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Comparison of perturb & observe and fuzzy logic in maximum power point tracker for PV systems

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Abstract

In this paper, an intelligent control method for the maximum power point tracking (MPPT) of a photovoltaic system under variable temperature and insolation conditions is discussed. The MPPT controller for boost converter based on fuzzy logic (FLC) is developed and compared to conventional tracking algorithm (P&O). The different steps of the design of these controllers are presented together with its simulation. Results of this simulation show that the system with MPPT using fuzzy logic controller increase the efficiency of energy production from PV.

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Keywords: Maximum power point tracking (MPPT); Photovoltaic system(PV); fuzzy logic (FLC); perturb and observe (P&O);

1. Introduction

Due to the fossil fuel exhaustion and the environmental problems caused by the conventional power generation such as gasoline, coal, etc..., renewable energy sources and among them photovoltaic panels and wind-generators are now widely used [1]. Photovoltaic (PV) energy is one of the most promising renewable energy it is clean, inexhaustible and free to harvest. However, there are two main drawbacks of PV system, namely the high installation cost and the low conversion efficiency of PV modules [2]. Besides that, PV characteristics are non linear and it is very much weather dependent. Fig.1 and Fig.2 show the I-V and P-V characteristics of a typical PV module for a series of temperatures and solar irradiance levels [3, 4]. It can be noticed that PV output voltage greatly governed by temperature while PV output current has approximate linear relationship with solar irradiances.
In general, there is a unique point on the I-V or P-V curve, called the Maximum Power Point (MPP), at which the entire PV system (array, converter, etc…) operates with maximum efficiency and produces its maximum output power. However, since the MPP varies with insolation and seasons, it is difficult to maintain MPP operation at all solar insolations without changes in the system parameters. To overcome this problem an intermediate DC-DC converter is proposed. The MPP tracking is applied to PV systems in order to extract maximum available power

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from the PV array at all solar insolations. There are several methods that have been widely implemented to track the MPP. Most control schemes use the P&O technique, which is based on iterative algorithms, because it is easy to implement but the oscillation problem is unavoidable, conductance incremental method requires complex control circuit, other intelligent based control schemes have been introduced (fuzzy logic, neural network) [5].The two last methods have some disadvantages such as high cost and complexity.

In this paper, a model of a PV has been developed using Matlab/Simulink and the model of a DC-DC boost converter in a first time with a P&O controller which oscillations around the MPP in search of the maximum power point. Therefore an intelligent control technique using fuzzy logic control associated with a MPPT controller are used to improve energy conversion efficiency of the photovoltaic system.

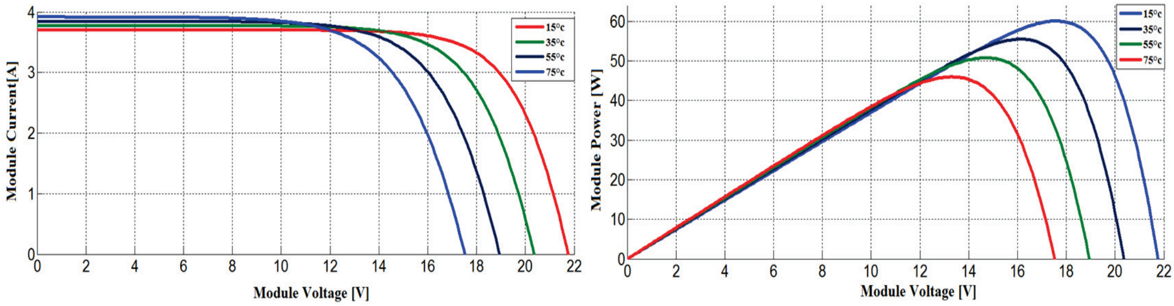


Fig. 1. I-V and P-V characteristics of a typical PV module for varied Temperatures.

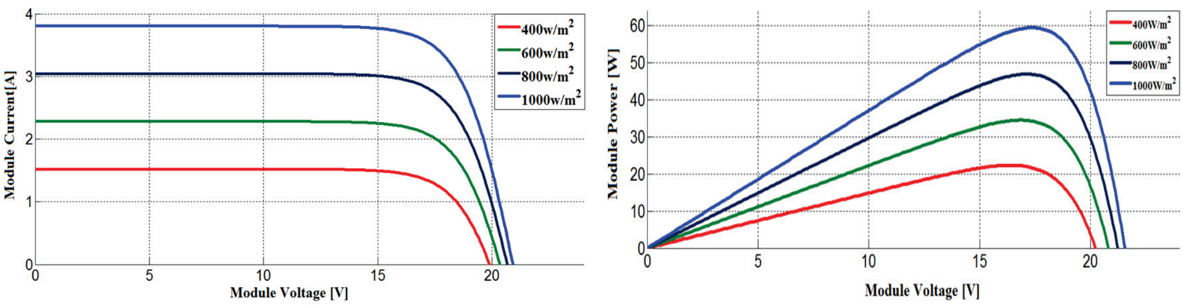


Fig. 2. I-V and P-V characteristics of a typical PV module for varied solar Irradiances.

2. Photovoltaic system

Photovoltaic cells consist of a silicon P-N junction that when exposed to light releases electrons around a closed electrical circuit. From this premise the circuit equivalent of a PV cell can be modeled through the circuit shown in Fig. 3. Electrons from the cell are excited to higher energy levels when a collision with a photon occurs. These electrons are free to move across the junction and create a current. This is modeled by the light generated current source$\boldsymbol{I_{ph}}$. The intrinsic P-N junction characteristic is introduced as a diode in the circuit equivalent [6].

The photocurrent I_{ph} generated in the PV cell is proportional to level of solar illumination, I is the output current of photovoltaic cell. , the current I_d through the diode varies with the junction voltage and the cell reverse saturation current I_s, V is the output of the photovoltaic cell, R_{sh} and R_s are the parallel and series resistances, respectively. Parallel resistance R_{sh} is very large while the series resistance R_s is small. When the number of cell in series is N_s and the number of cell in parallel is N_p. There are relevant mathematical equations expressing as following:

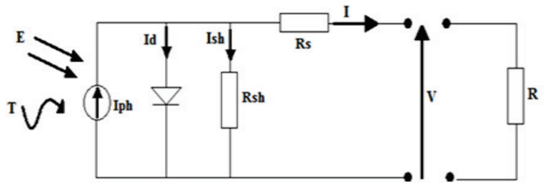


Fig. 3. Photovoltaic cell equivalent circuit.

$$I = N_p I_{ph} - N_p I_s * [\exp\left\{q\frac{(V+R_s I)}{N_s A k T}\right\} - 1] \quad (1)$$

$$I_{ph} = I_{ph}(T_{ref})[1 + a(T - T_{ref})] \quad (2)$$

$$I_{ph}(T_{ref}) = I_{sc}(T_{ref}) * \frac{E}{E_0} \quad (3)$$

$$a = \frac{I_{sc}(T_2) - I_{sc}(T_1)}{I_{sc}(T_1)} * \frac{1}{T_2 - T_1} \quad (4)$$

$$I_d = I_s * [\exp\left\{q\frac{(V+R_s I)}{AkT}\right\} - 1]\ ) \quad (5)$$

$$I_s = I_{so} * (\frac{T}{T_{ref}})^{\frac{3}{A}} * \exp[\left(-\frac{E_g}{Ak}\right) * (\frac{1}{T} - \frac{1}{T_{ref}})] \quad (6)$$

$$I_{so} = \frac{I_{sc}(T_{ref})}{(\exp\left(q\frac{V_{oc}(T_{ref})}{AkT_{ref}}\right) - 1)} \quad (7)$$

$$R_s = -\frac{dV}{dI_{V_{oc}}} - \frac{1}{X_V} \quad (8)$$

$$X_V = I_{so} * \frac{q}{AkT_{ref}} \exp\left(\frac{qV_{oc}(T_{ref})}{AkT_{ref}}\right) \quad (9)$$

The parameters of solar array (MXS60 at 25°C and 1000 W/m^2) used are given in Table 1.

Table 1. Parameter specification of MXS 60 PV module.

Parameter	Variable	Value
Maximum power	P_M	60 [W]
Maximum voltage	V_M	17. 1 [V]
Current at max power	I_M	3. 5 [A]
Open cct voltage	V_{oc}	21. 06 [V]
Short cct current	I_{sc}	3.74 [A]
Total cells in series	N_s	36
Total cells in parallel	N_p	1

Nomenclature

V	Output voltage of a PV cell [V].
I	Output current of a PV cell [A].
N_s	Number of modules connected in series.
N_p	Number of modules connected in parallel.
I_{ph}	Light generated current in a PV cell [A].
I_s	PV cell saturation current [A].
R_s	Series resistance of a PV cell [Ω].

A	Ideality factor.
B	Boltzman constant.
T	Cell temperature [Kelvin].
q	Electron charge.
T_{ref}	Reference temperature [Kelvin].
I_{sc}	PV cell short-circuit current at 25°c and 1000[w/m^2].
A	Short-circuit current temperature co-efficient at I_{sc} .
R_{sh}	Shunt resistance of a PV cell [Ω].
E	PV cell illumination [w/m^2].
I_{s0}	Saturation current at T_{ref} [A].
E_g	Band gap for silicon [eV]

3. DC – DC Boost Converter

Choppers are static DC-DC converters for generating variable DC voltage source from a fixed voltage source. The DC-DC converter consists of capacitors, inductors and switches. All of these devices in the ideal case do not consume power; this is the reason why the choppers have good yields. The switch is typically a MOSFET transistor which is a semiconductor device in mode (locked-saturated).
For a DC-DC boost converter, by using the averaging concept, the input–output voltage relationship for continuous conduction mode is given by:

$$\frac{V_o}{V_{in}} = \frac{1}{1-D} \tag{10}$$

Where, D is the duty cycle since the duty ratio "D" is between 0 and 1.
The data sheet details of the boost DC/DC converter are given in TABLE 2.

Table 2. Component values of dc to dc boost converter.

Description	Rating
L	350[μH]
C	560[μF]
R	50[Ω]

4. MPPT Algorithms

There are many MPPT algorithms have been developed and implemented by researchers [7-9]. In general, MPPT techniques can be divided into two categories, namely direct and indirect methods [2]. Direct method of MPPT algorithms is independent from prior knowledge of PV modules characteristics. The MPPT algorithms that include in this category are Perturb and Observe method (P&O), incremental conductance method (INCond), feedback voltage or current, fuzzy logic method and neural network method. Indirect method requires prior evaluation of PV generator; it is based on mathematical relationship obtained from empirical data. Methods like look-up table, open-circuit PV voltage, short circuits PV current and other MPPT algorithms are included in indirect method [2].

4.1. Perturb and Observe (P&O) Method

It is the most widely used algorithm to track the maximum power from the PV, and as the name itself states, it is based on the perturbation of the system by increasing or decreasing V_{ref} or by acting directly on the duty cycle of the DC-DC converter, and observing the effect on the output power of the panel. If the value of the current power P (k) of the panel is longer than its previous value $P(k-1)$ then we keep the same direction of disturbance if not reverses the disturbance of the previous cycle.

The P&O method has slow dynamic response, when there is a small increment in the value and low sampling rate is employed. Low increments are necessary to decrease the steady state error because the P&O always makes the operating point oscillate near the MPP. Considering that a low increment is necessary to achieve a satisfactory steady state error, the algorithm speed may be increased with a higher sampling rate. So there is always a compromise between the increment and the sampling rate in the P&O method.

The common problem in P&O algorithms is the array terminal voltage is perturbed every MPPT cycle: therefore when the MPP is reached, the output power oscillates around the maximum, resulting in power loss in the PV system. This is especially true in constant or slow-varying atmospheric conditions.

Thus, the implementation of fuzzy logic is expected to reduce the oscillation of the operating voltage and hence minimize the power loss in the PV system [10].

4.2. Fuzzy logic MPPT

Fuzzy logic was initiated in 1965 by Lotfi A. Zadeh, professor in computer science at the University of California in Berkeley. Fuzzy Logic controller (FLC) works with imprecise inputs, it does not need an accurate mathematical model and it can handle nonlinearity well. Besides, fuzzy is more robust compared to the conventional non-linear controller. The operation of fuzzy logic control can be classified into four basic elements. The four elements are fuzzification, rule base, inference engine and defuzzification.

In this study, the inputs of FLC are error, E and change in error, dE at sample time k, which are defined by (11) and (12), while the output of FLC is the duty cycle, D [11,12]. The two input variables are described by:

$$E(k) = \frac{P_{pv}(k)-P_{pv}(k-1)}{I_{pv}(k)-I_{pv}(k-1)} \tag{11}$$

$$dE(k) = E(k) - E(k-1) \tag{12}$$

Where $P_{pv}(k)$and $I_{pv}(k)$ are the power and the current of the PV module, respectively.

Fuzzification

Membership function values are assigned to the linguistic variables, using five fuzzy subsets: NB (negative big), NS (negative small), ZE (zero), PS (positive small), and PB (positive big). The partition of fuzzy subsets and the shape of membership function, which can adapt shape up to appropriate system, are shown in Fig 4.

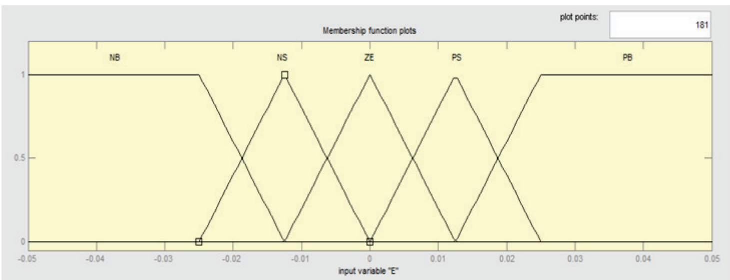


Fig. 4 (a). Membership function plots for ‘E’.

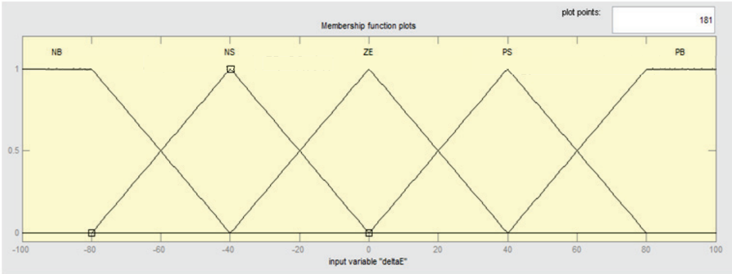


Fig. 4(b). Membership function plots for 'deltaE'.

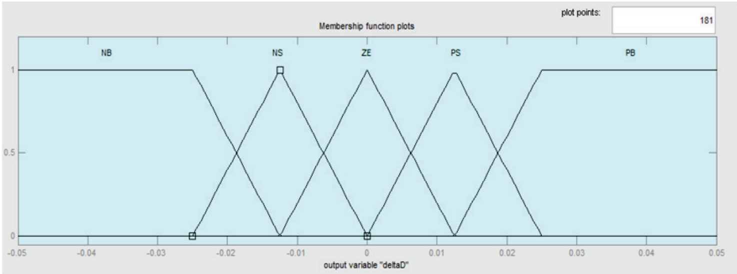


Fig. 4(c). Membership function plots for 'D'.

Inference method

Inference engine mainly consists of fuzzy rule base and fuzzy implication sub blocks. The inputs are now fuzzified are fed to the inference engine and the rule base is then applied. The output fuzzy set are the identified using fuzzy implication method. Here we are using MIN-MAX fuzzy implication method [13].

Table 3. Fuzzy inference table.

E dE	**NB**	**NS**	**ZE**	**PS**	**PB**
NB	ZE	ZE	PB	PB	PB
NS	ZE	ZE	PS	PS	PS
ZE	PS	ZE	ZE	ZE	NS
PS	NS	NS	NS	ZE	ZE
PB	NB	NB	NB	ZE	ZE

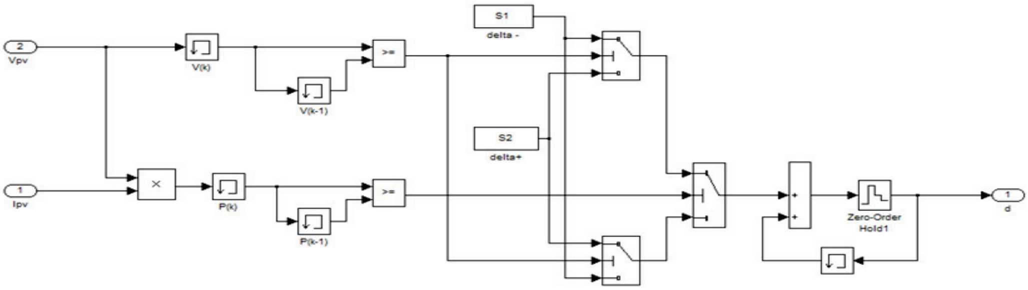
Defuzzification

For this system is the centre of gravity to compute the output of this FLC which is the duty ratio (cycle). The centre of gravity method is both very simple and very fast method. The centre of gravity defuzzification method in a system of rules by formally given by:

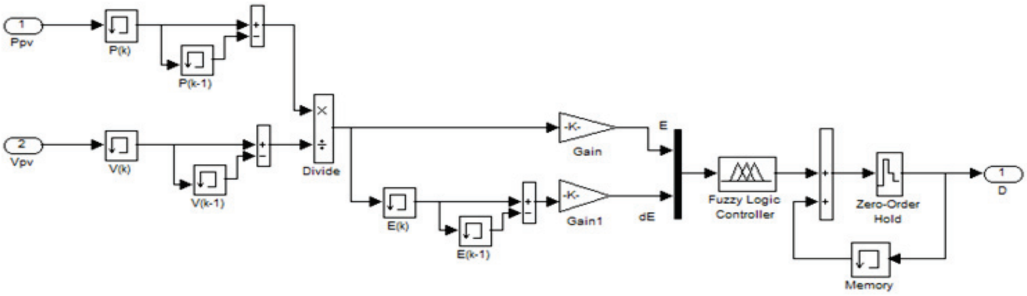
$$D = \frac{\sum_{j=1}^{n} \mu(D_j)-(D_j)}{\sum_{j=1}^{n}(D_j)} \quad (13)$$

Duty ratio, the output of fuzzy logic control uses to control through PWM which generated pulse to control MOSFET switch in DC–DC converter.

The configuration of the two MPPT algorithms perturb & observe (P&O) and fuzzy logic controller (FLC) are presented in Figure 5(a) and Figure 5(b); where the inputs are the courant and the voltage of the PV and the output is the duty cycle of the DC-DC boost converter .



(a)

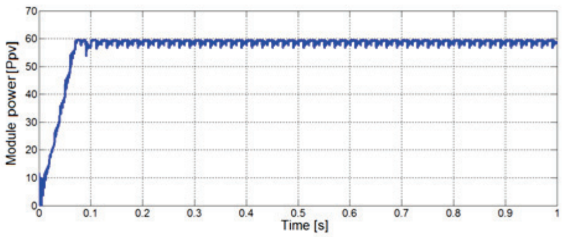


(b)

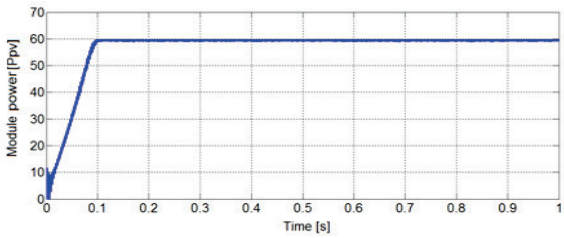
Fig.5. Configurations of MPPT algorithms in Simulink: (a) P&O MPPT algorithm, (b) FLC algorithm.

5. Simulation Results and Discussion

Fig 6. shows the PV power waveforms simulated using the Perturb and Observe (P&O) algorithm and the fuzzy logic control, respectively. The performances of P&O MPPT and fuzzy P&O MPPT have been investigated and compare at $1000[\mathrm{W/m^2}]$ and $25[°\mathrm{C}]$.



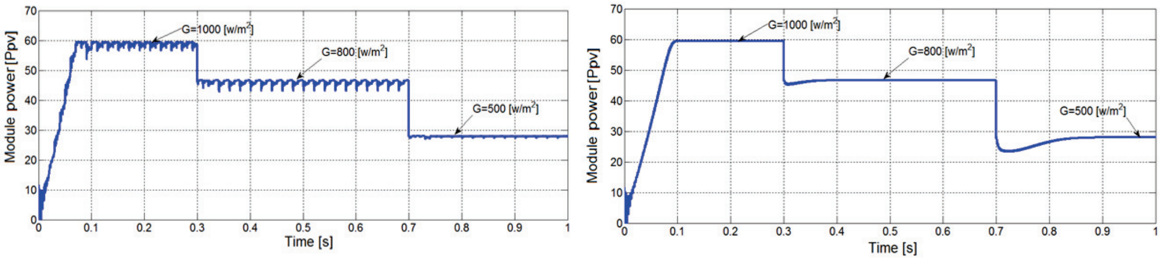
(a)



(b)

Fig.6. PV power curves generated by (a) Perturb and Observe algorithm and (b) Fuzzy Logic controller.

To highlight the proposed system good performances, the following simulation were presented for many solar irradiance values ($500[W/\mathrm{m}^2]$, $800[W/m^2]$ and $1000[W/\mathrm{m}^2]$) at fixed temperature of $25[°C]$.



(a) (b)

Fig 7. PV power curves generated by (a) Perturb and Observe algorithm and (b) Fuzzy Logic controller at temperature 25[$°C$] and solar irradiance change 1[kW/m^2], 0.8[kW/m^2] and 0.5 [kW/m^2].

From Fig. 7, it is noticed that both P&O MPPT and fuzzy logic MPPT can track the maximum power operating voltage point. For practical implementation, the FLC must be selected for its higher performance compared to the P&O controller. Hence the FLC has better performance and closed to the P&O and this is shown in Fig 7. FLC has better response time, less oscillation and much more accurate tracking at each step.

Conclusion

This paper presents P-V and I-V characteristics of MXS60 solar array, the comparison of fuzzy logic MPPT and conventional P&O MPPT have been developed to examine the performance of both controllers. In this work, the aim 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 insolation and temperature conditions. Based on the simulation it can be concluded that with the both controllers the PV panel can deliver the maximum power. However, the performance of fuzzy MPPT is better than the traditional controllers for the nonlinear systems, it has the capability of reducing perturbed voltage when MPP has been recognized. This action directly preserves a more stable output power compared to the conventional MPPT where the output power fluctuates around MPP.

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