm under different shading conditions. The P&O algorithm has slow rate of convergence when using small step size, and shows large inaccuracy when using large step size. Moreover, in both cases it can't deal well with the partial shading conditions that result in multi maxima. On the other hand, fuzzy controller, despite being fast to converge, has been found to lack the accuracy in some operating conditions. The simulation results show that the proposed algorithm efficiently reach MPP under uniform irradiation, sudden changes of irradiation, and partial shading.

REFERENCES

[1] K. Bataineh, "Optimisation analysis of solar powered organic Rankine cycle system", IET Renewable Power Generation, vol. 11(2), pp.342 – 350, 2017.
[2] A Allataifeh et al., "Maximum Power Point Tracking Using Fuzzy Logic Controller Under Partial Conditions", Smart Grid and Renewable Energy, vol. 6 (1), pp. 1-13, 2014.
[3] V. Salas et al., " Review of the maximum power point tracking algorithms for stand-alone photovoltaic systems", Solar Energy Materials & Solar Cells, vol. 90, pp. 1555–1578, 2006.
[4] T. Tafticht et al. A. An improved maximum power poin FLC algorithm t tracking method for photovoltaic systems. Renewable Energy, vol.33, pp.1508–1516, 2008.

[5] A. Amirullah, A. Kiswantono, "Power Quality Enhancement of Integration Photovoltaic Generator to Grid under Variable Solar Irradiance Level using MPPT-Fuzzy", International Journal of Electrical and Computer Engineering (IJECE), vol. 6, No 6, 2016.
[6] S. Hassan, "An Advanced MPPT Based on Artificial Bee Colony Algorithm for MPPT Photovoltaic System under Partial Shading Condition", International Journal of Power Electronics and Drive Systems (IJPEDS), vol. 8, no. 2, 2017.
[7] C. H. Lin, C. H., "Maximum photovoltaic power tracking for the PV array using the fractional-order incremental conductance method", Applied Energy, vol. 88, pp.4840–4847, 2011.
[8] R. Ahmed et al., "Improvement in Perturb and Observe Method Using State Flow Approach," Energy Procedia, vol. 42, pp. 614 – 623, 2013.
[9] H.Taheri et al. 2010, " A Novel Maximum Power Point Tracking Control of Photovoltaic System Under Partial and Rapidly Fluctuating Shadow Conditions Using Differential Evolution", Proc. IEEE Symposium on Industrial Electronics and Applications Conf., pp.82-87, 2010.
[10] L. Jiang et al., "A novel ant colony optimization-based maximum power point tracking for photovoltaic systems under partially shaded conditions", Energy and Buildings, vol. 58, pp. 227–236, 2013.
[11] Y. Liu, "Neural-network-based maximum power point tracking methods for photovoltaic systems operating under fast changing environments", Solar Energy, vol. 89, pp. 42–53, 2013.
[12] K. Punitha, "Artificial neural network based modified incremental conductance algorithm for maximum power point tracking in photovoltaic system under partial shading conditions", Energy, vol. 62, pp.330-340, 2013.
[13] M.A. Younis, "An Improved Maximum Power Point Tracking Controller for PV Systems Using Artificial Neural Network", PRZEGLĄD Elektrotechniczny (Electrical Review), vol.88, pp. 116-121, 2012.
[14] S. Subiyanto et al. Intelligent maximum power point tracking for PV system using Hopfield neural network optimized fuzzy logic controller", Energy and Buildings, vol. 51, pp. 29–38, 2012.
[15] B. N. Alajmi et al., "A Maximum Power Point Tracking Technique for Partially Shaded Photovoltaic Systems in Microgrids", IEEE Transactions on Industrial Electronics, vol. 60, pp. 1596-1606, 2013.
[16] S. Singh et al.,"Design and Simulation of Intelligent Control MPPT Technique for PV Module Using MATLAB/ SIMSCAPE," International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering, 2, pp. 4554-4566, 2013.
[17] H. Tsai et al. , "Development of Generalized Photovoltaic Model Using MATLAB/SIMULINK", in Proc. World Congress on Engineering and Computer Science WCECS, San Francisco, 2008.
[18] M. Seyedmahmoudian et al., "Analytical Modeling of Partially Shaded Photovoltaic Systems", Energies, vol. 6 , pp. 128-144, 2013.
[19] B. Salah et al. , "Mohamed Ouali, Comparison of fuzzy logic and neural network in maximum power point tracker for PV systems", Electric Power Systems Research, vol. 81 (1), pp. 43-50, 2011.
[20] N. S. D'Souza," Comparative study of variable size perturbation and observation maximum power point trackers for PV systems", Electric Power Systems Research, pp. 296–305, 2010.
[21] T. Salmi et al., "MATLAB/Simulink Based Modelling of Solar Photovoltaic Cell", International Journal of Renewable Energy Research, vol. 2, pp. 213-218, 2012.
[22] http://www.arcmansolar.com/products/28.aspx?cid=7-12-11

BIOGRAPHIES OF AUTHORS

Dr. Bataineh has is currently working as professor of Mechanical Engineering depertment at from Jordan University of Science and Technology. He received an M.S. from Carnegie Mellon in 2001. He received his Ph.D. in Mechanical Engineering from the University of Pittsburgh in 2005. His research focuses on utilizing solar energy either directly or by converting it to electrical energy. Currently, he is focusing on Concentrated Solar Power (CSP) which is a promising renewable energy technology for the Mediterranean and gulf countries (world's Sun Belt region). He is the author of about 40 reviewed journal articles and other technical publications. He participates yearly in international scientific conferences.

Dr. Taamneh is currently working as assciciate professor of Aeronautical Engineering, Aerospace from Jordan University of Science and Technology. He received his Ph.D. in Mechanical Engineering from the TU Kaiserslautern in 2009. His research focuses on solar to electric conversion. He is the author of about 30 reviewed journal articles and other technical publications. He participates yearly in international scientific conferences.