Journal of Theoretical and Applied Information Technology
20th December 2013. Vol. 58 No.2

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

A COMPARATIVE STUDY OF MPPT TECHNICAL BASED ON FUZZY LOGIC AND PERTURB OBSERVE ALGORITHMS FOR PHOTOVOLTAIC SYSTEMS

[1]R. EL GOURI, [1]M. BEN BRAHIM, [1]L. HLOU
[1] Laboratory of Electrical Engineering & Energy Systems
Faculty of Science Ibn Tofail University
Kenitra, Morocco
E-mail: [1]Elgouri.rachid@yahoo.fr, [1]hloul@yahoo.com

ABSTRACT

Maximum power point trackers (MPPT) play an important role in photovoltaic (PV) power systems because they maximize the power output from a PV system for a given set of conditions, and therefore maximize the array efficiency. The maximum power point tracking methods proposed in this study are two algorithms: Perturb and Observe (P&O) and Fuzzy Logic Control (FLC). The numerical modeling of the PV system shows the MPPT interest and then the MPPT algorithms are highlighted. In this paper, a PV system based on a boost converter as MPPT device is considered. The proposed algorithms were simulated in Matlab/Simulink environment for comparing the performances of P&O and fuzzy logic MPPT methods.

Keywords: *MPPT, Fuzzy Logic, Hill Climping, Solar Panel*

1. INTRODUCTION

The economic reasons, environmental concerns and political implications are the main causes that led to the search for alternative ways of obtaining electrical energy. With global warming on the rise, it is natural that scientific research is more and more oriented towards renewable energies development. Photovoltaic (PV) energy has attracted more attention in the last few years as it meets the requirements of being environmentally compatible and resource conserving [1]. Among renewable sources of energy, solar energy is a suitable choice for a variety of applications mainly due to its capability to be directly converted to electrical energy using solar cells. The output power of solar cells depends on the ambient temperature and the radiation intensity[2]. There is a single maximum power operating point the tracking of which is very important in order to ensure the efficient operation of the solar cell array. Maximum power point tracking (MPPT) is one of the most important issues in solar cell systems [3,4]. There have been numerous methods proposed for tackling this issue [5,6,7,8]. These methods differ in terms of complexity, speed of response, amount of investment, the number and types of sensors required and the hardware implementation.

In this paper, the numerical modeling of the PV system shows the MPPT interest then the Perturb and Observe (P&O) and fuzzy logic MPPT algorithms which can find the real Maximum Power Point (MPP) were reviewed. The proposed algorithms were simulated in Matlab/Simulink environment for Comparing the performances of P&O and fuzzy logic MPPT methods.

2. PHOTOVOLTAIC MODULE AND ARRAY MODEL

PV system naturally exhibits a nonlinear I_{pv}-V_{pv} and P_{pv}-V_{pv} characteristics which vary with the radiant intensity and cell temperature. Figure 1, shows the equivalent circuit models of cell.

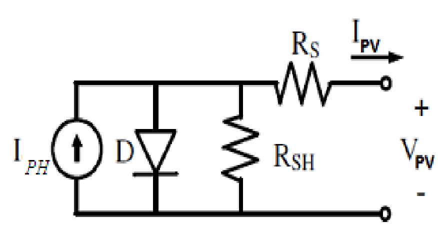


Fig. 1: Equivalent circuit model of PV cell

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

To produce enough high power, the cells must be connected in N series-parallel configuration on a module. A PV array is a group of several PV modules which are electrically connected in series and parallel circuits to generate the required current and voltage. The terminal equation for the current and voltage of the array becomes as follows [9,10,11,12,13].

$$I_{PV} = N_P I_{PH} - N_P I_S \left[\exp\left(\frac{q(V_{PV}/N_S + IR_S)/N_P}{kT_C A} \right) - 1 \right] - (N_P V/N_S + IR_S)/R_{SH} \quad (1)$$

where, I_{PH} is a light-generated current or photocurrent, I_S the cell saturation of dark current, q (= 1.6×10^{-19} C) is an electron charge, k (= 1.38×10^{-23}J/K) is a Boltzmann's constant, Tc is the cell's working temperature, A is an ideal factor, R_{SH} is a shunt resistance, and R_S is a series resistance. The photocurrent mainly depends on the solar irradiation and cell's working temperature, which is described as

$$I_{PH} = [I_{SC} + K_I(T_C - T_{ref})]G \quad (2)$$

Where I_{SC} is the cell's short-circuit current at a 25° C and 1kW/m^2 , K_I is the cell's short-circuit current temperature coefficient, T_{ref} is the cell's reference temperature, and G is the solar irradiation in kW/m^2. On the other hand, the cell's saturation current varies with the cell temperature, which is described as

$$I_S = I_{RS}(T_C/T_{ref})^3 \exp\left[\frac{qE_G(\frac{1}{T_{ref}} - \frac{1}{T_C})}{kA}\right] \quad (3)$$

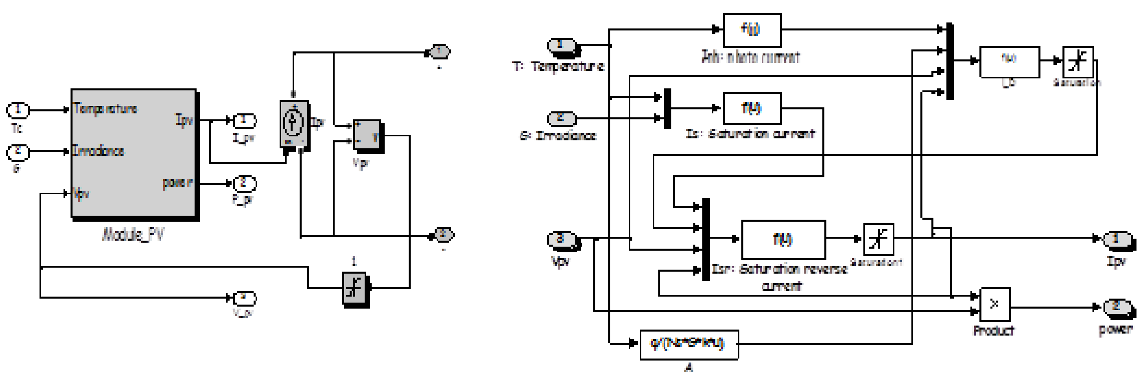
where I_{RS} is the cell's reverse saturation current at a reference temperature and a solar radiation ,E_G is the bang-gap energy of the semiconductor used in the cell. The ideal factor A is dependent on PV technology [14].

On the other hand, the VOC parameter is obtained by assuming the output current is zero. Given the PV open voltage VOC at reference temperature and ignoring the shunt leakage current, the reverse saturation current at reference temperature can be approximately obtained as

$$I_{RS} = I_{SC} / \left[\exp\left(\frac{qV_{OC}}{N_S k T_C A} \right) - 1 \right] \quad (4)$$

3. SIMULATION OF SOLAR PVMODULE IN MATLAB/SIMULINK

In this section the characteristic equations (1), (2), (3) & (4) for the PV module is implemented in Matlab/Simulink as shown in Fig. 2.



(a) (b)

Figure 2: Model of the PV module under Matlab/Simulink (a) Mask of model, (b) Model under mask

Journal of Theoretical and Applied Information Technology
20th December 2013. Vol. 58 No.2

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

The parameters chosen for modeling corresponds to the STP240-20/Wd module as listed in Table 1.

Table 1: Parameters of STP240-20/Wd solar module

Parameters	Values
Maximum Power (Pmax)	240 W
Voltage at Pmax (Vmp)	30.2 V
Current at Pmax (Imp)	7.95 A
Short circuit current (Isc)	8.43 A
Open-circuit voltage (Voc)	37.2 V
Maximum System Voltage	1000V DC
Temperature Coefficient of Isc	-0.055 %/°C
Temperature Coefficient of Voc	-0.33 %/°C
Temperature Coefficient of Power	-0.44 %/°C
NOCT	47+-2°C

Figures 3 and 4, shows the behavior of a photovoltaic panel simulation in accordance to irradiance and temperature variations under respectively constant temperature and irradiance. In fact, a PV generator connected to a load can operate in a large margin of current and voltage depending on weather conditions. Fig.4 shows that the open circuit voltage is increasing following a logarithmic relationship with the irradiance and decreasing slightly as the cell temperature increases. On the other hand, the short circuit current is linearly depending on the ambient irradiance in direct proportion, while the open circuit voltage decrease slightly as the cell temperature increases.

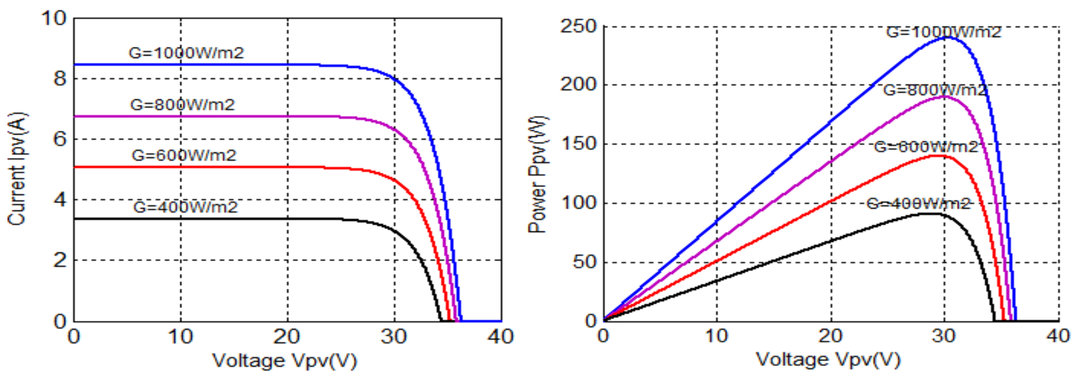


Figure 3 : Ipv and Ppv versus Vpv characteristics under different irradiation and T=25°C

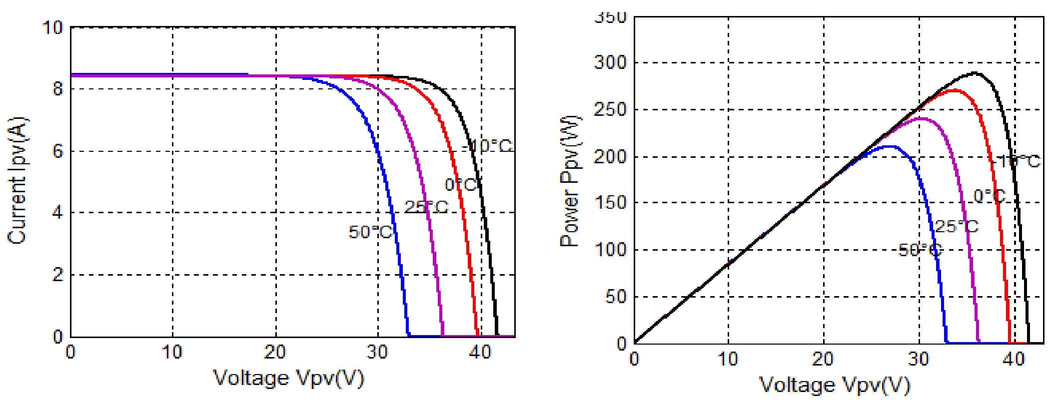


Figure 4 : Ipv and Ppv versus Vpv characteristics under different temperatures and $G=1000W/m^2$

Journal of Theoretical and Applied Information Technology
20th December 2013. Vol. 58 No.2

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

Therefore, the maximum power that could be generated by a PV system is slightly depending on the temperature and irradiance variations: the maximum power increases as the irradiance increases and vice versa, on the other hand a PV generator performs better for low temperature than raised one.
The solar module should always operate so as to extract the maximum power for a given input conditions. For this purpose various power point algorithms can be used.

4. PROPOSED PV SYSTEM WITH MPPT CONTROL

The maximum power that could be generated by a PV system is slightly depending on the temperature and irradiance variations, the maximum power increases as the irradiance increases and vice versa, on the other hand a PV generator performs better for low temperature than raised one.
To overcome this undesired effects on the PV power output, an electrical tracking have to be achieved through a power conditioning converter (DC-DC converter) inserted between the load and the source to insure an impedance adaptation by matching the load impedance with the varying PV source as shown in Fig.5 [8].

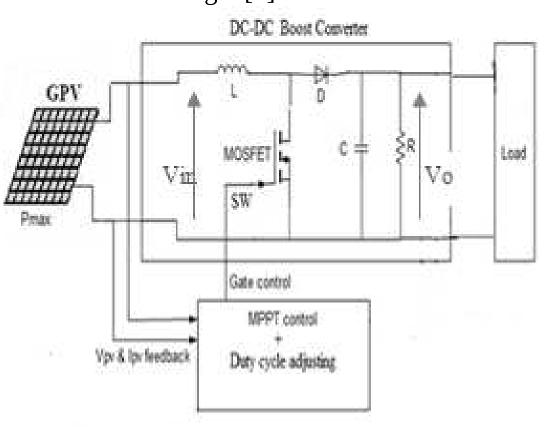


Figure 5: Photovoltaic power system with a Boost converter

A boost converter can be used to increase magnitude of output voltage and control the maximum power point. The MPPT control and pulse width modulation (PWM) method is used to generate a pulse for drive controllable switch (SW) . The output voltage of the boost converter can be calculated from:

$$\frac{V_o}{V_{in}} = \frac{1}{(1-D)} \quad (5)$$

Where Vin is the input voltage (output voltage of PV array), Vo is the output voltage and D is the duty ratio of controllable switch. With the boost topologies we can require output voltage higher than that at the input.

5. MAXIMUM POWER POINT TRACKING METHODS

The control objective is to track and extract maximum power from the PV arrays for a given solar insolation level. The maximum power corresponding to the optimum operating point is determined for different solar irradiation level. Many MPPT techniques have been reported in the literature, but there are two main methods, which are the most widely used:[3,7]

* Perturb and Observe (P&O)
* Fuzzy logic controller (FLC)

The first one is so called 'hill-climbing' method, and it's uses the fact that on the V-P characteristic, on the left of the MPP the variation of the power against voltage dP/dV> 0, while at the right, dP/dV< 0.The Fuzzy logic controller method is based on the fact that it does not require the knowledge of the exact model. It does require in the other hand the complete knowledge of the operation of the PV system by the designer.

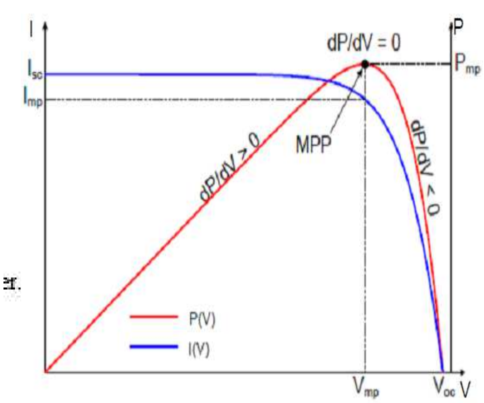


Figure 6: I, P versus PV voltage V and sign of the dP/dV at different positions on the power characteristic

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

5.1 Design of a MPPT Control with P&O

The most commonly used MPPT algorithm is the Perturb and Observe (P&O), due to its simple structure, fewer measured parameters and ease of implementation in its basic form [15]. It is also called mountain climbing method. Its control idea is to make solar cells more output power continuously in the direction of change and the corresponding adjustment of the size of the voltage. The nature of the P&O is a self-optimizing process [16]. As the MPPT control flowchart shown in Fig.7, the terminal voltage V and current I of PV arrays are first measured and PV power P is therefore obtained from the product of V and I If the maximum power point P_m is the demarcation point, when V(k)>V(k-1), if P(k)-P(k-1)>0, then the solar cell work in the left section of the curve. To make the operating point close to the maximum power P_m point, need to continue to increase the output voltage V; In contrast, V(k)>V(k-1), if P(k)-P(k-1)<0, then the solar cell work in the right part of the curve, in order to make the operating point near the point of maximum power P_m, require to reduce the output voltage V. With this control algorithm, the operating point of PV arrays can move toward the maximum power point corresponding to different temperature and irradiance.

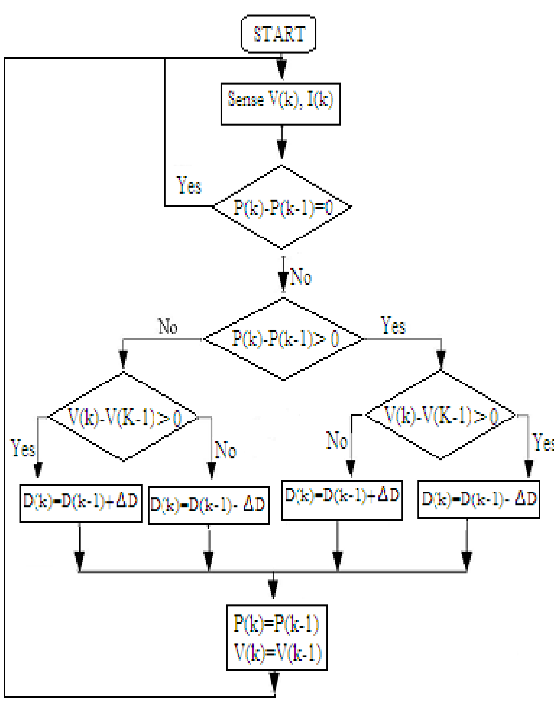


Figure 7 : The flowchart of the P&O algorithm

5.2 Design of a MPPT Control with Fuzzy Logic

Fuzzy control method is applied for the nonlinear characteristics of photovoltaic cells [17,18]. It is the changes to power on the voltage or current, and its rate of change as fuzzy input variables, by fuzzy processing and fuzzy identification based on expert experience, the membership adjusting the output is given, the final membership values carry on defuzzification to gain Adjust volume, to achieve control of the maximum power output. Advantage of this method is not dependent on accurate mathematical model of control object, and has good dynamic performance and accuracy, good robustness [19,20].
The basic composition of fuzzy controller contains a fuzzy interface, rule base, fuzzy reasoning, and clear part of the interface.

5.2.1 Determination of input and output variables and fuzzy

Fuzzy processing uses fuzzy linguistic variables E to describe the deviation. In this design, we use E and dE as the input of fuzzy controller, output is the MOSFET's PWM duty cycle variation dD (Fig.8). The fuzzy controller for dual input and single output is:

$$E = \frac{dP}{dV}(k) = \frac{p_{pv}(k) - p(k-1)}{v_{pv}(k) - v_{pv}(k-1)} \qquad (6)$$

$$dE = E(k) - E(k-1) =$$

$$\Delta(\frac{dP}{dV}(k)) = \frac{dP_{pv}}{dV_{pv}}(k) - \frac{dP_{pv}}{dV_{pv}}(k-1) \qquad (7)$$

$$D(k) = D(k-1) + dD(k) \qquad (8)$$

On the other hand, the error E and error change dE are normalized as follows:

$$\begin{cases} e = K_E.E \\ de = K_{dE}.dE \\ dd = K_{dD}^{-1}.dD \end{cases} \qquad (9)$$

Where K_E, K_{dE} and K_{dE} are the scale factors (standardization). We vary these factors until we have a proper transient control. In fact, it is they which will determine the performance of the MPPT controller.

Journal of Theoretical and Applied Information Technology
20th December 2013. Vol. 58 No.2

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

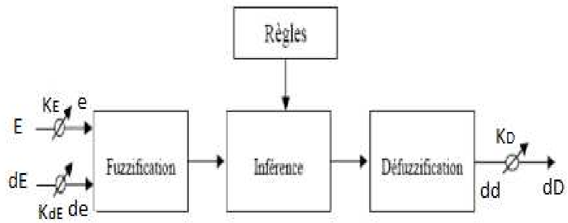


Figure 8 : Bloc diagram of the Fuzzy Logic Control

In this Fuzzy controller, the range of interest of each input variable and the output variable is divided into five classes which are denoted as follows:
NB: negative big,
NS: negative for small
ZO: for about zero,
PS: positive small
PB: positive for large

Input E, dE and output membership functions are shown in Figure Z.

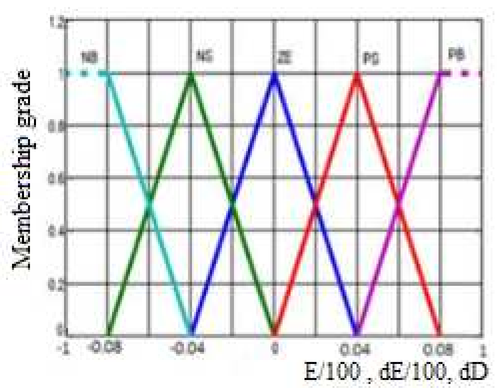


Figure 9: Membership function of E, dE and dD

The values -0.08, -0.04, 0, 0.04 and 0.08 are based on the range values of the numerical variable. In some cases the membership functions are chosen less symmetric or even optimized for the application for better accuracy [21,22].

5.2.2 The establishment of control rules table

The fuzzy rules used to determine the controller output signal as a function of the input signals. They connect the output to the input signals by linguistic terms which take into account the experience and know-how acquired by a human operator. Simply translating remarks sense. For example, it is quite clear that, if the error is strongly negative and its variation is also the control signal must be approximately zero, but if the error is approximately zero and its variation as it will be the same order.

Now, if the error is approximately zero, but its variation is strongly negative, the positive control signal is small, or if the error is strongly negative but the variation is approximately zero. The control signal will be strongly positive. These considerations lead to the adoption of a decision table anti- diagonal, summarizing the rules chosen, it is Table. 2

Table.2: Fuzzy Control Rule Table

dE \ E	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**	**ZE**	**ZE**	**ZE**
PB	**NB**	**NB**	**ZE**	**ZE**	**ZE**

5.2.3 Defuzzification

The last stage of the fuzzy logic control is the defuzzification. In this stage the output is converted from a linguistic variable to a numerical crisp one again using membership functions as those in Figure 9. There are different methods to transform the linguistic variables into crisp values. It can be said that the most popular is the center of gravity method which is calculated as follows.

$$dD(k) = \frac{\sum_{i=1}^{n} (\mu(D_i).D_i)}{\sum_{i=1}^{n} \mu(D_i)} \qquad (10)$$

Where, dD(k) is clear the amount of output variables, $\mu(D_i)$ is the first i-fuzzy output membership, that the output variable of fuzzy inference; D_i is the first i elements of a fuzzy output of the center position; n is the system-defined number of fuzzy output.

6. RESULTS AND DISCUSSION

The models proposed to test the dynamic performance of different MPPT algorithms (Fig.10), were developed in Matlab/Simulink and consists of a model of the PV array, Boost converter which consist of (Capacitors Ce=Cs=470µF, Inductor L=1mH, Diode and Mosfet), model of MPPT controllers and battery (48V) as a load.

Journal of Theoretical and Applied Information Technology
20th December 2013. Vol. 58 No.2

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

The following simulation were presented for different irradiation levels G (Fig.11), to evaluate the efficiency, reliability, stability performances of the fuzzy and P&O MPPT controllers under different slope and step of irradiation level. The obtained results are given in the figures 12 and 13 and table. 3.

As seen in Figure 12.a and b , the algorithm Perturb and Observe tracks accurately the MPP when the irradiance changes continuously under differents slope (30w/m2/s and 100w/m2/s). The PV array power Ppv in both cases, when the increment of the duty cycle dD is set to 0.01 and 0.005, track the MPP when the irradiation changes. However, when the irradiation is constant, it oscillates around the MPP value. The amplitude of the oscillations depends directly on the size of the increment in the duty cycle.

Also, when the irradiation is constant, the corresponding MPP is reached after a delay (Fig.13.a and b), which depends on the size of dD. In other words, when dD is 0.01, the oscillations around the MPP are greater but the time to reach the steady state is shorter than in the other case, when dD is 0.005.

Figures 12, 13 a and b, depicts the performance of the P&O algorithm under a step of irradiance. In this case the tracking is adequate. As expected, the convergence speed, i.e. how fast the steady state is reached, and the amplitude of the oscillations are a trade off, as both cannot be improved at the same time: if one is reduced the other increases, because both depend directly on the size of the duty increment.

As seen in Figure 12.c and 13.c, the algorithm fuzzy logic tracks accurately the MPP when the irradiance changes under steps, it is very fast than P&O algorithm to reach the maximum power point. Also, the fuzzy controller shows smoother power curve, less oscillating and better stable operating point than P&O.

When the irradiance changes continuously under slope with a gradient of 50 $w/m^2/s$ the tracking corresponding to the fuzzy logic algorithm gets bad at the beginning (Fig.12.c) because the controller does not detect the change in the irradiation and the duty is kept constant. When the gradient is small, the error and the change in the error are really small and both correspond to the ZERO membership functions, even though these membership functions are really narrow in both cases. Consequently, the increment in the reference voltage is set to zero and the MPP is not correctly tracked. In contrast, the algorithm fuzzy logic tracks accurately the MPP when the irradiance changes continuously under slope with a gradient of 100 $w/m^2/s$ (Fig.12.c).

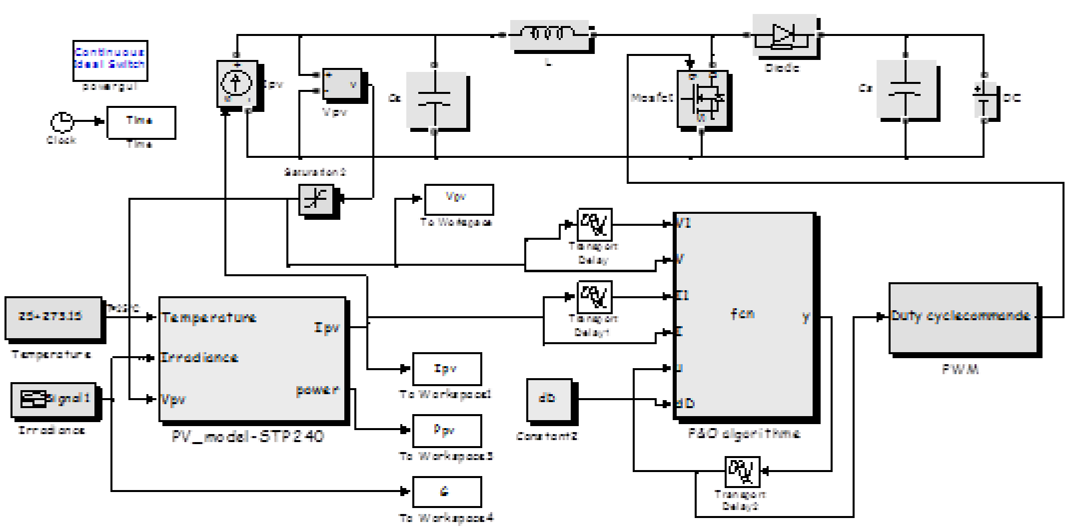


Figure10: Model used for simulations in Matlab/Simulink, wth P&O controller

Journal of Theoretical and Applied Information Technology
20th December 2013. Vol. 58 No.2

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

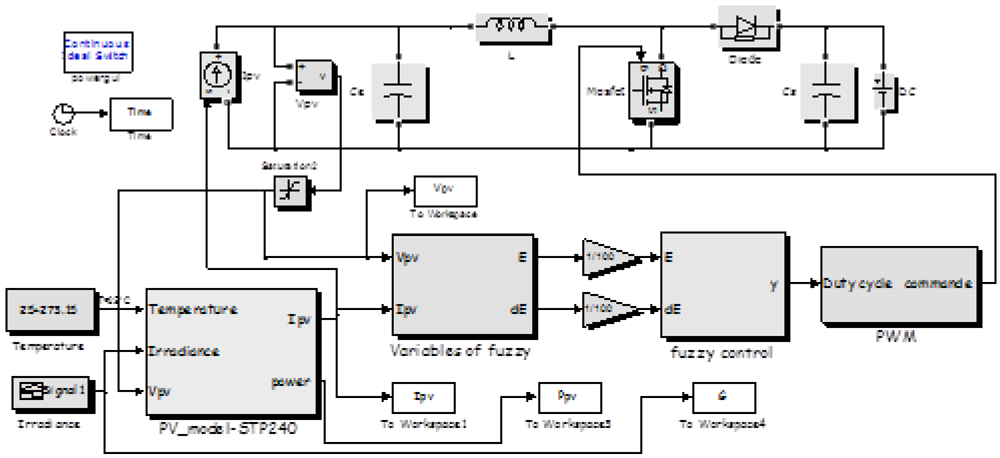


Figure10: Model used for simulations in Matlab/Simulink, with Fuzzy logic controller

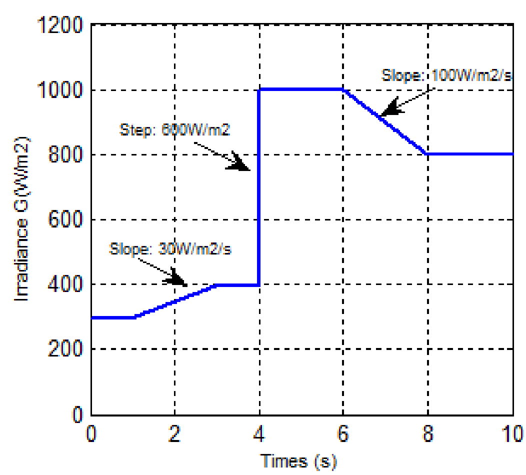


Figure11: Irradiation variation

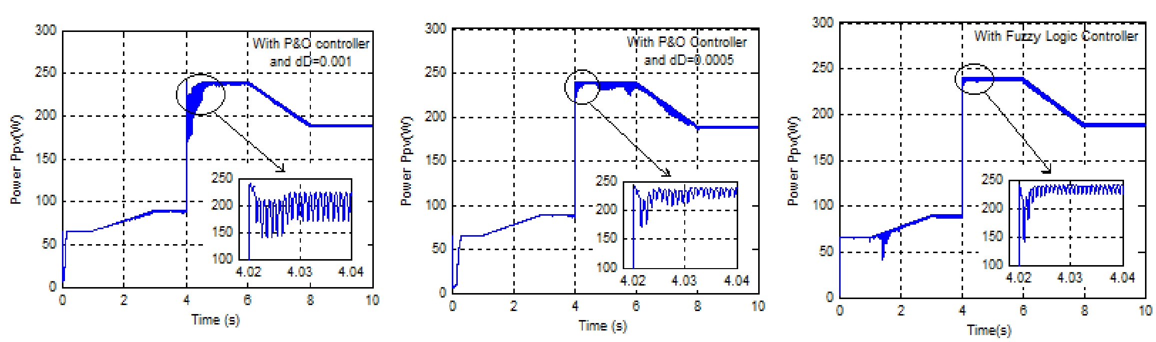


Figure12: Performance of MPPT algorithms under different steps and ramps irradiation change, With P&O and dD=0.01, (b) With P&O and dD=0.005, (c) Whith Fuzzy logic

Journal of Theoretical and Applied Information Technology
20th December 2013. Vol. 58 No.2

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

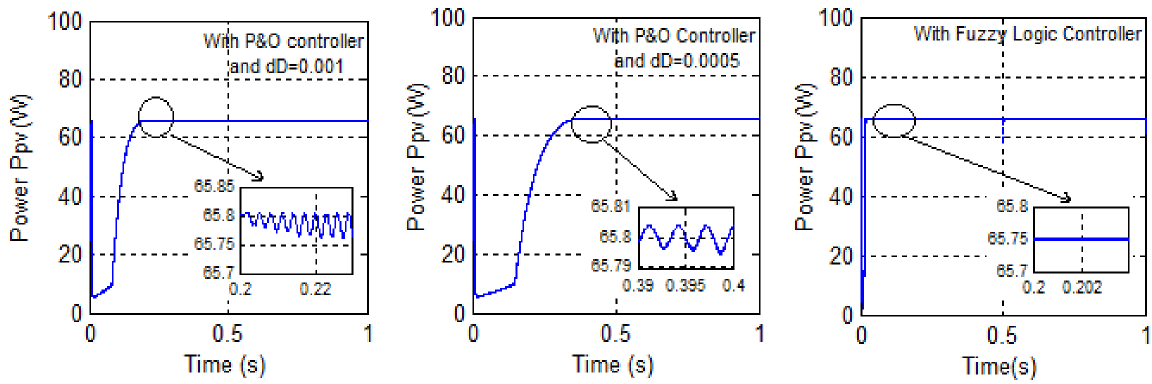


Figure 13 : Zoom in figure 12, between the time interval 0 and 1s

The dynamic efficiency was calculated as follows:

$$\eta_{MPPT} = \frac{P_{pv}}{P_{MPPT}} \quad (11)$$

where P_{pv} is the power obtained from the PV panel and P_{MPPT} is the theoretical maximum one. The maximum power point (MPP) data obtained when the irradiation changes was used to calculate the MPP power (P_{MPPT})
using Matlab. The efficiencies under the steps and slopes of irradiation proposed in Figure 11 are shown in Table 3.

Table.3: Dynamic efficiency

Efficiency (%)		Slope		Step of irradiance	
		50 [w/m²/s]	100 [w/m²/s]	100 [w/m²]	600 [w/m²]
MPPT	P&O	99.5%	99.48 %	99.45 %	99.41 %
	Fuzzy logic	99.4 %	99.42 %	99.53 %	99.52 %

Comparing the performances of (P&O) and fuzzy logic MPPT algorithms considered in this paper, it can be said that the dynamic efficiency of P&O algorithm when using the irradiation slopes 50 and 100 w/m^2/s, reaches 99.5 %. Furthermore, the P&O algorithm tracks the MPP under all ramps with better efficiencies, as seen in Table 3, who is 99.51 % for slope with a gradient of 50 w/m^2/s. In contrast, using the fuzzy logic algorithm, the efficiency is good with the slope with a gradient of 100 w/m2/s where the efficiency is 99.42 %, but when the gradient is smaller, 50 w/m^2/s, the tracking gets bad at the beginning (Fig.12.c) because the controller does not detect the change in the irradiation and the duty is kept constant. This leads to a severe drop in the power obtained from the PV array because the MPP is not tracked, thus the efficiency is 99.4 % , which is less than that is obtained with P&O algorithm. In contrast, the dynamique efficiency of fuzzy logic algorithm when using the irradiation steps, reaches 99.53 %, which is greater than that is obtained with P&O algorithm.

7. CONCLUSION

In this paper, the Perturb and Observe (P&O) and fuzzy logic MPPT algorithms which can find the real Maximum Power Point MPP were reviewed. The algorithm fuzzy logic tracks accurately the MPP when the irradiance changes under steps, it is very fast than P&O algorithm to reach the maximum power point. Also, the fuzzy controller shows smoother power curve, less oscillating and better stable operating point than P&O. The corresponding MPP for P&O algorithm is reached accurately after a delay with the oscillations around the MPP , which depends on the size of duty increment dD. The dynamic efficiency measured for both MPPT algorithms was above 99.4 % in all cases.

The fuzzy logic control is more difficult to design and tune, because all membership functions have to be customized for the PV array used in the system and the efficiency of the controller depends greatly on designer's expertise. In contrast, in the case of the P&O technique, the design steps are well defined and easily to implement.

The above conclusions are based on simulations results. The experimental validation could be done and that should be the next step to confirm the results from the simulations.

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

REFERENCES

[1] T. J. Hammons, J. C. Boyer, S. R. Conners, M. Davies, M. Ellis, M. Fraser, E. A. Holt, and J. Markard,"Renewable energy alternatives for developed countries," IEEE Transaction on Energy Conversion, vol. 15, December 2000, pp. 481-493.

[2] J. A. R. Hernanz, J. J. C. Martín, I. Z. Belver, J. L. Lesaka, E. Z. Guerrero, and E. P. Pérez., "Modelling of Photovoltaic Module," in International Conference on Renewable Energies and Power Quality (ICREPQ'10), Granada, 2010, pp. 1 - 5.

[3] V. Salas, E. Olias, A. Barrado and A. Lazaro, "Review of the maximum power point tracking algorithms for stand-alone photovoltaic systems", Solar Energy Meterials & Solar Cells, vol. 90, 2006, pp.1555-1578.

[4] T. Esram and P. L. Chapman, "Comparison of photovoltaic array maximum power point tracking techniques", IEEE Transactions on Energy Conversion, vol. 22, No.2, 2007, pp. 439-449.

[5] D.P. Hohm and M. E. Ropp, "Comparative study of maximum power point tracking algorithms", Progress in Photovoltaics: Research and Applications, vol. 11, pp. 47-62, 2003.

[6] S. Jain and V. Agarwal, "Comparison of the performance of maximum power point tracking schemes applied to single-stage grid connected photovoltaic systems", IET Electric Power Applications, vol. 1, No. 5, 2007, pp. 753-762.

[7] T. Esram, P. L. Chapman, "Comparison of photovoltaic array maximum power point tracking techniques," IEEE Transactions on Energy Conversion, vol. 22, June 2007, pp. 439-449.

[8] R.El gouri, A. Achachi, A. Hadjoudja, L. Hlou," design and implementation of a numerical maximum power point tracker for photovoltaic power conversion based on microcontroller ",Phys. Chem. News,Vol. 59, 2011, pp 34-42.

[9] M. G. Villalva, J. R. Gazoli, E. Ruppert F, "Comprehensive approach to modeling and simulation of photovoltaic arrays", IEEE Transactions on Power Electronics, vol. 25, No. 5, 2009, pp. 1198-1208.

[10] M. G. Villalva, J. R. Gazoli, E. Ruppert F, "Modeling and circuit-based simulation of photovoltaic arrays", Brazilian Journal of Power Electronics, vol. 14, no. 1, 2009, pp. 35-45.

[11] R. Sridhar, Dr. Jeevananathan, N. Thamizh Selvan, Saikat Banerjee, "Modeling of PV Array and Performance Enhancement by MPPT Algorithm", International Journal of Computer Applications, Vol.7, No.5, September 2010, pp.887– 975.

[12] Huan-Liang Tsai, Ci-Siang Tu, and Yi-Jie Su, "Development of Generalized Photovoltaic Model Using MATLAB/SIMULINK", Proceedings of the World Congress on Engineering and Computer Science 2008 WCECS 2008, October 22 - 24, 2008, San Francisco, USA.

[13] Ramos Hernanz, JA., Campayo Martín, J.J. Zamora Belver, I., Larrañaga Lesaka, J., Zulueta Guerrero, E. Puelles Pérez, E., "Modeling of Photovoltaic Module", International Conference on Renewable Energies and Power Quality (ICREPQ'10) Granada (Spain), 23th to 25th March, 2010.

[14] C. C. Hua and C. M. Shen, "Study of maximum p ower tracking dc converters for photovoltaic power system and control of dc-dc converters for photovoltaic power system," Proceedings of 29th annual IEEE Power Electronics Specialists Conference, vol. 1, 1998, pp. 86-93

[15] M.S.Ngan and C.W.Tan, "A Study of MaximumPower Point Tracking Algorithms for Stand-alone Photovoltaic Systems", IEEE Applied Power Electronics Colloquium, 2011, pp. 22-27.

[16] C. LIU, B.WU, R.CHEUNG, "Advanced Algorithm for MPPT Control of Photovoltaic System", Canadian Solar Building Conference, Montreal, August 20-24 2004

[17] L.A. Zadeh, "Fuzzy sets", Information and Control, Vol. 8, 1965, pp.338- 353.

[18] I.H. Altas and A.M. Sharaf, "A novel maximum power fuzzy logic controller for photovoltaic solar energy systems", Renewable Energy, vol. 33, no.3, 2008, pp. 388-399.

[19] A. Moreno, J. Julve, S. Silvestre, L. Castaner, "A fuzzy logic controller for stand alone PV systems," IEEE Photovoltaic Specialists Conference, Sep. 2000, pp. 1618-1621, 15-22.

[20] M. S. A. Cheikh, C. Larbes, G. F. T. Kebir, A.Zerguerras, "Maximum power point tracking using a fuzzy logic control scheme," Revue des Energies Renouvelables, vol. 10, 2007, pp. 387 – 395.

[21] T. Esram, P.L. Chapman, "Comparison of Photovoltaic Array Maximum Power Point

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

Tracking Techniques," IEEE Transactions on Energy Conversion, vol. 22, no. 2, June 200, pp. 439-4497.

[22] J. Li, H. Wang, "Maximum power point tracking of photovoltaic generation based on the fuzzy control method," in Proc. International Conference on Sustainable Power Generation and Supply, 2009, pp. 1-6.