The Journal of Energy: Engineering & Management
Vol. 6, No. 4, Winter 1395, P. 26-31

Maximum Power Point Tracking of the Photovoltaic System Based on Adaptive Fuzzy-Neural Method

R. khademi[1*], S. M.A. Mohammadi[2]

[1]Electrical Engineering Department, Shahid Bahonar University, Kerman, I.R.Iran
khademi2006@yahoo.com
[2]Electrical Engineering Department, Shahid Bahonar University, Kerman, I.R.Iran
a_mohammadi@uk.ac.ir

Abstract: The aim of this paper was to present an optimized method in order to use maximum capacity of the photovoltaic panels. In this regard, we presented a method for the maximum power point tracking in the photovoltaic systems by using the neural networks and adaptive controller. In the proposed system, we estimated an error by using neural network. If this error is lower than the allowable systems error, the system works at the maximum power point, and if the error value is greater than the allowable error, the output power can be adjusted by using the adaptive controller. The adaptive part of the proposed system consisted of two fuzzy controllers with two different rule bases. The first controller designed to produce the duty cycle of the boost converter and the second controller designed to adjust online the outputs scaling factor of the first controller. We simulated the proposed system in the MATLAB software and then compared the output power of this system with the output power of the conventional fuzzy and the P&O methods. The comparison results indicated that the proposed system had better performance compared to the two above-mentioned methods.

Keywords: Adaptive, Fuzzy, MPPT, Neural network, Photovoltaic.

* Corresponding Author

1. Introduction

According to the growth of humans in modern societies and disadvantages of the fossil fuels, finding the alternative fuels to the fossil fuels is essential. Thus, in recent years, the use of solar energy has been increased [1]. Recently, the photovoltaic panels have increasingly become important as a renewable resource, since these panels do not have the costs and pollution of the fossil fuels. Due to the structure of these panels, the output power-voltage curve in such systems is non-linear and by changes in the environmental conditions, it changes the operating point of these systems [2, 3]. There are several ways to do the maximum power point (MPP) tracking (MPPT) in the photovoltaic (PV) systems. Among these methods are: the Perturb and Observe (P&O) [4, 5, 6], Incremental Conductance (IC) [6, 7, 8, 9, 10], Constant Voltage (CV), Constant Current (CC) [11, 12, 13], Fuzzy method [14, 15, 16] and the neural networks [17, 18, 19, 20]. The neural networks and fuzzy methods are more intelligent and tracking the MPP better than previous methods [15, 16, 17, 18]. According to [18], the fuzzy method (FLC) has better performance in comparison to the neural network so that increases the efficiency of the system. In this paper, we presents a new method for tracking the MPP based on the neural network and adaptive controllers. We simulate the proposed system in MATLAB software and simulation results show that the proposed MPPT method has better performance in comparison to the conventional P&O and FLC methods. In Section 2, we will introduce the general MPPT method in the photovoltaic systems. Sections 3 and 4 respectively will introduce the fuzzy and neural methods. The proposed system simulations and the results will be mentioned in sections 5 and 6, respectively. Additionally, the proposed system will be compared with the P&O algorithm and conventional fuzzy method. Lastly, Section 7 presents the paper conclusion.

2. The General MPPT Method in the Photovoltaic Systems

The photovoltaic panel consists of many solar cells. These cells are connected in series and parallel with each other. Due to the structure of these cells, the output power-voltage curve in such systems is non-linear and by changes the environmental conditions, it changes the MPP [2, 3]. Fig. 1 shows the output power-voltage curve of the PV panel.

Tracking the MPP in photovoltaic systems is required to a DC/DC converter, which its place is between the load and the PV panel. Fig. 2 shows the schematic of the MPPT method with a PV panel and a DC/DC converter.

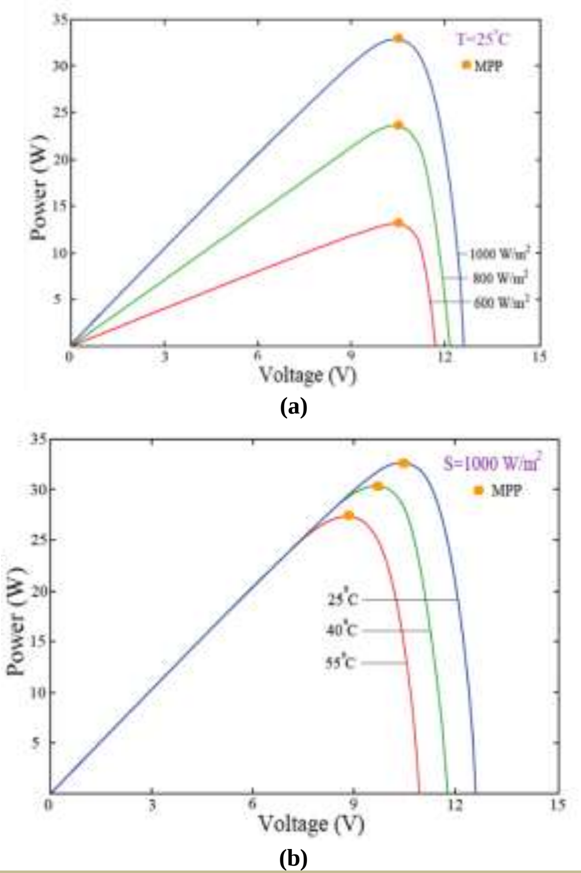


Fig. 1. The output power-voltage curve; a) constant temperature and variable radiation; b) constant radiation and variable temperature

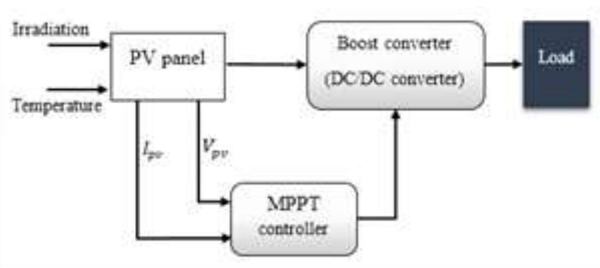


Fig. 2. The general schematic of the MPPT method

In this paper, we used the boost converter. Here, the task of boost converter is impedance matching between the load resistance and the output resistance of the PV terminals.

3. The Structure of Fuzzy Controller

Professor Lotfi (1965), for the first time, presented the theoretical fuzzy logic controller. This logic is based on "if – then" fuzzy rules. In addition, in accordance with Professor Lotfi's definition, the membership of any element in the fuzzy method is determined by a value in the range of [0 1]. Fig. 3 shows the schematic of the fuzzy logic controller. In general, the fuzzy system is made of four parts: the fuzzification interface, rule base, fuzzy inference mechanism, and defuzzification interface [21].

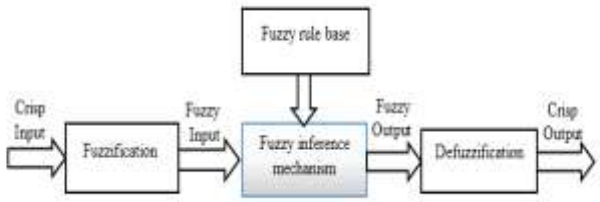


Fig. 3. The General Structure of the Fuzzy Controller

4. The Structure of Neural Networks

The neural network is composed of layers and weights. In general, there are three neuronal layers in neural networks: the input layer, hidden layers and output layer. Fig. 4 shows the overview schematic of the neural network where W_{ij} are the weights of the system and ($i, j = 0,1,2, \dots, n$).

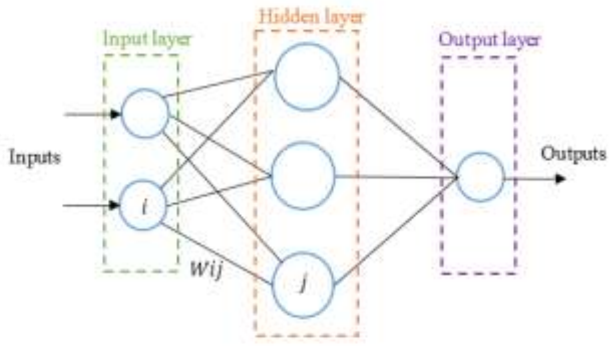


Fig. 4. The General Schematic of the Neural Network Algorithm

There are many types of neural networks. In this paper, we use Perceptron Neural networks for the MPPT. In this type of neural network, the weights and biases could be trained for a specific purpose [22].

5. The Proposed System

The proposed system consists of two parts: the neural part and adaptive controller. Fig. 5 shows the overall schematic of the proposed system.

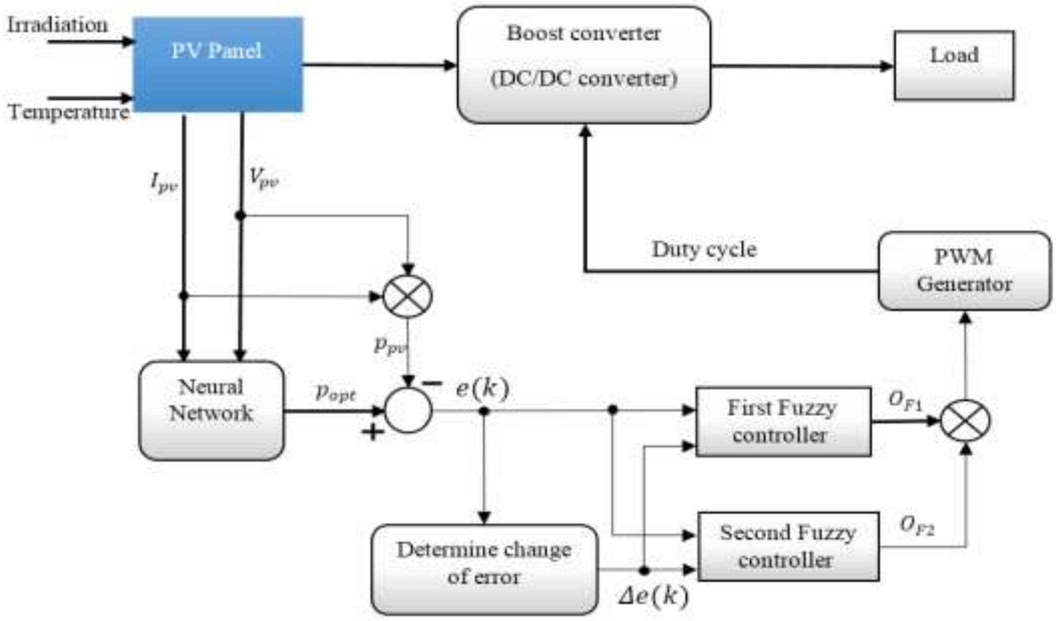
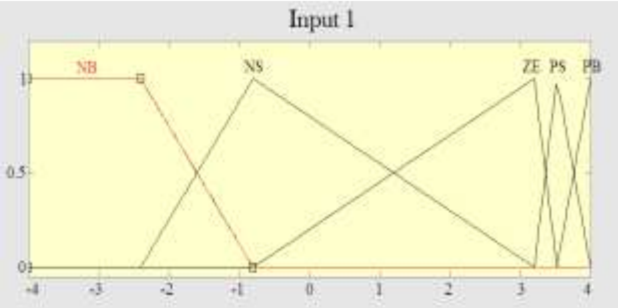


Fig. 5. General structure of the proposed system

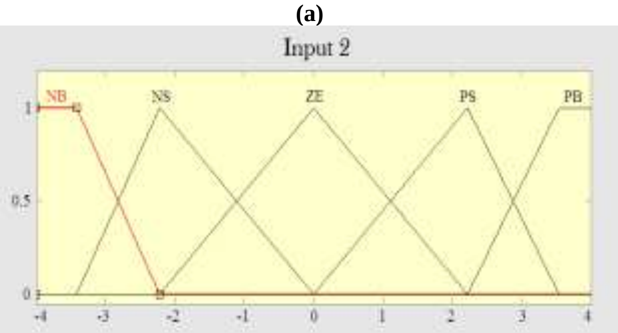
In the first part, the neural network produces an optimal power according to changes in voltage and current. Then by comparing this optimal power and operating power of the system, an error will be generated. If this error is lower than the allowable error, it indicates that the performance of the system is at the MPP, but if the error is greater than the allowable error, the adaptive controller should be produce (should be produced / should produce) a duty cycle and keep the system at the MPP. The adaptive part of the proposed system consists of two fuzzy controllers. The first controller (FLC1) is a design to produce the duty cycle and the second controller (FLC2) is a design to adjust online the output scaling factor of the first controller. These two fuzzy controllers have different membership functions and rule base. The inputs of these controllers are the error (obtained by neural network) and the change of this error calculated by the following equation:

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

According to [23], whenever a fuzzy controller is in use and changes the fuzzy controller parameters (membership functions, rules or output scaling factor), we can state that this system is an adaptive controller, otherwise the system is a simple fuzzy system. Here, since the output scaling factor of the FLC1 tuning with the FLC2, we had named as the adaptive controller. Fig. 6 shows the inputs membership functions of the first and second fuzzy controllers and Fig. 7 shows the output membership functions of the first and second fuzzy controllers. Tables 1 and 2 show the rule base of the FLC1 and FLC2, respectively.

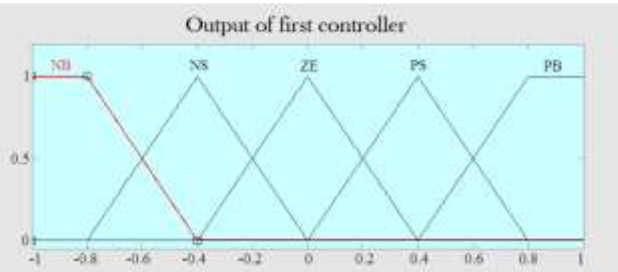


(a)

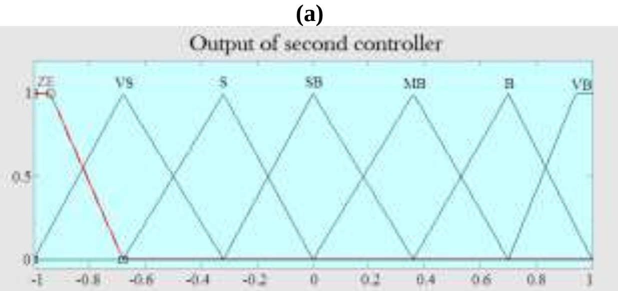


(b)

Fig. 6. The input membership functions of the fuzzy controllers, a) the first input, b) the second input



(a)



(b)

Fig. 7. The output membership functions of the fuzzy controllers, a) the first controller, b) the second controller.

Table. 1. The rule bases of FLC1.

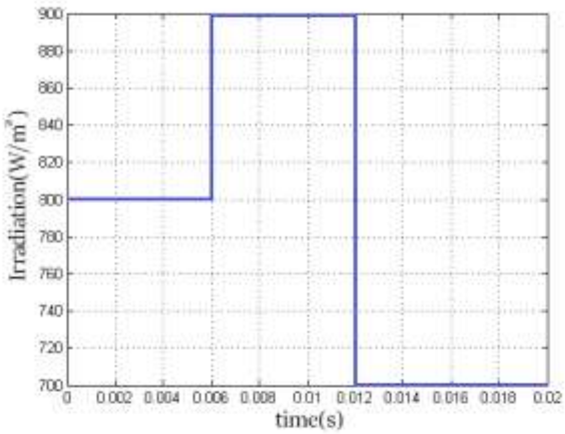
Of1 (e \ Δe)	NB	NS	ZE	PS	PB
NB	ZE	ZE	PB	PB	PB
NS	ZE	ZE	PS	PS	PS
ZE	PS	ZE	ZE	ZE	NS
PS	NS	NS	NS	ZE	ZE
PB	NB	NB	NB	ZE	ZE

Table. 2. The rule bases of FLC2.

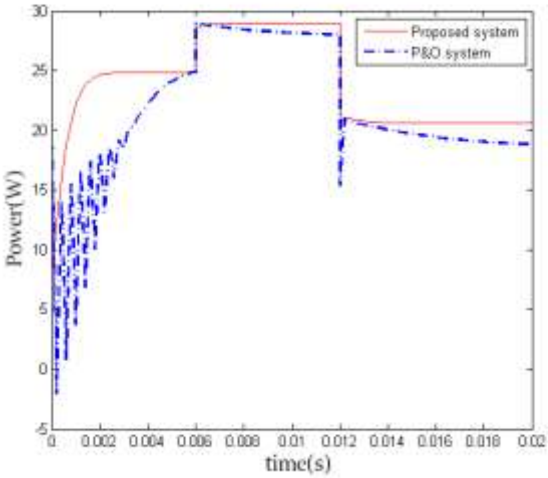
Of2 (e \ Δe)	NB	NS	ZE	PS	PB
NB	ZE	ZE	MB	B	VB
NS	ZE	ZE	VB	VS	SB
ZE	S	ZE	ZE	ZE	S
PS	S	SB	VS	ZE	ZE
PB	VB	VS	SB	ZE	ZE

6. Simulation and Comparison Results

In this section, we simulate the proposed system in MATLAB/Simulink software. First, we compare the proposed system by P&O method. Here, we use [6] for the simulation of the P&O method. We assume that the environment condition for both MPPT methods is the same and the temperature is constant at 25 ° C and the radiation is variable at the levels of 800, 700 900$(\frac{rad}{m^2})$. These changes take in the time interval 0.02 second. Figs 8-a and 8-b, respectively, show the change of radiation and the output power for both methods.



(a)



(b)

Fig. 8. a) The change of irradiation, b) output power for both controllers

As you can observe in Fig. 8-b, the P&O method cannot track the MPP accurately and in radiation 800 ($\frac{rad}{m^2}$) increases the settling time of the output power. Furthermore, in the change of radiation from 900 to 700($\frac{rad}{m^2}$), the output power has a huge overshoot. In general, the P&O method decreases the efficiency of the system, but the proposed method tracks the MPP better than the P&O method so that increases the efficiency of the system.

In this regard, we compare the proposed system and the fuzzy method. Here, we use [16] for the simulation of the fuzzy method. In this paper, instead of using two-input fuzzy controller (which used in most papers), is using of the three-input fuzzy controller. The inputs to this controller include system error, change of the system error and the PV panel voltage. Moreover, in this paper, the membership function of the fuzzy controller is tuned by the GA algorithm (FLCGA). In [16], it is shown that the FLCGA have had better performance in comparison to the conventional fuzzy method. Now, we simulate the FLCGA controllers. Here, we will avoid mentioning the FLCGA membership functions and rules, and the respected readers can refer to [16] for more information in this regard. For simulation, we assume that the environmental conditions are the same as the previous ones. In other words, the temperature is constant at 25 °C and the radiation is variable at the levels of 800, 700 and 900($\frac{rad}{m^2}$) . Fig.8-a shows the change of irradiation and Fig. 9 shows the power variation for both methods.

As you can observe in Fig. 9, in rapid changes of radiation, the proposed system have had better performance compared to the FLCGA system so that decreases the output power settling time and oscillation, and causes to increase the efficiency of the system. Table 3 shows the output power settling time for both controllers.

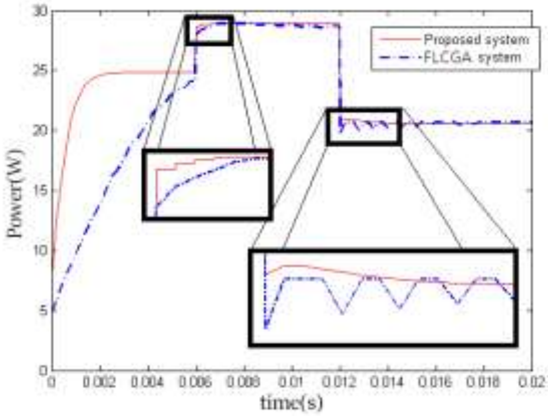


Fig. 9. The output power for both proposed and FLCGA systems.

Table 3. The output power settling time for the proposed and FLCGA systems.

Settling time (Millisecond)	The proposed system	The FLCGA system
Change of radiation from 0 to 800	3	7
Change of radiation from 800 to 900	0.7	1
Change of radiation from 900 to 700	1	6

If we define system efficiency by the following equation, then Table 4 describes the comparison of operation in all above-mentioned methods [12].

$$\eta = \left(\frac{1}{n}\sum_{i=0}^{n}\frac{P_i}{P_{max,i}}\right).100 = \left(\frac{1}{n}\sum_{i=0}^{n}1-\frac{P_l}{P_{max,i}}\right).100 \quad (2)$$

Where P_i , $P_{max,i}$, $P_l(= P_{max,i} - P_i)$ and n are solar panel power, the maximum power, power loss, and sample rate, respectively.

Table 4. Comparison of system efficiency and operation of the proposed system and conventional P&O and FLCGA methods.

	The proposed system	FLCGA	P&O
Overall efficiency	94.37%	90.31%	85.93%

7. Conclusion

In modern societies, use of renewable energy has tremendously increased. Nowadays, one of the best methods in the field of clean energy is the use of the PV systems. Due to the high cost of these systems, using the maximum power of these systems is essential. In this paper, we presented a new method for the MPPT in which this performance was based on the neural networks and adaptive controller. Then, we simulated the proposed system in MATLAB software and then we compared the results of these method with the conventional P&O and fuzzy methods. As we observed, the proposed system had better performance in comparison to the two above-mentioned controllers so that decreased the settling time and increased the efficiency of the system.

References

[1] Mousazadeh, H., Keyhani, A., Javadi, A., Mobli, H., Abrinia, K., Sharifi, A., "*A Review of Principle and Sun-Tracking Methods for Maximizing Solar Systems Output*", Renewable and Sustainable Energy Reviews, Vol. 13, pp. 1800–1818, 2009.

[2] Gheibi, A., Mohammadi, S. M. A., Farsangi, M., "*Comparing Performance of PID and Fuzzy Controllers In the Present of Noise for A Photovoltaic System*", Journal of Mathematics and Computer Science, Vol. 9, pp. 69-76, 2014.

[3] Gheibi, A., Mohammadi, S. M. A., Farsangi, M., "*Maximum Power Point Tracking of Photovoltaic Generation Based on the Type 2 Fuzzy Logic Control Method*", ICSGCE, 27–30 September, Chengdu, China, 2011.

[4] Femia, N., Petrone, G., Spagnuolo, G., Vitelli, M., "*Optimization of Perturb and Observe Maximum Power Point Tracking Method*", IEEE Transactions on Power Electronics, Vol. 20, No. 4, 2005.

[5] Elgendy, M. A., Zahawi, B., Atkinson, D. J.,"*Assessment of Perturb and Observe MPPT Algorithm Implementation Techniques for PV Pumping Applications*", IEEE Transactions on Sustainable Energy, Vol. 3, No. 1, 2012.

[6] Nissah Zainudin, H., Mekhilef, S., "*Comparison Study of Maximum Power Point Tracker Techniques for PV Systems*", Proceedings of the 14th International Middle East Power Systems Conference (MEPCON'10), Cairo University, Egypt, 2010.

[7] Soon Tey, K., Mekhilef, S., "*Modified Incremental Conductance MPPT Algorithm to Mitigate Inaccurate Responses under Fast-changing Solar Irradiation Level*," Solar Energy, Vol. 101, pp. 333–342, 2014.

[8] Swathy, A. S., Archana, R., "*Maximum Power Point Tracking Using Modified Incremental Conductance for Solar Photovoltaic System*", International Journal of Engineering and Innovative Technology (IJEIT), Vol. 3, 2013.

[9] Safari, A., Mekhilef, S., "*Incremental Conductance MPPT Method for PV Systems*", IEEE CCECE, 2011.

[10] Selvan. S., "*Modeling and Simulation of Incremental Conductance MPPT Algorithm for Photovoltaic Applications*", International Journal of Scientific Engineering and Technology, Vol.2, pp. 681-685, 2013.

[11] Coelho, R. F., Concer, F. M., Martins, D. C., "*A MPPT Approach Based on Temperature Measurements Applied in PV Systems*", 9th IEEE/IAS International Conference on Industry Applications, 2010.

[12] Reisi, A. R., Moradi, M. H., Jamasb, S., "*Classification and Comparison of Maximum Power Point Tracking Techniques for Photovoltaic System: A review* ", Renewable and Sustainable Energy Reviews, Vol. 19, pp. 433–443, 2013.

[13] De Brito, M. A. G., Sampaio, L. P., Jr, L. G., Melo, G. A., Canesin, C. A., "*Comparative Analysis of MPPT Techniques for PV Applications*", IEEE, 2011.

[14] Alajmi, B. N., Ahmed, K. H., Finney, S. J., Williams, B. W., "*Fuzzy-Logic Control Approach of a Modified Hill-Climbing Method for Maximum Power Point in Microgrid Standalone Photovoltaic System*", IEEE Transactions on power electronics, Vol. 26, No. 4, 2011.

[15] Serhoud, H., Benattous, D., Labbi, Y., "*Simulation of New Simple Fuzzy Logic Maximum Power Point Tracking for Photovoltaic Array*", Rev. Sci. Fond. App, Vol. 2, pp.96-107, 2010.

[16] Rezaei, A., Gholamian, S. A., ,"*Optimization of New Fuzzy Logic Controller by Genetic Algorithm for Maximum Power Point Tracking in Photovoltaic System*", ISESCO journal of Science and Technology, Vol. 9 , pp. 9-16, 2013.

[17] Bahgat, A. B. G., Helwab, N. H., Ahmad, G. E., El Shenawy, E. T.,"*Maximum Power Point Traking Controller for PV Systems Using Neural Networks*", Renewable Energy Vol. 30, pp. 1257–1268, 2005.

[18] Ben Salah, C., Ouali, M., "*Comparison of Fuzzy Logic and Neural Network in Maximum Power Point Tracker for PV Systems*", Electric Power Systems Research, Vol. 81, pp. 43–50, 2011.

[19] Ika Putri, R., Rifa'i, M., "*Maximum Power Point Tracking Control for Photovoltaic System Using Neural Fuzzy*", International Journal of Computer and Electrical Engineering, Vol.4, No.1, 2012.

[20] Zaki, A. M., Amer, S. I., Mostafa, M.,"*Maximum Power Point Tracking for PV System Using Advanced Neural Networks Technique*", International Journal of Emerging Technology and Advanced Engineering, Vol. 2, 2012.

[21] L Wang. A., "*Course in Fuzzy Systems and Control*", Pentice-Hall Pub, 1997.

[22] Demuth, H., Beale, M., "*Neural Network Toolbox*", Version 4, 2002.

[23] Guenounou, O., Dahhou, B., Chabour, F., "*Adaptive Fuzzy Controller Based MPPT for Photovoltaic Systems*", Energy Conversion and Management, Vol. 78, pp. 843–850, 2014.