International Journal of Smart Electrical Engineering, Vol.2, No.4, Fall 2013
pp.237:244
ISSN: 2251-9246
EISSN: 2345-6221

Design of Maximum Power Point Tracking in Solar Array Systems Using Fuzzy Controllers

Marjaneh Hashemi[1], Shahram Javadi [2]

[1]Electrical Engineering Department, Islamic Azad University Central Tehran Branch, Tehran, Iran. Email: marjaneh.hashemii@yahoo.com
[2] Islamic Azad University Central Tehran Branch, Tehran, Iran. Email: sh.javadi@iauctb.ac.ir (Corresponding Author)

Abstract

In recent year's renewable energy sources have become a useful alternative for the power generation. The power of photovoltaic is nonlinear function of its voltage and current. It is necessary to maintain the operation point of photovoltaic in order to get the maximum power point (MPP) in various solar intensity. Fuzzy logic controller has advantage in handling non-linear system. Maximum power point trackers are so important in photovoltaic systems to increase their efficiency.
Many methods have been proposed to achieve the maximum power that the PV modules. This paper proposed an intelligent method for MPPT based on fuzzy logic controller. The system consists of a photovoltaic solar module connected to a DC-DC Boost converter and the fuzzy logic controller for controlling on/off time of MOSFET switch of a boost converter. The proposed MPPT controller for grid-connected photovoltaic system is tested using model designed by Matlab/Simulink program. Comparison of different performance parameters such as: tracking efficiency and response time of the system shows that the proposed method gives higher efficiency and better performance than the conventional perturbation and observation method.

Keywords: *Photovoltaic (PV) systems, MPPT, Fuzzy Logic Controller, Boost Converter, Perturb and Observe (P&O).*

1. Introduction

Energy has the great importance for our life and economy. The energy demand has greatly increased due to the industrial revolution. Fossil fuels have been started to be gradually depleted. The sustainability of our civilization is seriously threatened. On the other hand the greenhouse gas emissions are still increasing due to the conventional generation of energy. It is a really global challenge to reduce carbon dioxide emissions and ensuring secure, clean and affordable energy, and to achieve more sustainable energy systems [1]. The photovoltaic (PV) energy as an alternative Energy source has been widely used because it is pollution Free, abundant, and broadly available as a consequence the PV systems are becoming more and more a relevant part Both in power generation/distribution systems and in Industrial and domestic plants [2].

There are many sources of renewable energy such as solar energy, wind energy, etc. Photovoltaic (PV) system has taken a great attention by the researchers where it appears to be one of the most promising renewable energy sources [1-3].

However, two important factors limit the implementation of photovoltaic systems. These are high installation cost and low efficiency of energy conversion [3]. In order to reduce photovoltaic power system costs and to increases the utilization efficiency of solar energy, the maximum power point tracking system of photovoltaic modules is one of the effective methods [4]. Maximum power point tracking, frequently referred to as MPPT, is a system used to extract the maximum power of the PV module to deliver it to the load, and the efficiency is increased

[5]. An important consideration in the use of PV systems is to operate the system near maximum power point (MPP) so as to increase the output efficiency of PV. For any PV system, the output power can be increased by tracking the MPP of the system by using a controller connected to a boost converter between the PV panel and load.

Different techniques have been developed to maximize the output power of the photovoltaic modules. Incremental Conductance Method is one of these methods.

The other method is the constant voltage tracking (CVT) method. This method compares the measured voltage (current) of the PV module with a reference voltage (current) to continuously alter the duty cycle of the DC-DC converter and hence operate the PV module at the predetermined point close to the MPP [7]. Although the CVT method is very simple, however, the constant voltage cannot track the maximum power point under the temperature changing. Perturbation and observation (P&O) method is an alternative method to obtain the maximum power point of the PV module. It measures the voltage, current and power of the PV module. Then it perturbs the voltage to encounter the change direction. However, this method suffers of slow of tracking speed and high oscillations around MPP [1-5-6-7]. Fig.2 shows the flow chart of the P&O MPPT algorithm.

This paper presents a new method based fuzzy logic Controller to achieve maximum power point tracking. The proposed method depends on measuring the change in the PV voltage. The performance of the FLC method is evaluated by Matlab/Simulink.

2. Method

2.1. Characteristics of Solar Module

In order to model a PV module, a PV cell model must be initially accomplished. An electrical equivalent circuit makes it possible to model the characteristic of a PV cell. In a practical PV cell, there are two resistances: series resistance and parallel resistance. Series resistance is associated with the losses in the current path due to the metal grid, contacts, and current collecting bus. Parallel resistance due to the loss path in parallel with the built-in device and due to the p-n junction is not ideal [7]. Since parallel resistance is larger than series resistance, this paper neglects the parallel resistance. The equivalent circuit of the PV cell is shown in Fig. 1.

The characteristic power curve for a PV array is a non-linear function and, in order to obtain the maximum efficiency, the array must operate at the point where the product V*I is maximum (MPP). The MPP depends on the temperature and insulation level (G) therefore, in order to preserve the maximum efficiency, the operating point of the PV array must be repeatedly updated (maximum power point tracking, MPPT).

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 output current delivered to the load can be expressed as

$$I = I_{pv,cell} - I_{0,cell}\left[\exp\left(\frac{qv}{akT}\right) - 1\right] \quad (1)$$

Where:

I is the output current of the solar module (A), v is the output voltage of the solar cell (V), which can be obtained by dividing the output voltage of the PV module by the number of cells in series, $I_{pv,cell}$ is the current source of the PV module by solar irradiance(A), $I_{o,cell}$ is the reverse saturation current of a diode(A), α is the ideality factor of the diode (n =1~2), q is the electric charge of electron ($1.6\times e^{-19}c$), k is the boltzmann's constant ($1.38\times10^{-23}\, j/k$), T is the given temperature ($^\circ K$)[9].

In order to model the PV module, the current generated by the incident light should be first calculated. This current is given as [9]:

$$I_{pv} = (I_{scn} + K_I(T_a - T_n))\frac{G}{G_n} \quad (2)$$

$$I_0 = \frac{I_{SC,n} + K_I\Delta T}{\exp\left(\frac{V_{oc,n} + K_v\Delta T}{aV_t}\right) - 1} \quad (3)$$

Where I_{scn} is the short circuit current at normal conditions (25 $^\circ$ C, 1000 w/m^2), I_{pv} is the short circuit current at a given temperature of the cell (T_a), K_I is the temperature coefficient of I_{sc}, G_n is the nominal value of irradiance, which is normally 1000 *w/m*^{2}. G is irradiation on the surface of the device, $V_{oc,n}$ is the open circuit voltage at normal conditions.

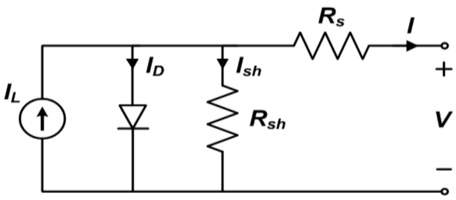

Fig1. Equivalent circuit of PV cell.

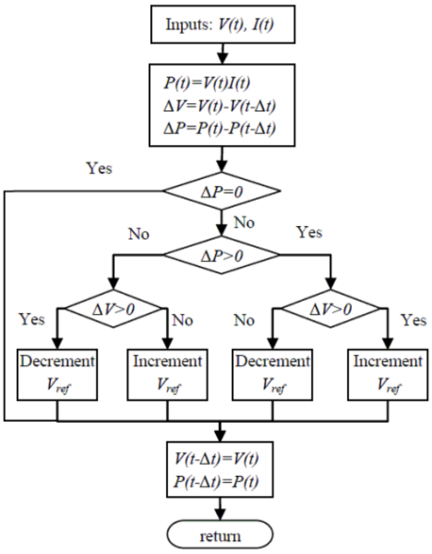

Fig 2. Flow chart for P&O algorithm [10].

Equations are modeled using Matlab/Simulink in order to set up the PV model module as well as to simulate the P-V and I-V curves. Fig. 3 shows the P-V curves of the PV module under changing solar radiation from 200W/m2 to 1000W/m2 while keeping the temperature constant at 25°C. Fig. 4 shows the I-V curves of the PV module.

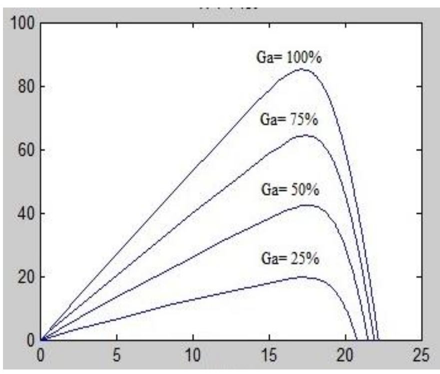

Fig3. P-V curves under changing the solar radiation.

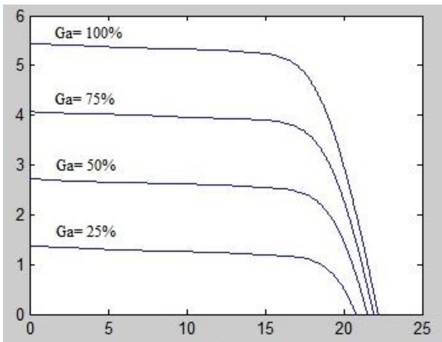

Fig4. I-V curves under changing the solar radiation.

2.2. DC-DC Boost Converter

The DC-DC converter is an electronics circuit which is used to provide a loss less transfer of energy between different circuits at different DC voltage levels. There are many DC-DC converters. One of the popular types of DC-DC converters is Boost converter. A boost converter (step-up converter) is a dc – dc power converter with an output voltage greater than its input voltage. Power for the boost converter can come from any suitable DC sources, such as batteries, solar panels, rectifiers and DC generators. Since power must be conserved, the output current is lower than the source current.

Boost converter is circuit that operating using switching mode power supply. Boost converter used to step up the DC voltage by changing the duty ratio of the switch. When the duty ration is less than 0.3, the output voltage is less than the input voltage and vice versa. The Boost converter circuit is shown in Fig. 5.

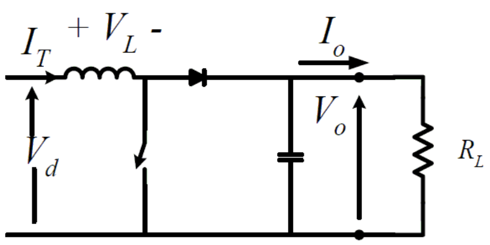

Fig. 5: The Boost converter circuit.

The relation between input voltage over the output vaolate it is as:

$$\frac{V_o}{V_d} = \frac{1}{1-D} \qquad (4)$$

Where D it is the duty ratio.

2.3. The Proposed MPPT Fuzzy Login Base Method

Fuzzy logic controller has wide range of applications in renewable energy applications. The use of fuzzy logic controllers has been increased over the last decade because of its simplicity, deal with imprecise inputs, doesn't need an accurate mathematical model and can handle nonlinearity [10]. FLC can be used as a controller to obtain the maximum power that the PV modules capable of producing under changing weather conditions.

The process of FLC can be classified into three stages, fuzzification, rule evaluation and defuzzification. These components and the general architecture of a FLS are shown in Fig. 6.

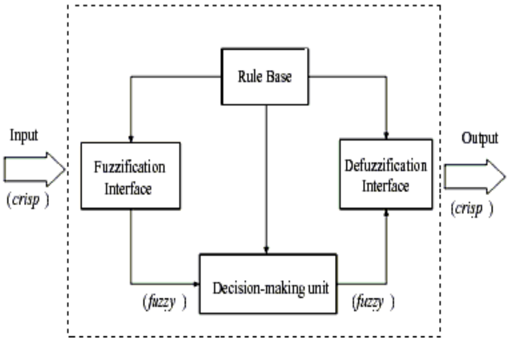

Fig. 6: Block Diagram of Fuzzy Logic Controller

The fuzzification step involves taking a crisp input, such as the change in the voltage reading, and combining it with stored membership function to produce fuzzy inputs. To transform the crisp inputs into fuzzy inputs, membership function must be first assigned for each input. Once the membership functions are assigned, fuzzification take a real time inputs and compares it with the stored membership function information to produce fuzzy input values.

The second step of fuzzy logic processing is the rule evaluation in which the fuzzy processor uses linguistic rules to determine what control action should occur in response to a give set of input values. The result of rule evaluation is a fuzzy output for each type of consequent action.

The last step in fuzzy logic processing in which the expected value of an output variable is derived by isolating a crisp value in the universe of discource of the output fuzzy sets. In this process, all of the fuzzy output values effectively modify their respective output membership function. One of the most commonly used defuzzification techniques is called Center of Gravity (COG) or centroid method.

Fuzzy logic controller has been used for tracking the maximum power of PV systems since it has the advantages such as it is robust, relatively simple to design and does not require the knowledge of an exact model [10-11].

In this paper, a new method based FLC is proposed to achieve tracking the maximum power of the PV module under changing solar radiation and input current. The oscillation around MPP is decreased and the response is faster in compared with the conventional P&O method. The proposed fuzzy logic based MPPT controller has two inputs and one output. Fuzzy sets for each input and output variable are defined as shown in Fig.7 and Fig. 8. Five fuzzy subsets Negative Big (NB), Negative Small (NS), Zero (ZE), Positive Small (PS), and Positive Big (PB) are chosen for the input variable ΔP_k. Eleven subsets are used for the input and output variable ΔD_{k-1}. The subsets are NB, Negative Medium (NM), Negative Medium Medium (NMM), NS, Negative Small Small (NSS), ZE, Positive Small Small (PSS), PS, Positive Medium Medium (PMM), Positive Medium (PM), and PB. Eleven fuzzy subsets were chosen for ΔD_{k-1} in order to smooth the control action. As shown in Fig.7 and Fig. 8, triangular and trapezoidal shapes have been adopted for the membership functions; the value of each input and output variable is normalized. The same membership function is used for the output value ΔD_k and the input value ΔD_{k-1}.

The general way of representing human knowledge is by forming natural language expression given by IF antecedent THEN consequent. The fuzzy rule-base includes 55 control rules. These rules are implemented by a computer and used for the control boost converter such that maximum power is achieved at the output of the solar panel at all operating conditions. The rule-base is given in the table 1. The fuzzy inference of the FLC is based on the Mamdani's method which is associated with the max-min composition. The defuzzification technique is based on the centroid method which is used to compute the crisp output.

Table 1.
Fuzzy controller rule base

	NB	NS	ZE	PS	PB
NB	PM	PM	NM	NM	NM
NM	PS	PMM	NM	NMM	NMM
NMM	PS	PS	NMM	NS	NS
NS	PSS	PSS	NS	NSS	NSS
NSS	PSS	PSS	NSS	NSS	ZE
ZE	NB	NS	ZE	PS	PS
PSS	NSS	NSS	PSS	PSS	PSS
PS	NSS	NSS	PM	PSS	PSS
PMM	NMM	NS	PMM	PS	PS
PM	NMM	NMM	PM	PMM	PMM
PB	NM	NM	PM	PM	PM

ISSN: 2251-9246
EISSN: 2345-6221

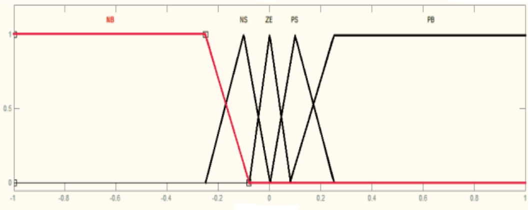

Fig.7: The Membership function of the input variable ΔP_k.

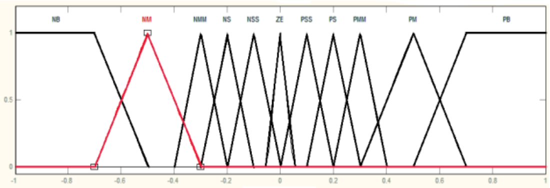

Fig.8: The Membership function for change in duty cycle.

Results

In order to verify the MPP tracker for the photovoltaic simulation system, the proposed MPPT method is compared with conventional controller applied on the same system. This controller is perturbation and observation controller. The proposed method is by implementing a maximum power point tracker controlled by fuzzy logic controller and using boost DC-to-DC converter to keep the PV output power at the maximum point all the time. This controller was tested using Matlab/Simulink program, and the results was compared with a perturbation and observation controller applied on the same system. The comparison shows that the fuzzy logic controller was better in response and don"t depend on knowing any parameter of PV panel.

The model used for simulation is shown in Fig. 10. The output of the MPPT control block is the Duty cycle signal which is used to drive the MOSFET. The principle of this controller is done by changing the PWM duty cycle (D) and observing the effect on the output PV power, this can be detailed as follows:

-when dp/dv > 0, the voltage is increased, this is done through D (k) = D (k − 1) + C.
(C : incrimination step),

-when dp/dv < 0, the voltage is decreased through D (k) = D (k − 1) – C.

Electrical characteristics of the modeled PV are given in theTable 2.

Table 2.
Electrical Characteristics of PV Cell.

Maximum Power (Pmax)	85.14(W)
Short-circuit current	5.45(A)
Open-circuit voltage	22.2(V)
Current at Pmax	4.95(A)
Voltage at Pmax	17.2(V)

The Boost converter is designed under the maximum power 84.67W, under the maximum power point voltage 19.26V. The load is set to be 100Ω. Table 3 shows the parameters of the DC-DC boost converter.

Table 3.
Boost Converter Parameters.

Inductance	200(μH)
Initial inductor current	4 (A)
Capacitance	10(μF)
Initial capacitor voltage	200 (V)
Switching frequency	100(KHZ)

Maximum power point tracker (MPPT) tracks the new modified maximum power point in its corresponding curve whenever temperature and/or insolation variation occurs. MPPT is used for extracting the maximum power from the solar PV module and transferring that power to the load. A dc/dc (step up) converter acts as an interface between the load and the module. The MPPT changing the duty cycle to keep the transfer power from the solar PV module to the load at maximum point [13].

The membership functions for ΔP_k and ΔD_{k-1} are made denser at the center in order to provide more sensitivity as the variation of power approaches zero. The duty cycle is internally limited to a maximum value of 90% to prevent operation at low efficiencies. It is also limited to a minimum value of 10% to ensure that the converter switching process does not stop as operation at $D = 0$ will indicate a false maximum power point. In the case when the maximum power is used; there is no need to enter the duty cycle as an input. Since, the duty cycle is changed by the algorithm till the mentioned parameter reaches to the appropriate value. On the other hand, if the maximum power is not employed, the user should enter the constant duty cycle as an input to the system.

When the duty cycle is in ON state, the diode become as reversed biased and the inductor will deliver current and switch conducts inductor current. The current through the inductor increase, as the source voltage would be greater. The energy stored in inductor increased when the current increase, and the inductor acquires energy. Capacitor will provides smooth out of inductor current changes into a stable voltage at output voltage. When the duty cycle is in OFF state, the diode is ON and the inductor will maintains current to load. Because of inductive energy storage, inductor current will continues to flow. While inductor releases current storage, it will flow to the load and provides voltage to the circuit. The diode is forward biased. The current flow through the diode which is inductor voltage is equal with negative output voltage.

In this paper, the fuzzy logic control demonstrates good performance. Furthermore, fuzzy logic offers the advantage of faster design, and emulation of human control strategies. Also fuzzy control worked well for nonlinear system and shown higher efficiency over the covenantal controllers.

Comparing the tracking using FLC with that obtained using P&O MPPT method, the P&O tracked the maximum power but the oscillation around maximum power is larger in compared with that obtained in the FLC method.

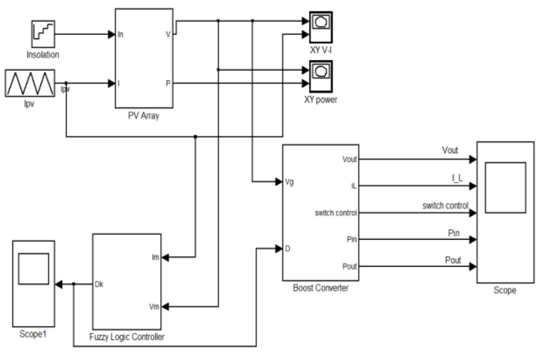

Fig.10: Fuzzy MPPT Simulink Simulation Model.

$$\eta_{mppt}(t_k) = \frac{P_{achieved}(D_k, t_k)}{P_{mpp}(t_k)} \quad (5)$$

Where, $P_{achieved}(D_k, t_k)$ is the power achieved by the algorithm at duty cycle D_k, and $P_{mpp}(t_k)$ is the actual maximum power possible. The average of $\eta_{mppt}(t_k)$ overall t gives a good measure of the effectiveness of the algorithm. The efficiency of tracking using FLC MPPT method is over 98%. This means that over 98% of the available power was captured by the tracking algorithm.

The number of modules of array photovoltaic is changed and the simulation is repeated. The results are represented in Table 4. It should be mentioned that entrance voltage of the exchanger is a function of number of modules. For instance, the entrance voltages are 19.26, 38.52, 115.56 and 231.12 (V) for one, two, six and twelve modules, respectively. The other parameters are changed as given in Table 4.

Table 4.
Input and output values of the fuzzy algorithm with changing the number of photovoltaic modules.

contoller	Vin(V)	Vout(V)	Pin(W)	Pout(W)	iL(A)
Fuzzy	19.26	56.55	21.88	31.98	0.77
Fuzzy	38.52	88.43	59.07	78.2	1.05
Fuzzy	115.56	231.6	366.8	536.3	3.17
Fuzzy	231.12	463.2	1467	2145	6.34

When there are changes in solar radiation, maximum power point changes. As a result, the Duty Cycle required for the operation of the model is changed. If a constant Duty Cycle is applied to, the maximum power point cannot be tracked, so the system becomes less efficient. Module voltage, inductor current, switch control, and input and output power is shown in Fig. 11. By reducing the time Fig. 12 and Fig 13 are obtained as the previous figure, but in less time. According to Fig.12, the voltage waveform module, the inductor current and output, power input to the system is triangular. Control switch is a step waveform.

From the simulation show that voltage input for both controller is almost the same. Perturb and Observe Controller shows a not stable condition. From the simulation result is shows that controller that connected with Boost converter which will give a stable output is the FLC. Fuzzy Logic controller can achieve maximum output value at 88.43(V) that better than Perturb and Observe controller.

Table 5 shows a comparison between the two controller's perturbation and observation and FLC controller on the same PV power. The response of FLC is better than the response of the perturbation and observation controller since it take more settling time. Other drawback point in perturbation and observation controller is that it depends on knowing the value of the voltage at the maximum power point (Vm).

Table 5.
Comparison Input and Output Value Between FLC MPPT and Perturb & Observe in Boost Converter.

Controller	Vin (V)	Iout(A)	Pout(W)	Pin(W)	Vout(V)
Fuzzy	38.52	0.96	84.67	59.07	88.43
P & O	38.79	1.9	72.18	73.7	37.99

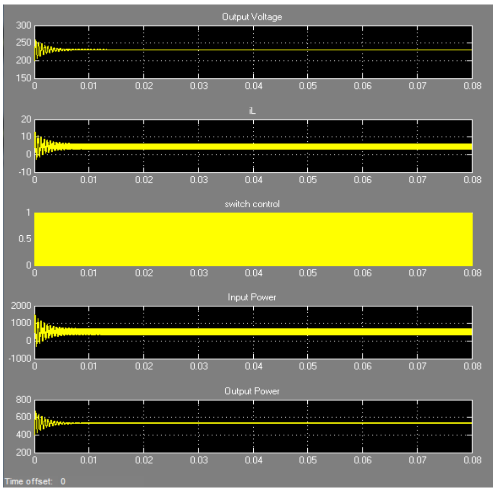

Fig.11. Module voltage, inductor current, switch control, and input and output power, the settling time of 0.08.

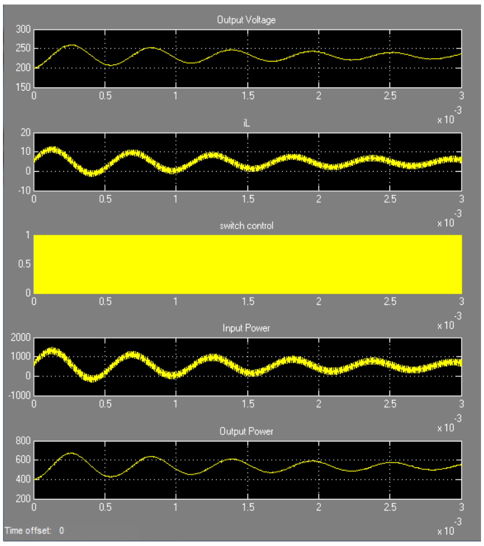

Fig 12. Module voltage, inductor current, switch control, and input and output power, the settling time of 3×10^{-3}.

3. Conclusion

Photovoltaic model using Matlab/Simulink and design of appropriate DC-DC Boost converter with a maximum power point tracking facility are presented in this paper. A new method for MPPT based fuzzy logic controller is presented and compared with the conventional P&O MPPT method.

The oscillation around MPP is decreased in compared with the conventional methods. Comparing the tracking efficiency of both methods indicates that the proposed method has a higher efficiency than the conventional P&O MPPT method. In this paper, the fuzzy logic control demonstrates good performance.

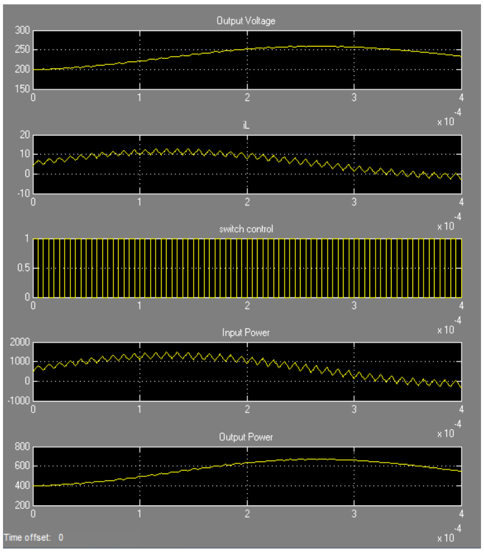

Fig.13. Module voltage, inductor current, switch control, and input and output power, the settling time of 4×10^{-3}.

Furthermore, fuzzy logic offers the advantage of faster design, and emulation of human control strategies. Also fuzzy control worked well for nonlinear system and shown higher efficiency over the covenantal controllers. Other drawback point in perturbation and observation controller is that it depends on knowing the value of the voltage at the maximum power point (Vm).

References

[1] Jancarle L. Dos Santos, Fernando L. M. Antunes and Anis Chehab, “A Maximum Power Point Tracker for PV Systems Using a High Performance Boost Converter”, Solar Energy, Vol.80, Iss.7, pp.772- 778, 2005.

[2] S. J. Chiang, K.T. Chang, C. Y. Yen, “Residential Photovoltaic Energy Storage System”, IEEE Trans. On Ind. Electronics, Vol.45, No.3, June 1998, pp.385-394 and M. Oliver, T. Jackson, “The market for solar photovoltaics”, Energy Policy Vol.27, pp.371-380, 1999.

[3] Ting-Chung Yu and Tang-Shiuan Chien, "Analysis and Simulation of Characteristics and Maximum Power Point Tracking for Photovoltaic Systems", Proceeding of power Electronic and drive systems Conference, pp.1339-1344, Taipei, 2009.

[4] Roberto Faranda, Sonia Leva, “Energy Comparison of MPPT techniques for PV Systems”, Wseas Transctions on Power System, Vol. 3, Iss.6, pp.446-455, June 2008.

[5] D. P. Hohm and M. E. Ropp, “Comparative Study of Maximum Power Point Tracking Algorithms using an experimental, programmable, maximum power point tracking test bed”, Proceedings of Photovoltaic Specialists Conference, pp.1699-1702, USA,2000.

[6] Trishan Esram and Patrick L. Chapman, “Comparison of Photovoltaic Array Maximum Power Point Tracking Techniques”, Energy Conversion, Vol.22, Iss.2, pp.439-449, May 2007.

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

[8] Castafier, Luis & Santiago Silvestre, "Modelling Photovoltaic Systems using PSpice", John Wiley & Sons Ltd, 2002.

[9] Villalva,M. Gazoli,J. and Ruppert ,E. "Modeling and Circuit-Based Simulation of Photovoltaic Arrays", IEEE Transactions on Power Electronics, Vol.24, No.5, May 2009.

[10] I. Laird, H. Lovatt, N. Savvides, "Comparative Study of Maximum Power Point Tracking Algorithms for Thermoelectric Generators", Australasian Universities Power Engineering Conference (AUPEC'08), Paper P-217, 2008.

[11] C. Larbes, S.M. Af't Cheikh, T. Obeidi, A. Zerguerras, " Genetic algorithms optimized fuzzy logic control for the maximum power point tracking in photovoltaic system", Renewable Energy, Vol. 34, Iss.19, pp.2093-2100, 2009.

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

[13] Aït,M. Cheikh,S. C.Larbes, (Septembre 2007) *Maximum power point tracking using a fuzzy logic control scheme*.