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Fuzzy logic control of Maximum Power Point Tracking for Photovoltaic system

Youcef Soufi [#1], Mohcene Bechaouet [#1], Aziz Boukadoum[#1] , Tahar Bahi[*2]
[#1]Labget Laboratory, Department of Electrical Engineering, University of Tébessa, Algeria
[*2] Department of Electrotechnic, University of Annaba, Algeria
[1] y_soufi@yahoo.fr, mohcene.oui@gmail.com, azizboukadoum@yahoo.fr
[2]tbahi@yahoo.fr

***Abstract*— In this paper, a fuzzy logic control (FLC) based "Mamdani" is proposed to control the maximum power point tracking (MPPT) for a photovoltaic (PV) system. The proposed technique uses the fuzzy logic control to specify the size of incremental current in the current command of MPPT. As results indicated, the convergence time of maximum power point (MPP) of the proposed algorithm is better than that of the conventional Perturb and Observation (P&O) technique.**

***Keywords*— Photovoltaic system, MPPT, FLC, P&O**

I. INTRODUCTION

Fuzzy logic has been considered as an efficient and effective tool in managing uncertainties and nonlinearities of systems since Zadeh's seminal paper [1] was published. A Fuzzy Controller is generally designed in the light of experience and expert knowledge [2]. The knowledge base of a Fuzzy Logic Controller (FLC) contains two components, namely, a fuzzy rule base and a data base [3], both being closely related to the concept of a linguistic variable [4]. A rule-base, i.e., a collection of fuzzy IF–THEN rules, is used to describe a particular control strategy.

One of the most simple and popular techniques of MPPT is the Perturb & Observation P&O technique. The main concept of this method is to push the system to operate at the direction which the output power obtained from the PV system increases.

PV system cannot be modeled as a constant DC current source because its output power is varied depending on the load current, temperature and irradiation.

Generally, MPPT is adopted to track the maximum power point in the PV system. The efficiency of MPPT depends on both the MPPT control algorithm and the MPPT circuit. The MPPT control algorithm is usually applied in the DC-DC converter, which is normally used as the MPPT circuit. Typical diagram of the connection of MPPT in a PV system is shown in Fig. 1.
In this paper, we propose a comparison between P&O and a fuzzy controller for Mamdani zero-order.

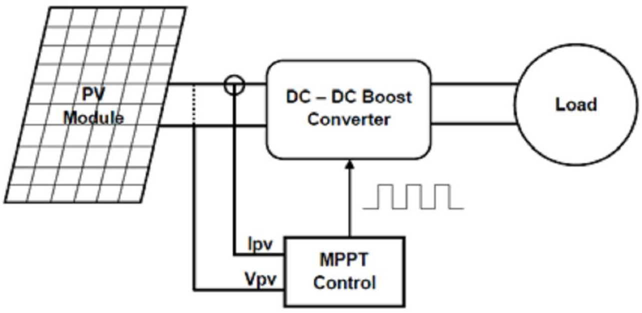

Fig. 1 Typical diagram of MPPT in a PV System

II. PHOTOVOLTAIC EQUIVALENT CIRCUIT

The model of solar cell can be categorized as p-n semiconductor junction; when exposed to light, the DC current is generated. As known by many researchers, the generated current depends on solar irradiance, temperature, and load current. The typical equivalent circuit of PV cell is shown in Fig. 2 [5].

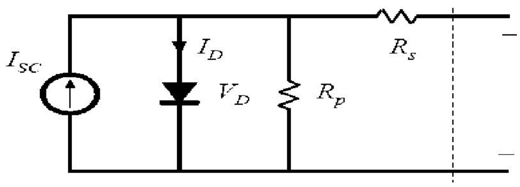

Fig. 2 Typical circuit of PV solar cell

The basic equations describing the I-V characteristic of the PV model are given in the following equations:

$$0 = I_{SC} - I_P - \frac{V_D}{R_P} - I_{PV} \quad (1)$$

$$I_D = I_0\left(e^{V_D / V_T} - 1\right) \quad (2)$$

$$V_{PV} = V_D - R_S I_{PV} \quad (3)$$

I_{PV} is the cell current (A).
I_{SC} is the light generated current (A).
I_D is the diode saturation current (A).
R_S is the cell series resistance (ohms).
R_P is the cell shunt resistance (ohms).
V_D is the diode voltage (V).
V_T is the temperature voltage (V).
V_{PV} is the cell voltage (V).

III. MPPT USING FUZZY LOGIC CONTROL

A. MPPT of PV Using Fuzzy Controller:

Maximum power point tracking system uses dc to dc converter to compensate the output voltage of the solar panel to keep the voltage at the value which maximizes the output power. MPP fuzzy logic controller measures the values of the voltage and current at the output of the solar panel, then calculates the power from the relation (P=V*I) to extract the inputs of the controller. The crisp output of the controller represents the duty cycle of the pulse width modulation to switch the dc to dc converter. Figure 6 shows the Maximum power point tracker (MPPT) system as a block diagram [6].

B. MPPT Fuzzy Logic Controller

The FLC examines the output PV power at each sample (time_k), and determines the change in power relative to voltage (dp/dv). If this value is greater than zero the controller change the duty cycle of the pulse width modulation (PWM) to increase the voltage until the power is maximum or the value (dp/dv) =0, if this value less than zero the controller changes the duty cycle of the PWM to decrease the voltage until the power is maximum as shown in Fig. 3.

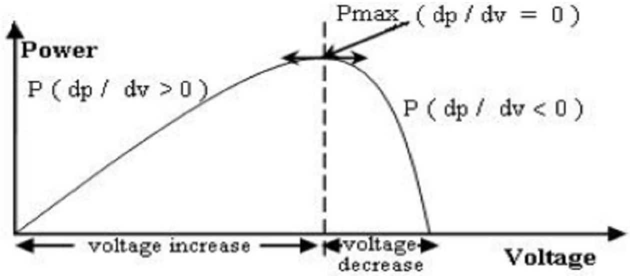

Fig. 3 Power-voltage characteristic of a PV module

FLC has two inputs which are: error and the change in error, and one output feeding to the pulse width modulation to control the DC-to-DC converter. The two FLC input variables error E and change of error CE at sampled times k defined by:

$$Error\ (k) = \frac{P(k) - P(k-1)}{V(k) - V(k-1)} \quad (4)$$

$$Change\_Error\ (k) = Error\ (k) - Error\ (k-1) \quad (5)$$

Where: $P(k)$ is the instant power of the photovoltaic generator.
The input error (k) shows if the load operation point at the instant k is located on the left or on the right of the maximum power point on the PV characteristic, while the input ***Change_Error*** expresses the moving direction of this point. The fuzzy inference is carried out by using Mamdani method, FLC for the Maximum power point tracker. FLC contains three basic parts: Fuzzification, Base rule, and Defuzzification.

1. Fuzzification

Fig.4 illustrates the fuzzy set of the ***Error*** and ***Change_Error*** inputs which Triangular memberships

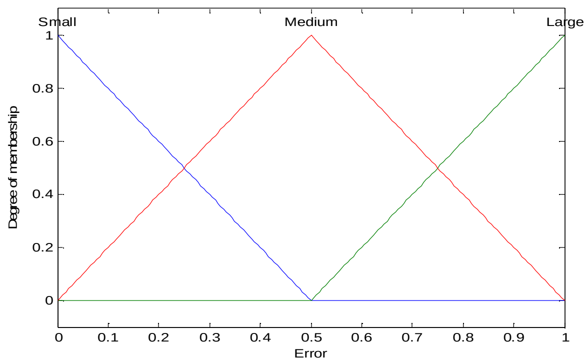

Fig.4 Membership function of inputs

Fig. 5 illustrates the fuzzy set of the ***Iref*** output which Triangular memberships

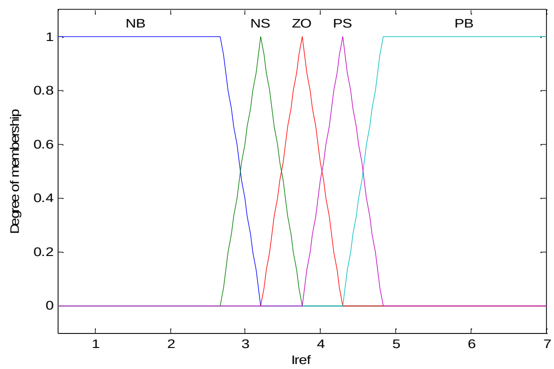

Fig.5 Membership function of output

2. Control rule base

The knowledge base defining the rules for the desired relationship is between the input and output variables in terms of the membership functions illustrated in Table 1. The control rules are evaluated by an inference mechanism, and represented as a set of:
IF Error is ... and Change of Error is ... THEN the output will …

TABLE I
FLC RULES

C_E \ E	Small	Medium	Large
Small	ZO	ZO	NS
Medium	ZO	NB	ZO
Large	ZO	NB	ZO

For example: Rule1: IF Error is ***Small*** and Change of Error is ***Small*** THEN the Iref is ***NS***.
Figure 6 shows the surface of the base rules using in FLC.

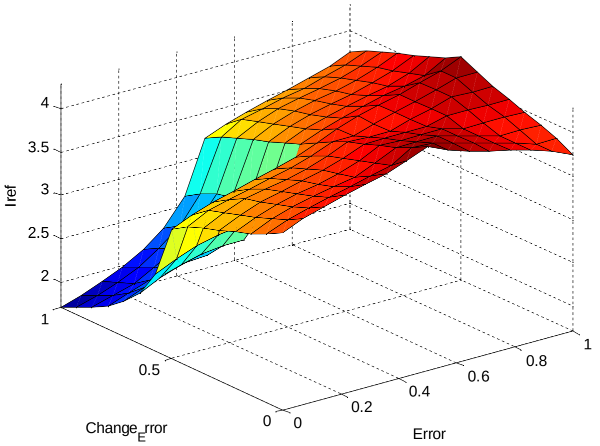

Fig. 6 Rule surface of FLC

IV. MPPT USING P&O

One of the most simple and popular techniques of MPPT is the P&O technique. The main concept of this method is to push the system to operate at the direction which the output power obtained from the PV system increases. Following equation describes the change of power which defines the strategy of the P&O technique [5].

$$\Delta P = P_K - P_{K-1} \tag{6}$$

If the change of power defined by (6) is positive, the system will keep the direction of the incremental current (increase or decrease the PV current) as the same direction, and if the change is negative, the system will change the direction of incremental current command to the opposite direction. This method works well in the steady state condition (the radiation and temperature conditions change slowly). However, the P&O method fails to track MPP when the atmospheric condition is rapidly changed. Flow chart of the P&O method is described in Fig. 7.

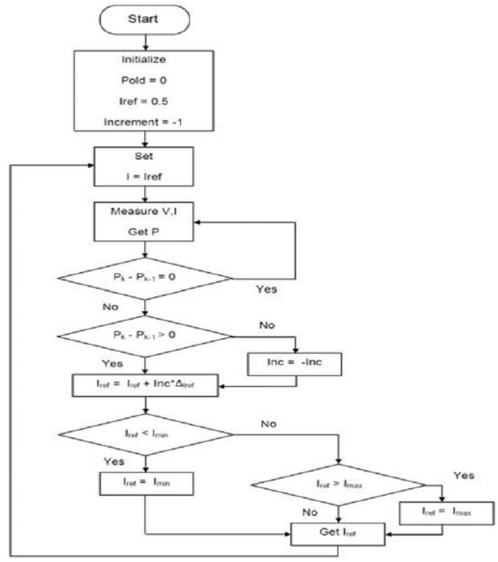

Fig.7 Flow Chart of the P&O Method.

V. MODEL OF THE SYSTEM

The proposed Fuzzy Logic Control and P&O based MPPT has been modelled and simulated using **MATLAB/Simulink**. Fig.8 shows our developed ***Simulink*** model. In the simulation study, the fuzzy logic based MPPT control and P&O is simulated and under the operating condition assuming the constant temperature and constant isolation (1000 W/m2). The MPPT control consists of two main parts, FLC and current control, as depicted in Fig. 8. The specifications of PV module used in this simulation are shown in Table 2.

Short Circuit Current	7.8 A
Open Circuit Voltage	21 V
Current at Pmax	6.72A
Volt at Pmax	12.7V

TABLE 2 THE SPECIFICATION OF PV MODULE USED IN THE SIMULATION

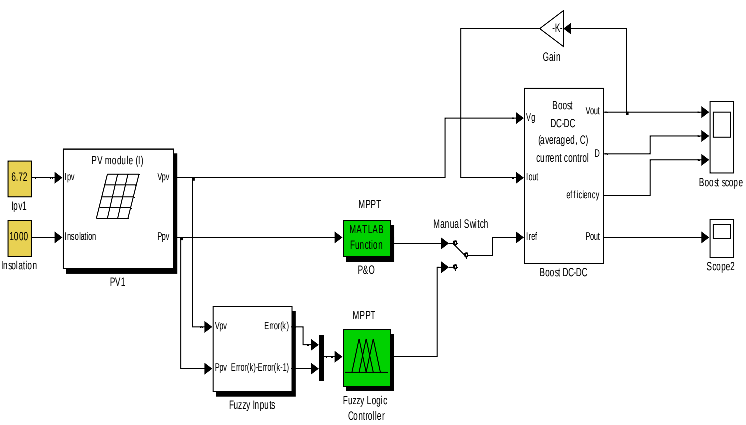

Fig. 8 Model of the developed PV System in MATLAB/Simulink

VI. RESULTS AND SIMULATION

The performance of MPPT using the FLC and the simple P&O techniques is verified by operating them under the variation of irradiance.

Fig. 8 shows the transient responses of the tracking power curves obtained from both control algorithms.

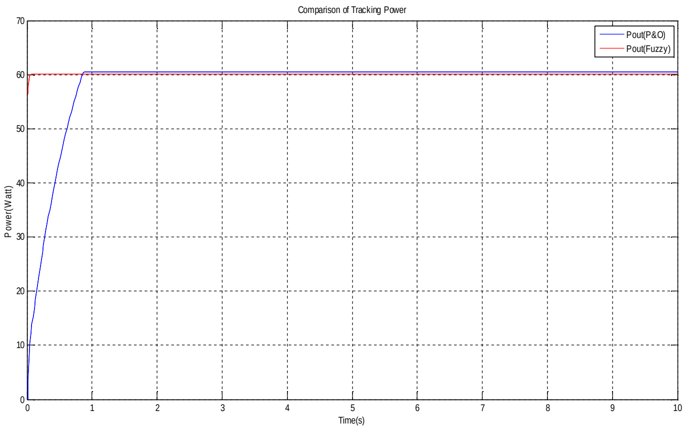

Fig. 8 Tracking curves by the FLC and P&O Methods

Fig. 9 shows the duty cycle used P&O

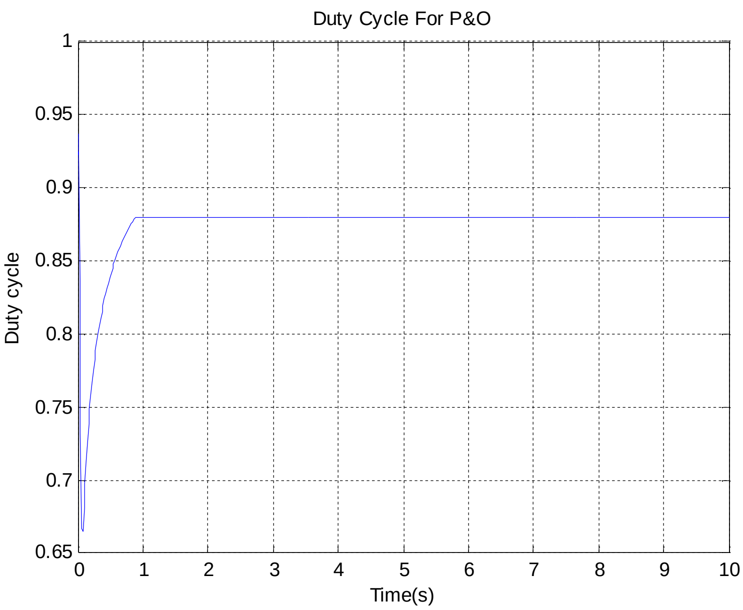

Fig. 9 Duty cycle used P&O

Fig. 10 shows the duty cycle used Fuzzy

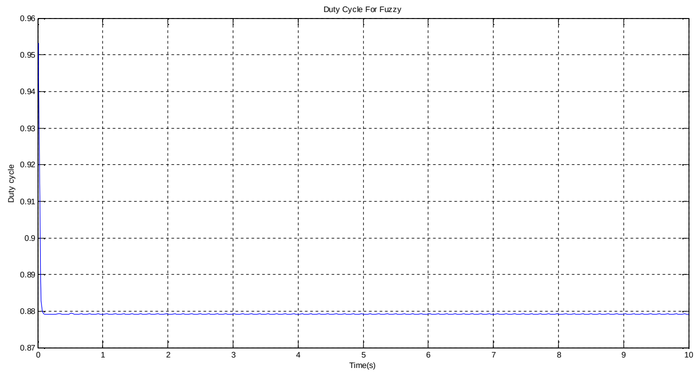

Fig. 10 Duty cycle used Fuzzy

VII. CONCLUSION

This paper presents an intelligent control strategy of MPPT for the PV system using the FLC and P&O. Simulation results show that the proposed fuzzy can track the MPP faster when compared to the P&O. In conclusion, the proposed MPPT using fuzzy logic can improve the performance of the system.

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