Comparative study of three MPPT algorithms for a photovoltaic system control

Lashab, Abderezak; Bouzid, Aissa; Snani, Hamza

Published in:
2015 World Congress on Information Technology and Computer Applications (WCITCA)

Publication date:
2015

Document Version
Accepted author manuscript, peer reviewed version

Comparative study of three MPPT algorithms For a photovoltaic system control

Lashab Abderezak
Laboratoire d'Electrotechnique de Constantine
Université des frères Mentouri
Constantine, Algeria
abderezak.lashab@lec-umc.org

Bouzid Aissa
Laboratoire d'Electrotechnique de Constantine
Université des frères Mentouri
Constantine, Algeria
you.bouzid@yahoo.fr

Snani Hamza
Laboratoire d'Electrotechnique de Constantine
Université des frères Mentouri
Constantine, Algeria
snani.hamza@yahoo.fr

Abstract— **In this paper, we compare between three types of algorithm which track the maximum power point (MPPT) of a photovoltaic (PV) system under variable temperature and solar irradiation conditions, the PV system is constituted by photovoltaic arrays, a resistive load, and a MPPT to control a DC-DC boost converter, The simulation results present a clear performance enhancement of MPPT technique for energy production from PV panel based on fuzzy control in comparison with perturb and observe (P&O), and Incremental Conductance (INC) algorithm.**

Keywords— ***MPPT; maximum power point tracking, P&O; perturbation and observation, INC; incremental conductance, FLC; fuzzy logic controlle .***

I. INTRODUCTION

In the last years, the accumulation of the demand in energy as well as the pollution coming from the needs to use of fossil energies force the general public to use renewable energies[1]. In this framework, the PV energy is one of the important renewable energy sources which presents an outcome to our problems of energy production. Moreover, this energy seems non polluting, most promising and inexhaustible, the production of this energy is non linear and it varies according to the temperature and solar irradiation. Consequently, the operation point of the PV panel does not coincide with the MPP. So we need a controller which has the ability to extract the maximum power at the output of PV generator regardless of atmospheric conditions, via an intermediate DC-DC converter. Therefore, several studies have focused on the PV systems, they tried to improve algorithms to extract the maximum energy converted by the panel then allowing optimal operation of the PV system [2], Research work Found in the literature use different algorithms which based on the following methods: the Perturbation & Observation (P&O) (which is the most known) and Incremental Conductance (INC) [3], [4]. There are also called smart controls that are based on fuzzy logic (FLC) [5], [6], [7] . In this paper, a model of a PV has been developed using Matlab/Simulink as well as the model of a DC-DC boost converter, first with a P&O controller which oscillate around the MPP searching for it, second with a INC controller, Therefore an intelligent control technique using fuzzy logic associated with a MPPT controller are used to improve energy conversion performance of the PV system [8].

II. PHOTOVOLTAIC POWER GENERATION

The essential component of the PV array is the photovoltaic cell, this latter may be regarded as an ideal current source which provides the current Iph, and this is proportional to the incident light power, in parallel to the current source there is a diode D and a high resistance Rsh which is represented by the junction PN. All these elements are in series with a small resistor Rs, Therefore, the PV cell can be modeled by Fig. 1[9] The corresponding equations are as follows:

$$I = I_{ph} - I_{sat}\left[e^{\left(\frac{q\left(V_{ph}+R_S\times I\right)}{nKT}\right)} - 1\right] - \frac{V_{ph}+R_S\times I}{R_{sh}} \qquad (1)$$

By considering the parallel resistance Rsh is infinite ($Rsh = \infty$), the equation (1) becomes:

$$I = I_{ph} - I_{sat}\left[e^{\left(\frac{q\left(V_{ph}+R_S\times I\right)}{nKT}\right)} - 1\right] \qquad (2)$$

Such as:

$$I_{Ph} = I_{SC_{Tref}}\frac{E}{E_0}\left[1 + a(T - T_{ref})\right] \qquad (3)$$

$$a = \frac{I_{sc_T} - I_{sc_{Tref}}}{Isc_{Tref}}\frac{1}{T - T_{ref}} \qquad (4)$$

$$I_{sat} = I_{so}\left(\frac{T}{T_{ref}}\right)^{\frac{3}{A}} e^{\left(\frac{-Eg}{AK}\right)\left(\frac{1}{T} - \frac{1}{T_{ref}}\right)} \qquad (5)$$

And the series resistor Rs,

$$R_S = -\frac{dV}{dI_{Vco}} - \frac{1}{Ki} \qquad (6)$$

$$Ki = I_{so}\frac{q}{nKT_{ref}}exp^{\left(\frac{q\,V_{co_{Tref}}}{nKT_{ref}}\right)} \qquad (7)$$

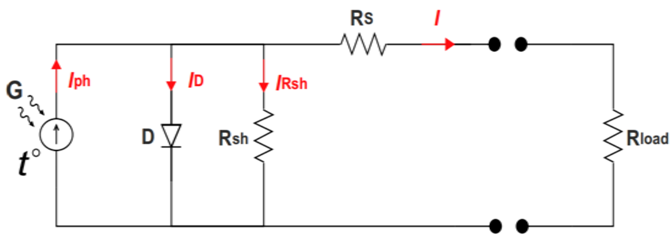

Fig. 1. Photovoltaic cell equivalent circuit.

$$I_{so} = \frac{I_{scTref}}{exp^{\left(\frac{q\,V_{coTref}}{nKT_{ref}}\right)}} \tag{8}$$

Where Vph and I are respectively the voltage and the current output of PV array, Iph is the generated light current (A) at certain insulation, Isat indicates a diode reverse saturation current (A), q is the electronic charge q=1.6×10−19C, k is Boltzmanns constant K=1.3807×10−23Jk−1, n denotes the dimensionless deviation factor from the ideal PN junction diode, Eg is the Band gap for silicon, E is the PV cell insulation and T is the Cell temperature (Kelvin) . The data sheet details of a photovoltaic generator (TOTAL ENERGY TE 600) at 25°C, 1000w/m^2 used in this paper are given in the table 1

TABLE I. DATA SHEET OF **TOTAL ENERGY TE 600** PV ARRAY

parameter	value
Maximum power, PM	63W
voltage at max power, VM	17.75V
Open circuit voltage, Voc	22.5 V
Short circuit current, Isc	3.5 A
Total cells in series, Ns	36
Total cells in parallel, Np	1

The output characteristics of the PV array are non-linear as it is dependent on the cell temperature and the solar irradiance as shown in Fig. 2 and Fig. 3 [10], [11], these figures show the I-V and P-V characteristics of a typical PV module for different degrees of insulation intensity and temperature, we can notice that the output voltage of the PV array has a great influence by the temperature, The increase of the PV module temperature decreases the output power, An increase of temperature by 1K, leads to approximately a 0.4 to 0.5% decrease in the electrical efficiency of the crystalline silicon and nearly 0.25% in the amorphous silicon cells [12], while PV output current has approximate linear relationship with the insulation intensities. In fact, there is only one point on the I-V or P-V curve, called the Maximum Power Point (MPP), Hence it is necessary to continuously track the MPP under the environmental changes in order to maximize the output power from the PV array, there is a need to determine its exact location, this can be operates at its MPP. In general, a MPPT system controls a done using an MPPT system. An MPPT system is an electronic control device, its role is to guarantee always operates at its MPP. In general, a MPPT system controls a DC-DC converter, installed between

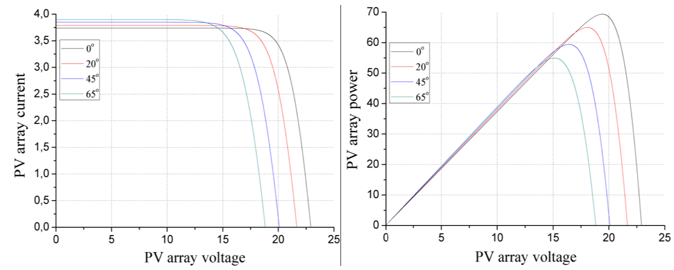

Fig. 2. I-V and P-V characteristic of a typical PV module for fixed insulation intensity $G = 1000W/m^2$, and varied Temperatures.

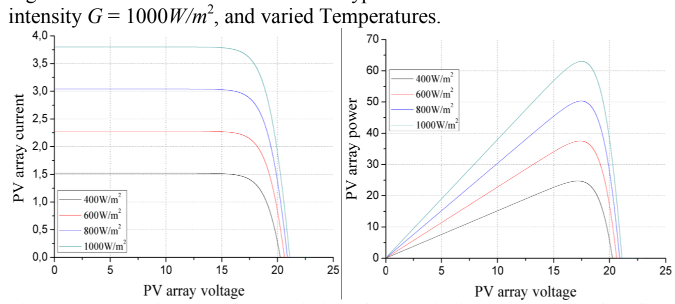

Fig. 3. I-V and P-V characteristic of a typical PV module for fixed Temperatures $T = 25$ °C, and varied insulation intensity.

the PV module and the load [12], The DC-DC converter is controlled by an algorithm, which calculates the value of the duty cycle.

III. DC-DC BOOST CONVERTER

The chopper or DC-DC converter is a power electronics device that is implements one or more controlled switches and which changes the value of the voltage of a DC voltage source, the choppers have excellent yields ,because of the low power consumption of the of the composite elements such as capacitors, the inductors and mainly switches .

For $t \in]0, \alpha T]$, the transistor is on. Thereafter, the converter can be modeled by the following equations:

$$L\frac{dI_L}{dt} = V_1 \tag{9}$$

$$\frac{dV_2}{dt} = -\frac{V_2}{R_{Load}\times C} \tag{10}$$

For $t \in]\alpha T, T]$, the transistor is off. Thereafter, the converter can be modeled by the following equations:

$$L\frac{dI_L}{dt} = V_1 - V_2 \tag{11}$$

$$\frac{dV_2}{dt} = \frac{I_L}{C} - \frac{V_2}{R_{Load}\times C} \tag{12}$$

Where T is the period of the boost converter and α is the ratio cycle. The data sheet details of the boost DC-DC converter are given in table 2.

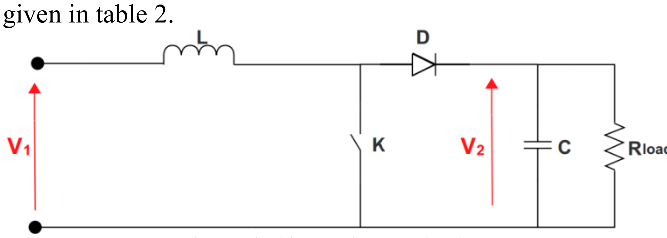

Fig. 4. Ideal boost chopper circuit.

TABLE II. COMPONENT VALUES OF DC-DC BOOST CONVERTER.

Parameter	Value
Resistance, R_{load}	100Ω
Inductor, L	0.0001H
Capacitor, C	400μF

IV. MPPT ALGORITHM

MPPT control is an essential control for optimum operation of the PV system. The principle of this control is based on the automatic variation of the cyclic ratio α by bringing it to the optimal value to maximize the power output of the PV panel, For this reason, we will present and discuss later the most popular control algorithms. The more popular PV MPPT algorithms are Constant Voltage, P&O, INC, Short Circuit Current and Open Circuit Voltage [13], these algorithms use PV output voltage data, output current data, or both, to track the MPP, and it is based on mathematical relationship obtained from empirical data.

A. Perturb and Observe (P&O) Method

The perturbation method and observation P&O is an approach widely prevalent in the research MPPT because it is simple and requires only voltage measurements and current of the photovoltaic panel V_{PV}, I_{PV} respectively, it can detect the MPP even during variations in illumination and temperature. As its name denotes, the P&O method works with voltage perturbation V_{PV} and observing the effect of this change on the output power of the photovoltaic's panel. With the algorithm of the P&O method, at each cycle, $P_{pv}(k)$ is calculated through the measurement of V_{PV} and I_{PV}, this instantaneous value $P_{pv}(k)$ is compared with the previous value $P_{pv}(k-1)$ which is calculated in the previous cycle.

If the output power of the PV array has increased, V_{PV} is adjusted in the same direction as in the previous cycle, if the output power of the PV array decreased, V_{PV} is adjusted in the opposite direction than in the previous cycle. When the MPP is reached, V_{PV} oscillates around the optimum value V_{opt}, this oscillation increases with the step of the incrementing of the perturbation, consequently causes a loss of power, if this step is big, the MPPT algorithm can responds quickly to sudden changes in atmospheric conditions. In addition, if the step increment is small, the losses, during stable or slow changes in operating conditions will be lower but the system cannot respond quickly to sudden changes in temperature or light. The ideal step increment is experimentally determined according to the needs.

B. Algorithm of Incremental conductance

In this algorithm the derivative of the output power of the panel is calculated otherwise, it is calculated as a function of the voltage V and the difference dV and the current I and its difference dI, this derivative is zero at the MPP, positive on the left of point MPP and negative on the right. The solar panel power is given by:

$$P = V \times I \tag{13}$$

The partial derivative dP/dV is given by:

$$P\frac{dP}{dV} = I + V\frac{dI}{dV} \tag{14}$$

$$\frac{P}{V}\frac{dP}{dV} = \frac{I}{V} + \frac{dI}{dV} \tag{15}$$

We define the conductance of the source $G = \frac{I}{V}$ and incremental conductance $\Delta G = \frac{dI}{dV}$ Since the voltage V of the panel is always positive, the equations (16) explains that the point of maximum power MPP is achieved if the conductance of the source G equals the incremental conductance ΔG of the source with a minus sign, and is left of this point when the conductance G is greater than the incremental conductance ΔG and vice versa, as follows:

$$\begin{cases} \frac{dP}{dV} > 0\,; & if \quad \frac{I}{V} > -\frac{dI}{dV} \\ \frac{dP}{dV} = 0\,; & if \quad \frac{I}{V} = -\frac{dI}{dV} \\ \frac{dP}{dV} < 0\,; & if \quad \frac{I}{V} < -\frac{dI}{dV} \end{cases} \tag{16}$$

The Voltage and the current of the panel are monitories, so that the controller can calculate the conductance and incremental conductance and decide their behavior. This algorithm involves a large number of derivations.

C. fuzzy logic algorithm

Recently, the control based on fuzzy logic has been used in the track of MPP systems this control offers the advantage of being a robust control and which does not require the knowledge exact mathematical model of the system, In particular, this command is better suited to nonlinear systems. The operation of this algorithm is in three blocks: fuzzification, inference and defuzzification figure Fuzzification allows the conversion of the input physical variable in the fuzzy sets. In our case, we have two entries error E and change in error ΔE which expresses the moving direction of the MPP [14]. These entries are defined as follows:

$$E = \frac{P_{pv}(k) - P_{pv}(k-1)}{I_{pv}(k) - I_{pv}(k-1)} \tag{17}$$

$$\Delta E = E(k) - E(k-1) \tag{18}$$

Where, K is the sampling time, Ppv(k) is the instantaneous power of the PVG, and Ipv(k) is the corresponding instantaneous current.

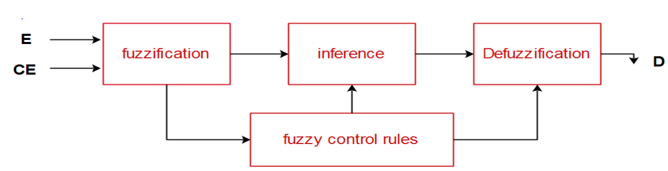

Fig. 5. diagram of fuzzy logic algorithm.

1) Fuzzification: Attributed to change in error ΔE and error E the linguistic variables: big negative (BN), small negative (SN), Zero (ZE), small positive (SP) and big positive (BP). The shape of membership function and the partition of fuzzy subsets, which can adapt shape up to suitable system, are shown in Fig. 6, Fig. 7 and Fig. 8

2) Inference method: In the inference step, making decisions. Indeed, it embeds logical relationships between inputs and output while defining membership rules. The fuzzy implication method is used to identify the output fuzzy set. Here we are using MIN-MAX fuzzy implication method [15], subsequently, it paints a table's inference rules (table 3)

3) Defuzzification: For this system, the output of this FLC is the duty ratio (cycle), to compute it we used the centre of gravity, the gravity centre method is both very fast and very simple method. The gravity centre defuzzification method in a rules's system by formally given by:

$$D = \frac{\sum_{j=1}^{n} \mu(Dj)-(Dj)}{\sum_{j=1}^{n}(Dj)} \tag{19}$$

The Duty cycle is the output of FLC uses to control through PWM which generated pulse to control the switch in DC-DC converter.

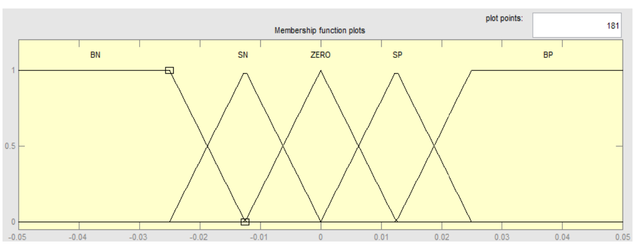

Fig. 6. Membership function plots for input E.

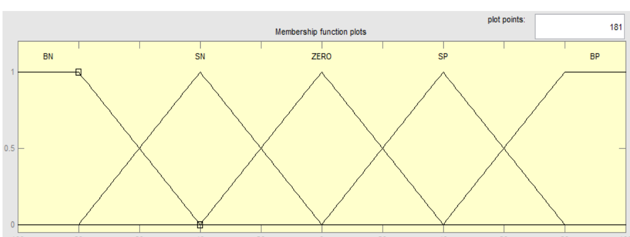

Fig. 7. Membership function plots for input ΔE.

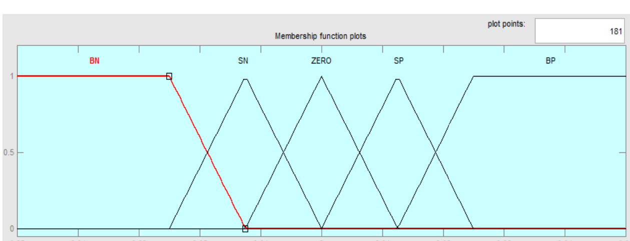

Fig. 8. Membership function plots for output D.

V. SIMULATION RESULTS AND DISCUSSION

The PV model with its controlled DC-DC boost converter is simulated using MATLAB/Simulink software, to demonstrate the features of the MPPT algorithms based fuzzy logic in comparison with the INC and the Conventional P&O MPPT

TABLE III. FUZZY INFERENCE TABLE.

E \ ΔE	NB	NS	ZE	PS	PB
NB	ZE	ZE	BP	BP	Bp
NS	ZE	ZE	SP	SP	SP
ZE	SP	ZE	ZE	ZE	SN
PS	SN	SN	SN	ZE	ZE
PB	BN	BN	BN	ZE	ZE

method. The first test consists to verify the ability to track the MPP for the three methods under the standard conditions which is: 25°C of temperature and 1000W/m^2 of solar irradiation, Fig. 9 shows the result of the tracked power by the three controllers. From Fig. 9, it is noticed that P&O, INC and fuzzy logic can track the maximum power operating voltage point.

The next simulation is under fast variation of solar irradiation, at 0.02 sec from 1000W/m^2 to 800W/m^2 and at 0.03 sec from 800W/m^2 to 600W/m^2. Another simulation is under a fast variation of temperature, at 0.02 sec from 45°C to 30°C and at 0.03 sec from 30°C to 15°C. According to the Fig. 9, Fig.10 and Fig. 11, The MPPT which made in FLC method have been shown to be functioning well under varying atmospheric conditions, we can see that the P&O method has a major disadvantage which is bad behavior following an abrupt change of illumination (clouds).

The INC Algorithm seems to have an improvement over the P&O algorithm, indeed, it behaves better during a fast change of the metrological conditions. However, the FLC algorithm it is more complex than the precedent, the algorithm based on fuzzy logic is a robust and effective algorithm. Indeed, this algorithm functions at the optimal point with less oscillation, and it has better response time comparing to P&O and INC method. Moreover, it is characterized by a good behavior in transitory state.

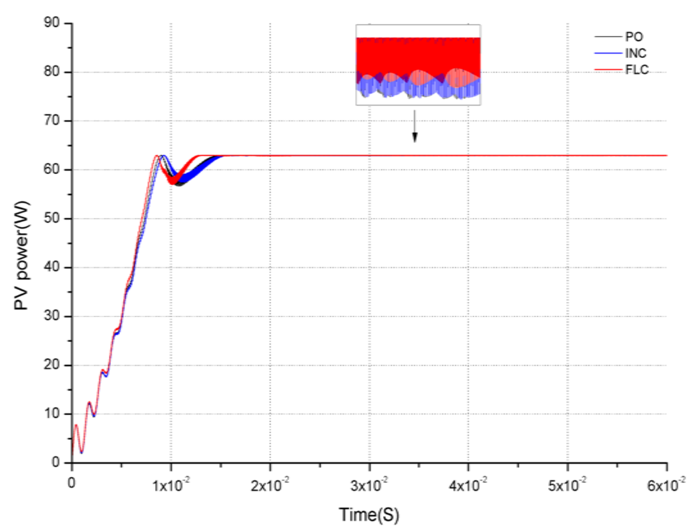

Fig. 9. PV power curves generated by P&O algorithm, INC algorithm and FLC at 25°C of temperature and 1000W/m^2 of solar irradiation.

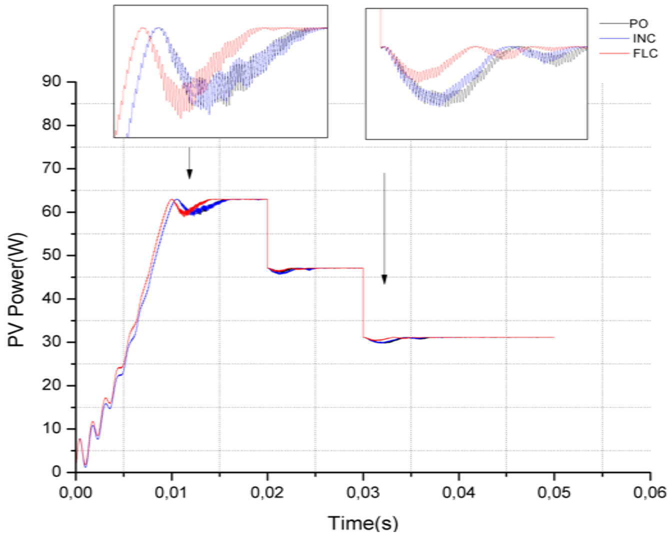

Fig. 10. PV power curves generated by P&O algorithm, INC algorithm and FLC at temperature 25°C and different solar irradiation levels 1000W/m^2, 800W/m^2 and 600W/m^2.

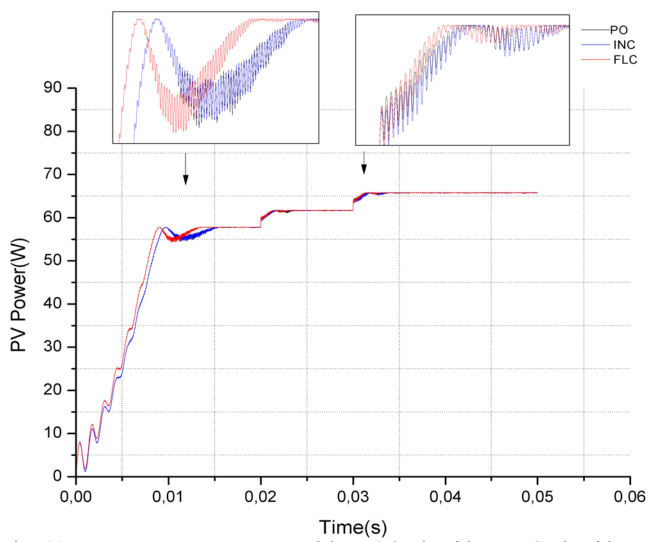

Fig. 11. PV power curves generated by P&O algorithm, INC algorithm and FLC at solar irradiation 1000W/m^2 and different temperature levels 45°C, 30°C and 15°C.

VI. CONCLUSION

In this paper, we described the principal elements of system statement that is a Photovoltaic panel. Then, we presented the P-V and the I-V characteristics of TOTAL ENERGY TE600 solar array, we pointed out the principle of three of the most popular MPPT algorithms, Lastly, we finished by a simulation of the various algorithms. The goal of this work was to control the duty cycle of the boost converter in order to obtain the maximum power possible from a PV generator, whatever the solar insulation and temperature conditions. The results of simulations show that the INC algorithm gives results better than the P&O one. In addition, the P&O and the INC are widely used but the control based on fuzzy logic shows a good behavior and better performances compared to the other methods.

REFERENCES

[1] Eftichios Koutroulis, Kostas Kalaitzakis and Nicholas C. Voulgaris, ”Development of a Microcontroller-Based, Photovoltaic Maximum Power Point Tracking Control System,” IEEE TRANSACTIONS ON POWER ELECTRONICS, VOL. 16, NO. 1, p.p. 46, JANUARY 2001.

[2] Hairul Nissah Zainudin, Saad Mekhilef, ”Comparison Study of Maximum Power Point Tracker Techniques for PV Systems ”, MEPCON10, Cairo University, Egypt, p.p. 750, December 2010.

[3] Dezso Sera, Laszlo Mathe, Tamas Kerekes, Sergiu Viorel Spataru and Remus Teodorescu, ”On the Perturb-and-Observe and Incremental Conductance MPPT Methods for PV Systems,” IEEE JOURNAL OF PHOTOVOLTAICS, VOL. 3, NO. 3, p.p. 1070, JULY 2013.

[4] M. A. G. de Brito, L. Galotto, L. P. Sampaio, G. de Azevedo e Melo, and C. A. Canesin, ”Evaluation of the Main MPPT Techniques for Photovoltaic Applications,” IEEE Transactions on Industrial Electronics, vol. 60, p.p. 1156-1167, 2013.

[5] T.Balamurugan, Dr.S.Manoharan, P.Sheeba, M.Savithri ”Design A Photovoltaic Array With Boost Converter Using Fuzzy Logic Controller ”,Vol. 3, Issue 2, 2012, p.p. 444-456.

[6] B. N. Alajmi, K. H. Ahmed, S. J. Finney, and B. W. Williams,”FuzzyLogic-Control Approach of a Modified Hill-Climbing Method for Maximum Power Point in Microgrid Standalone Photovoltaic System,” IEEE Transactions on Power Electronics, vol. 26, p.p. 1022-1030, 2011.

[7] Ahmad El Khateb, Nasrudin Abd Rahim, Jeyraj Selvaraj, and Mohammad Nasir Uddin, ”Fuzzy-Logic-Controller-Based SEPIC Converter for Maximum Power Point Tracking,” IEEE TRANSACTIONS ON INDUSTRY APPLICATIONS, VOL. 50, NO. 4, p.p. 2349, JULY/AUGUST 2014.

[8] S. Lalouni, D. Rekioua, T. Rekioua and E. Matagne, ”Fuzzy logic control of stand-alone photovoltaic system with battery storage,” Journal of Power Sources 193 2009, p.p. 899.

[9] Jiyong Li, and Honghua Wang, ”Maximum Power Point Tracking of Photovoltaic Generation Based on the Fuzzy Control Method,” IEEE SUPERGEN09, p.p. 1-6, 2009.

[10] V. Salas, E. Ols, A. Barrado and A. Lazaro, ”Review of the maximum power point tracking algorithms for stand-alone photovoltaic systems,” Solar Energy Materials Solar Cells 90 (2006) p.p. 1555-1578.

[11] Kok Soon Tey , Saad Mekhilef, ”Modified Incremental Conductance Algorithm for Photovoltaic System Under Partial Shading Conditions and Load Variation,” IEEE TRANSACTIONS ON INDUSTRIAL ELECTRONICS, VOL. 61, NO. 10, p.p. 5384-5385 OCTOBER 2014.

[12]] F. Ghani, M. Duke, and J. K. Carson, ” Effect of flow distribution on the photovoltaic performance of a building integrated photovoltaic/thermal (BIPV/T) collector,” Sol.Energy, vol.86, no.5, pp. 1523-1524, May 2012.

[13] R. F. Coelho, F. M. Concer, and D. C. Martins, ”A MPPT approach based on temperature measurements applied in PV systems,” in 2010 9th IEEE/IAS International Conference on Industry Applications (INDUSCON), pp. 1-6, 2010.

[14] F. Chekired, C. Larbes, D. Rekioua and F. Haddad, ”Implementation of a MPPT fuzzy controller for photovoltaic systems on FPGA circuit,” Energy Procedia 6, p.p. 541-549, 2011.

[15] G.Balasubramanian, S.Singaravelu, ”Fuzzy logic controller for the maximum power point tracking in photovoltaic system,” International Journal of Computer Applications (0975-8887) Volume 41-No.12, p.p. 390-391 March 2012.