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Article *in* Journal of Innovative Image Processing · May 2022

DOI: 10.36548/jiip.2022.1.006

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Journal of Innovative Image Processing (ISSN: 2582-4252)
www.irojournals.com/iroiip/

Fuzzy Logic Based Maximum Power Point Tracking of Photovoltaic System

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Abstract

A photovoltaic (PV) system converts light into electricity and has nonlinear characteristics between power and voltage. The PV system is affected by changes in environmental conditions and other factors. In PV system, the maximum power is obtained at the operating point. Many Maximum Power Point Tracking (MPPT) algorithms have been presented and explored in the literature, however many of them have drawbacks in terms of adaptability, efficiency, and accuracy. Traditional controllers are incapable of providing a better response due to the nonlinear nature of PV module current-voltage characteristics. The primary objective of this work is to design and implement a fuzzy logic control for obtaining MPPT for a photovoltaic system. Fuzzy logic control is a heuristic method to controller design that uses artificial intelligence to track maximum power. In this method, desirable results are achieved by defining the logical rule and specific range of membership functions. Simulink is used to develop and simulate a maximum power point tracking system that includes a photovoltaic voltaic module, a quadratic boost converter, and a fuzzy controller.

Keywords: Fuzzy logic, MPPT, PV System, Controller

1. Introduction

Solar energy is one of the world's most environmentally friendly and abundant energy sources. In the future, it will be our primary power source. Solar energy has been used in industries, businesses, homes, and military applications. Factors such as sunlight incident angle, irradiation, cell temperature, and load conditions all affect the amount of solar power generated by PV cells. To maximize power output, PV systems use tracking so as to obtain the point at which maximum power can be obtained [1]. Power converter duty ratio is steadily increased or decreased in response to the PV cell output (P vs V) curve or (V vs I)

DOI: https://doi.org/10.36548/jiip.2022.1.006
Received: 21.03.2022, received in revised form: 30.04.2022, accepted: 07.05.2022, published: 19.05.2022

curve, MPPT algorithms maximize its power output [7]. An Intelligent fuzzy logic control system is employed.

FLC is distinguished by its potential to mimic human thought. The input and output variables chosen for the particular system define the fuzzy MPPT algorithm. The duty ratio of the power converter is normally the fuzzy MPPT algorithm's output variable [6, 12-15]. Power-versus-voltage curve slope and the change in slope are considered as input variable for MPPT. [2] has discussed a number of methods for PV array maximum power tracking. [9] proposed a new method for tracking maximum power named Constant Voltage Tracking (CVT). A simple structure has been designed with a low-power PV. This method is validated by tracking the maximum power and feeding it to the charger controller. [4] has presented a Fuzzy Logic Controller based on adjustable Self-Organizing map for an integrated MPPT system on a low-cost microcontroller. The boost converter is a high-performance device. An adjustable Self-Organizing Fuzzy Logic Controller is implemented on a microcontroller with an embedded MPPT system.

[8] devised a tracking of PV panel maximum power that uses the panel's open-circuit voltage and short-circuit current. When compared to FLC, the suggested MPPT approach was significantly more robust in monitoring the point of maximum power even under quickly changing irradiance scenarios. Simulation results demonstrate a clear improvement in attaining the maximum point when irradiance is altered. [4] presented the PV charging system design based on the output characteristics of the PV array with maximum power tracking. To implement tracking of maximum power point of a PV array, an approach based on current output of DC/DC converter and variable duty cycle is designed. [11] demonstrated a fuzzy-based MPPT for solar panels. SIMULINK from MATLAB environment is used to simulate and analyze the system. According to simulation studies, fuzzy-based MPPT has superior performance and produces more power. [10] recommended that stressing the controller with a low voltage to increase the output range is more effective. The duty cycle ratio can be regulated by choosing passive components since the voltage gain is based on it.

2. Photovoltaic System

A photovoltaic array is a combination of cells that converts solar energy into electrical energy. A photovoltaic array is a collection of cells that turn sunlight into electricity. A single PV cell does not supply enough power for everyday use. For high voltage demand, the needed power is achieved by connecting multiple single PV cells in series and for high current demand the cells are connected in parallel. The serial and parallel arrangement of PV cell is called Module. The commercial module consists of 36 or 72 cells. The efficiency of the photovoltaic array is due to changes in internal series resistance. Change in Shunt resistance will not affect the efficiency [3, 5].

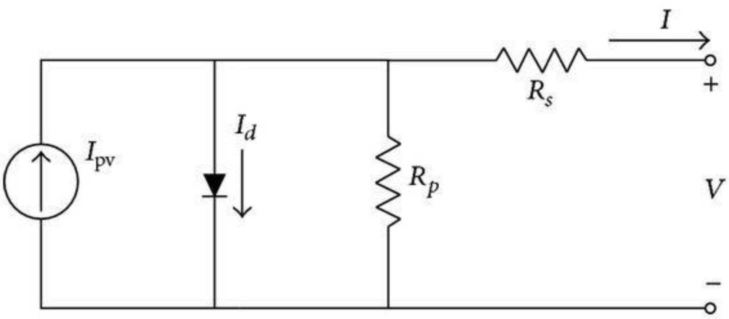

Figure 1. PV cell

Table 1. PV Array Parameters

Parameter	Values
Number of Cells per module (N cell)	36
$V_{oc}(V)$	64.2 V
$I_{sc}(A)$	5.96 A
$V_{mp}(V)$	59.4 V
I_{mp}(A)	5.52 A
Strings connected in parallel	2
Modules connected in series per string	3

3. Quadratic Boost Converter

The quadratic boost converter uses a single MOSFET switch, where the input and the output voltage are denoted by E and V_{C_2} respectively. In this arrangement to forms a three-terminal network, the model has active and passive switch pairs. This methodology, on the other hand, may be used to analyse a quadratic boost converter which contains a total of three passive switches and an active switch [12]. Thus, current sources replace diode D2 and the MOSFET switch, while voltage sources replace diodes D1 and D3.

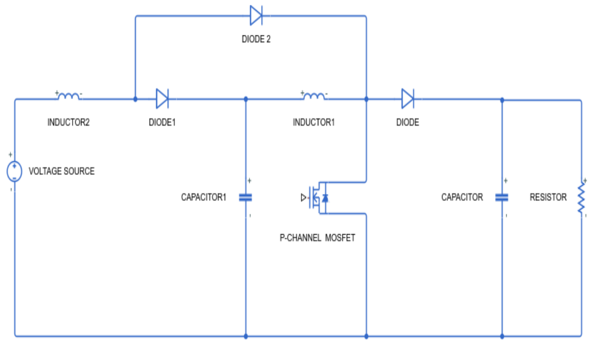

Figure 2. Circuit diagram for Quadratic Boost Converter

Mode 1

Because of the huge values of capacitors, the voltage across the capacitors V_{C_1} and V_{C_2} is practically constant across a switching period, assuming ideal circuit performance. D2 is forward biased whereas D1 and D3 are reverse biased when switch S is turned ON. The Currents to L1 and L2 by provided by V_{in} and C1 respectively.

Mode 2

Here, D_1 and D_3 are forward biased, whereas D_2 is reverse-biased [3]. C1 and C2 are being charged by L1 and L2 respectively. During this state, currents iL_1 and iL_2 are reduced.

4. Designing of Quadratic Boost Converter

V_{in} is the maximum voltage obtained from the PV array. Considering the output of the boost converter as 380V and the frequency of the triangular wave generator is 25 kHz. From this data, the inductance, capacitance, resistance, and output current of QBC are calculated and modeled by the quadratic boost converter.

$$V_{in} = 178.2V; \quad V_{out} = 380V; \quad P = 2000W; \quad F_s = 25000Hz;$$

$$I_o = \frac{P}{V_{OUT}} = \frac{2000}{380} = 5.26A$$

$$R = \frac{V_{OUT}}{I_o} = \frac{380}{5.26} = 72\Omega$$

$$D = 1 - \sqrt{\frac{V_{in}}{V_{OUT}}} = 0.312$$

$$I_{L1} = \frac{I_o}{(1-D)^2} = \frac{5.26}{(0.685)^2} = 11.2A$$

ISSN: 2582-4252

$$\Delta IL_1 = 0.2 * 11.2 = 2.24A(20\% \ of \ I_{L1})$$

$$I_{L2} = \frac{I_o}{(1-D)^2} = \frac{5.26}{(0.685)^2} = 7.67A$$

$$\Delta IL_2 = 0.2 * 7.67 = 1.53A(20\% \ of \ I_{L2})$$

$$L_1 = \frac{V_{in} * D * (1-D)^2}{\Delta I_{L1} F_s} = \frac{178.2 * 0.315 * (0.685)^2}{2.24 * 25000} = 470\mu H$$

$$L_2 = \frac{V_{in} * D * (1-D)}{\Delta I_{L2} F_s} = \frac{178.2 * 0.315 * (0.685)}{1.534 * 25000} = 1mH$$

$$\Delta V_{c1} = 2\% * \frac{V_{in}}{(1-D)} = 5.20V$$

$$\Delta V_{c2} = 2\% * \frac{V_{in}}{(1-D)^2} = 7.6V$$

$$C_1 = \frac{I_o * D}{F_s * (1-D) * \Delta V_{c1}} = \frac{5.26 * 0.315}{25000 * 0.685 * 5.2} = 18\mu F$$

$$C_2 = \frac{I_o * D}{F_s * \Delta V_{c2}} = \frac{5.26 * 0.315}{25000 * 7.6} = 8.72\mu F$$

5. Fuzzy Logic Controller (FLC)

Fuzzy logic is a heuristic approach that uses logical variables to analyses analog inputs values in terms of continuous values between 0 and 1.

The series of inputs are considered as assumptions and for every degree change of input, the output signal is generated so that the process is controlled precisely. A fuzzy logic method aids in the solution of a problem once all relevant data has been examined [8,10,11].

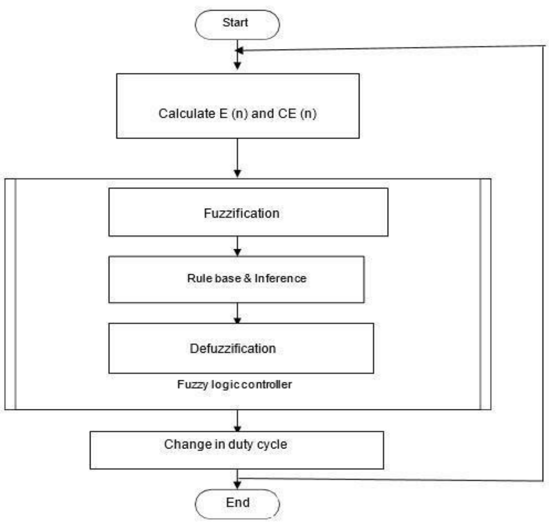

Figure 3. Workflow of the Fuzzification Process

The P-V slope and change in slope are the fuzzy controller's input variables. The key advantage of using this technique is that it can quickly determine the location of operating point from the Maximum Power Point, allowing for easier duty cycle increase or decrease. To prevent fluctuations, change of slope can be used to establish the operational point's movement direction. The fuzzy input variables are used to create fuzzy rules.

The inputs for FLC [2] are,

$$\mathrm{E(n)} = \frac{\Delta \mathrm{P_{PV}}}{\Delta \mathrm{V_{PV}}} = \frac{\mathrm{I_{PV}(n).V_{PV}(n) - I_{PV}(n-1).V_{PV}(n-1)}}{\mathrm{V_{PV}(n) - V_{PV}(n-1)}}$$

$$\mathrm{CE(n) = E(n) - E(n-1)}$$

5.1 Fuzzification

It is the process of changing a precise value to a linguistic value. There is a subset rule in every fuzzy system. The members of variable here are manifested a positive and negative with different ranges of membership function.

5.2 Rule Base

The inference engine applies logical rules to the rule base and develops new rules.

5.3 Defuzzification

It is a procedure of changing an uncertain value to a precise value by taking the union of each rule’s output.

5.4 Five-Term Fuzzy Set

1. Positive big (PB)
2. Positive small (PS)
3. Zero (ZE)
4. Negative small (NS)
5. Negative big (NB)

Fuzzy controller output is the duty ratio of the Quadratic-boost converter. It changes the PV cell’s output voltage and current. Once the PV cell output changes, fuzzy input variables values will be altered. Accordingly, the output commands will be adjusted by the controller [7]. Selection of input and outputs plays a major role in the design of controller and the final system output. The steps in defining the membership functions are given here,

1. PB and NB region boundaries are initially defined depending on the features of the input variables.
2. Using the MPPT objective as a guideline, the range of ZE is determined (efficiency criteria)

The limits of PB, NB, and ZE are decided first, followed by the boundaries of PM and NM. To get the optimal outcome, iterations are frequently required [7].

Table 2. Rules of fuzzy logic

Fuzzy Rule		**E(n)**				
		NB	**NS**	**ZE**	**PS**	**PB**
CE(n)	**NB**	ZE	PB	PS	ZE	NB
	NS	PB	PS	ZE	ZE	NB
	ZE	PB	PS	ZE	NS	NB
	PS	PB	ZE	ZE	NS	NB
	PB	PB	ZE	NS	NB	ZE

Triangular membership functions (mf) have been used here. By analyzing the oscillation of each signal, the range for the membership function is selected.

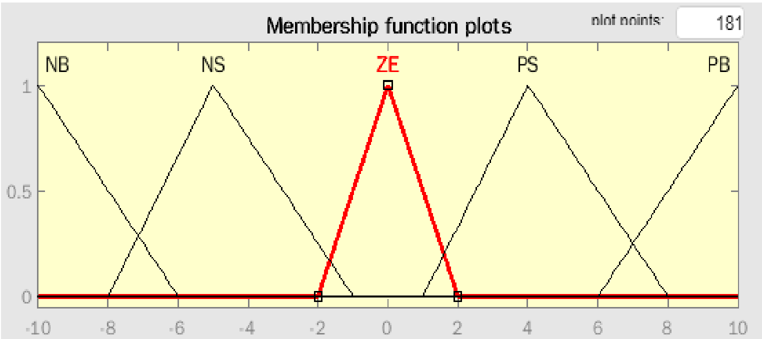

Figure 4. Input mf 1

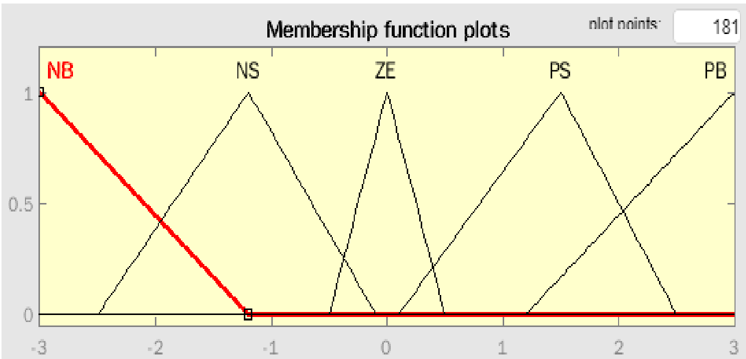

Figure 5. Input mf 2

6. Simulation

The PV system Simulink model with quadratic boost converter and controller is shown in Fig.6. The Fuzzy MPPT controller incorporates the photovoltaic system and the maximum power point algorithm. The PV module voltage and power are combined and sent to the converter and controller. The simulation is run with a temperature of 25°C and a solar irradiation of 1000 W/m^2.

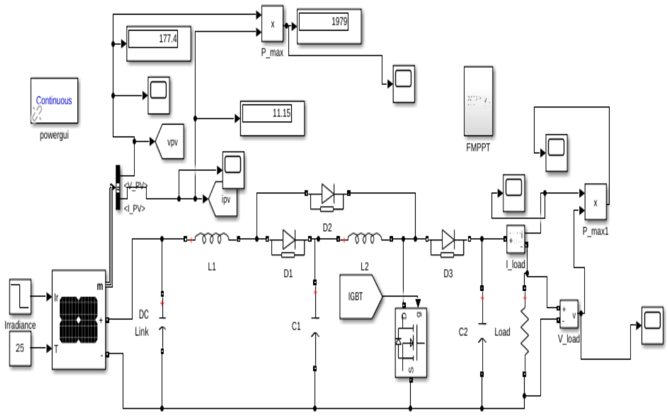

Figure 6. Simulation of MPPT

The computation of error and change in error from the current and prior values of voltage and current collected from solar panel systems is part of a fuzzy inner loop. E (n) and C E (n) are the fuzzy inputs, which are multiplexed and fuzzified. The output of fuzzy networks after defuzzification is the duty cycle, which is applied to the MOSFET switch in the QBC.

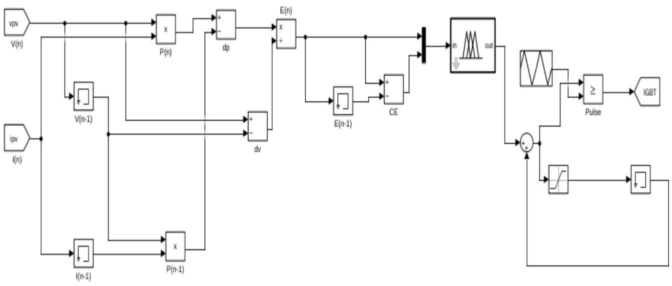

Figure 7. Fuzzy inner loop

7. Results and Discussion

The PV array maximum power tracked is around 2000W for 250C and 1000 W/m2 solar irradiation. Output Voltage of QBC is adjusted in such a way to get constant maximum voltage at the PV array. Fig.8 represents Time vs QBC Voltage plot, QBC voltage oscillates around 360V to 380V.

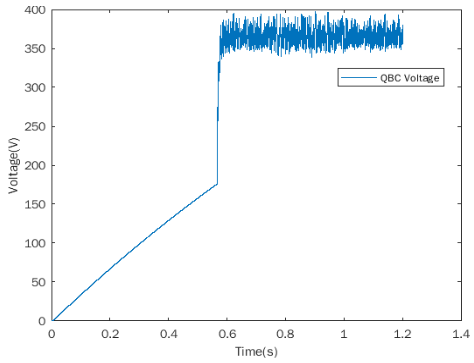

Figure 8. Output voltage of QBC with FMPPT

Output Current of QBC is adjusted in such a way to get constant maximum current at PV array. Fig.9 represents Time vs QBC Current graph, QBC Current is around 4.9A to 5.1

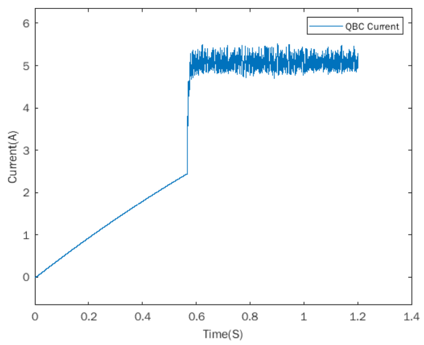

Figure 9. Output current of QBC with FMPPT

The maximum voltage from the PV array after proper modeling of QBC is obtained to be 177V as desired which is shown in Fig.10 which represents the Time vs PV array Voltage graph. The graph depicts how the Voltage is maintained constant even in the presence of temperature and irradiance variations.

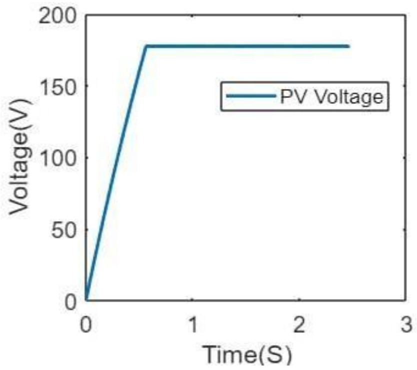

Figure 10. Output Voltage of PV array with FMPPT

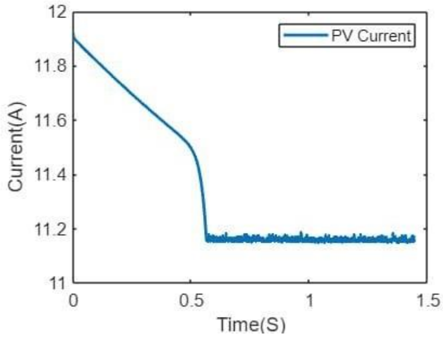

Figure 11. Output Current of PV with FMPPT

The PV array's maximum power obtained is found to be 2000W as expected. Fig.12 represents the PV array Power vs Time which is increasing for a very short period and maintaining its steady-state response.

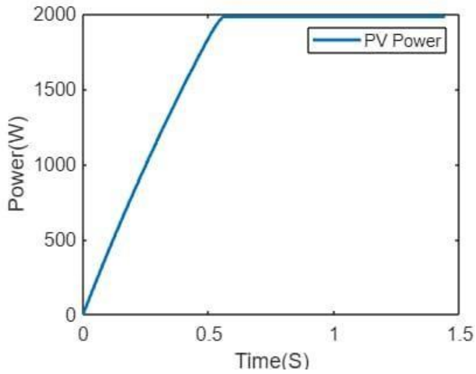

Figure 12. Output power of PV system with FMPPT

So according to the modeling, maximum power has been obtained constantly from the PV array using the Fuzzy MPPT algorithm. Hence fuzzy proves to be a better option for tracking Maximum Power Point in Solar Array.

8. Conclusion

The theoretical analysis and the derivation of the QBC have been presented in this study. QBC has a single active switch with a very high frequency that yields high efficiency. The quadratic boost converter produces a higher output voltage than the boost converter for the same duty ratio. According to the results of the comparison, the quadratic boost converter is better suitable for PV panels and fuel cells than the boost converter. The goal of maximum power tracking is to get the most power possible from the solar panels to the load. To increase efficiency of power tracking, fuzzy logic control is applied. The proposed approach is simulated with MATLAB Simulink software to create a tracking of maximum power point. To maintain the PV output power at its maximum, it is managed using a fuzzy logic controller and a quadratic boost converter.

References

[1] Z. Salam, J. Ahmed and B. S. Merugu, 2013, "The application of soft computing methods for MPPT of PV system: a technological and status review," Applied Energy, vol.107, pp.135-148.

[2] Trishan Esram, 2007 ," Comparison of Photovoltaic Array Maximum Power Point Tracking Techniques", Energy Conversion, Vol. 22, pp.439.

[3] Jyotirmayee Priyadarshini," Modelling & Simulation Of Pv System With Fuzzy Mppt Based Converter," International Conference on Recent Innovations in Electrical, Electronics & Communication Engineering

[4] M. Ajaamoum, M. Kourchi, R. Alaoui, and L. Bouhouch, 2013, "Fuzzy controller to extract the maximum power of a photovoltaic system," in Proceedings of the 1st International Renewable and Sustainable Energy Conference (IRSEC '13), pp. 141–146.

[5] D. Beriber and A. Talha, 2013, "MPPT techniques for PV systems," in Proceedings of the 4th International Conference on Power Engineering, Energy and Electrical Drives (POWERING '13), pp. 1437–1442.

[6] Jaw-Kuen shiau, Yu-Chen Wei and B0-Chih Chen," A Study on the fuzzy logic-based solar Power MPPT Algorithms using different Fuzzy Input Variables," Algorithms 2015,8, pp.100-127.

[7] R. Garraoui, L. Sbita, and M. Ben Hamed, 2013, "MPPT controller for a photovoltaic power system based on fuzzy logic," in Proceedings of the 10th International Multi-Conference on Systems, Signals, and Devices (SSD '13), pp. 1–6.

[8] X.Wang, S.Yuvarajan and Lingling Fan, 2010, "MPPT Control for a PMSG-based grid-tied wind generation System," North American Power Symposium, pp. 1-7.

[9] R. Vinifa and A. Kavitha, 2013, "Fuzzy based maximum power point tracking on a PV system," in Proceedings of the International Conference on Energy Efficient Technologies for Sustainability (ICEETS '13), pp. 329–333.

[10] Selva Kumar. R, Vignesh.C. J, Gayathri Deivanayaki. V. P, Naveena. P, 2016," Design and Comparison of Quadratic Boost Converter with Boost Converter", International Journal of Engineering Research & Technology (IJERT), Vol. 5 Issue 01.

[11] C.S. Chin, P.Neelakantan, H.P.Yoong, K.T.K.Teojune 2011, " Optimization of Fuzzy Based Maximum Power Point Tracking in PV system For Rapidly Changing Solar Irradiation," Transaction on Solar Energy and Planning, Vol.2

[12] H. Ibrahim and M. Ibrahim, 2012, "Comparison between fuzzy and P&O control for MPPT for a photovoltaic system using boost converter," Journal of Energy Technologies and Policy, vol. 2, no. 6, pp. 1–11.

[13] M. M. Algazar, H. Al-Monier, H. A. El-Halim, and M. E. E. K. Salem, 2012, "Maximum power point tracking using fuzzy logic control," International Journal of Electrical Power and Energy Systems, vol. 39, no. 1, pp. 21– 28. 32

[14] L. Donghui and Z. Xiaodan,2011, "Research on the fuzzy controller for photovoltaic power system," in Proceedings of the International Conference on Electric Information and Control Engineering (ICEICE '11), pp. 3506–3509.

[15] Talha, H. Boumaaraf and O. Bouhali,2011, "Evaluation of maximum power point tracking methods for photovoltaic systems," Archives of Control Sciences, vol. 21, no. 2, pp.151–165.

[16] Tavares, Leite, Suemitsu, Bellar, 2009, "Performance evaluation of photovoltaic solar system with different MPPT methods", Proceedings of Industrial Electronics Conference, pp. 719-724.

[17] V. Salas, E. Olias, A. Barrado, A. Lazaro,2008, "Review of the Maximum Power Point Tracking Algorithms for Stand-alone Photovoltaic Systems", Solar Energy Materials and Solar Cells, Issue 11, Vol. 90, pp. 1555- 1578