Maximum power point tracking using a fuzzy logic control scheme

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Abstract - *This paper proposes an intelligent control method for the maximum power point tracking (MPPT) of a photovoltaic system under variable temperature and insolation conditions. This method uses a fuzzy logic controller applied to a DC-DC converter device. The different steps of the design of this controller are presented together with its simulation. Results of this simulation are compared to those obtained by the perturbation and observation controller. They show that the fuzzy logic controller exhibits a much better behaviour.*

Résumé – *Cet article propose une méthode de contrôle intelligent pour la recherche du point de puissance maximum (MPPT) d'un système photovoltaïque dans des conditions variables de la température et d'insolation. Cette méthode emploie un contrôleur de logique floue appliqué à un dispositif de convertisseur de DC-DC. Les différentes étapes de la conception de ce contrôleur sont présentées, ainsi que sa simulation. Des résultats de cette simulation sont comparés à ceux obtenus par le contrôleur de perturbation et d'observation. Ils prouvent que le contrôleur de logique floue montre un comportement bien meilleur.*

Keywords: MPPT - Fuzzy logic - Photovoltaic system - DC-DC converter.

1. INTRODUCTION

Due to energy crisis and environmental issues such as pollution and global warming effect, photovoltaic (PV) systems are becoming a very attractive solution. Unfortunately the actual energy conversion efficiency of PV module is rather low. So to overcome this problem and to get the maximum possible efficiency, the design of all the elements of the PV system has to be optimised.

In order to increase this efficiency, MPPT controllers are used. Such controllers are becoming an essential element in PV systems. A significant number of MPPT control schemes have been elaborated since the seventies, starting with simple techniques such as voltage and current feedback based MPPT to more improved power feedback based MPPT such as the perturbation and observation (P&O) technique or the incremental conductance technique [1-3]. Recently intelligent based control schemes MPPT have been introduced.

In this paper, an intelligent control technique using fuzzy logic control is associated to an MPPT controller in order to improve energy conversion efficiency.

2. PRINCIPLE OF MAXIMUM POWER POINT TRACKING CONTROL

The photovoltaic module operation depends strongly on the load characteristics, (Fig. 1 and 2) to which it is connected [4, 5]. Indeed, for a load, with an internal resistance R_i, the optimal adaptation occurs only at one particular operating point, called Maximum Power Point (MPP) and noted in our case P_{max}.

Thus, when a direct connection is carried out between the source and the load, (Fig. 1), the output of the PV module is seldom maximum and the operating point is not optimal.

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To overcome this problem, it is necessary to add an adaptation device, MPPT controller with a DC-DC converter, between the source and the load, (Fig. 3), [3].

Furthermore the characteristics of a PV system vary with temperature and insolation, (Fig. 4 and 5) [6, 7]. So, the MPPT controller is also required to track the new modified maximum power point in its corresponding curve whenever temperature and/or insolation variation occurs.

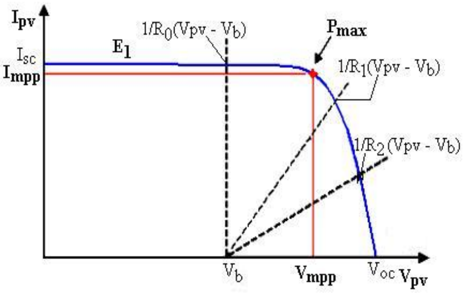

Fig. 1: Current-voltage characteristic of a PV module

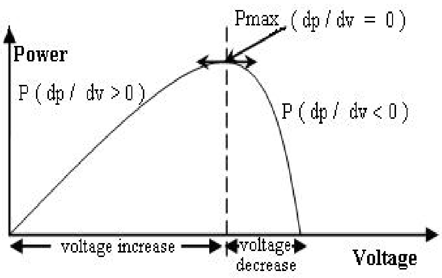

Fig. 2: Power-voltage characteristic of a PV module

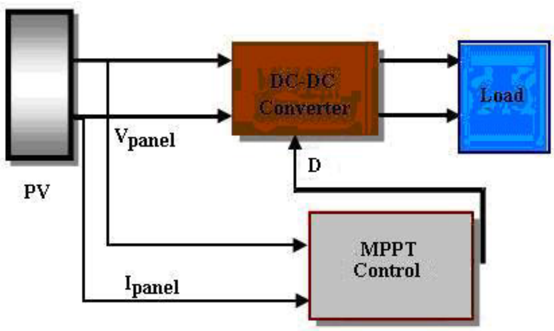

Fig 3: Photovoltaic system

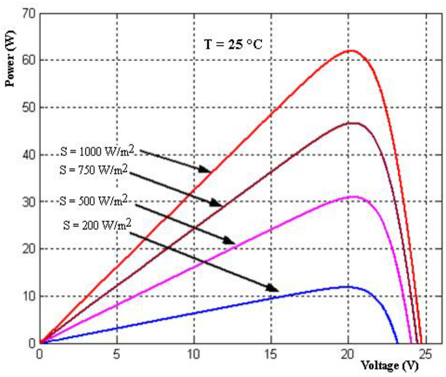

Fig. 4: Influence of the solar radiation for constant temperature

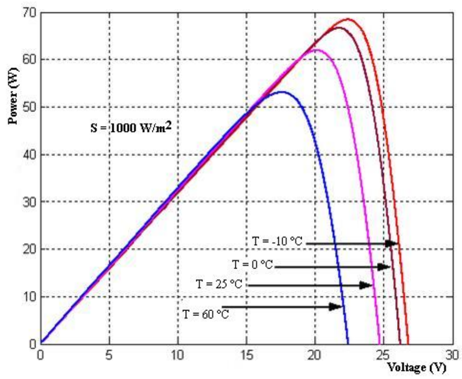

Fig. 5: Influence of the temperature of junction for constant insolation

Many MPTT control techniques have been conceived for this purpose these last decades [1, 2]. They can be classified as:

- Voltage feedback based methods which compare the PV operating voltage with a reference voltage in order to generate the PWM control signal of the DC-DC converter [8],

- Current feedback based methods which use the PV module short circuit current as a feedback in order to estimate the optimal current corresponding to the maximum power.

- Power based methods which are based on iterative algorithms to track continuously the MPP through the current and voltage measurement of the PV module. In this category, one of the most successful and used method is perturbation and observation (P&O), which is presented in the next section.

3. P&O CONTROLLER

This controller is introduced briefly here [9-11].

The principle of this controller is to provoke perturbation by acting (decrease or increase) on the PWM duty cycle and observing the effect on the output PV power. If the instant power $P(k)$ is greater than the previous computed power $P(k-1)$, then the direction of perturbation is maintained otherwise it is reversed. Referring to figure 2 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 : incrementation step),

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

To simulate this P&O algorithm, a boost chopper, as a DC-DC converter which is described by the equations (1), (2) and (3), (Fig. 6), is used.

$$i_1 = i - C_1 \frac{dv}{dt} \tag{1}$$

$$i_b = (1-D)\, i_1 - C_2 \frac{dv_b}{dt} \tag{2}$$

$$v = (1-D)\, v_b + L \frac{di_1}{dt} \tag{3}$$

The parameter D indicates the duty cycle of this chopper, which is the closing time of the switch over one period.

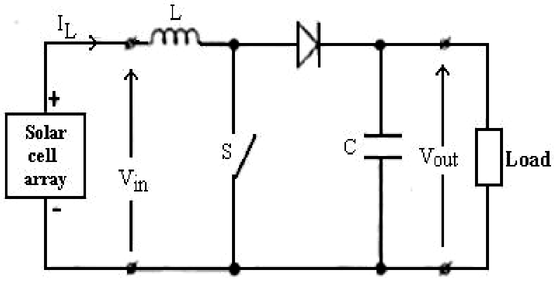

Fig. 6: Basic circuit of the boost chopper

Results of simulation for different tests obtained with the P&O algorithm are presented and compared to those obtained with the fuzzy logic MPPT controller in section 5.

4. FUZZY LOGIC MPPT CONTROLLER

Recently fuzzy logic controllers have been introduced in the tracking of the MPP in PV systems [12-14]. They have the advantage to be robust and relatively simple to design as they do not require the knowledge of the exact model. They do require in the other hand the complete knowledge of the operation of the PV system by the designer.

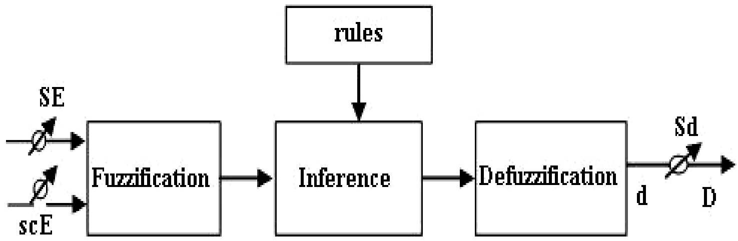

Fig. 7: General diagram of a fuzzy controller

The proposed FL MPPT Controller, shown in Figure 7, has two inputs and one output.

The two FLC input variables are the error E and change of error CE at sampled times k defined by:

$$E(k) = \frac{P_{ph}(k) - P_{ph}(k-1)}{V_{ph}(k) - V_{ph}(k-1)} \tag{4}$$

$$CE(k) = E(k) - E(k-1) \tag{5}$$

where $P_{ph}(k)$ is the instant power of the photovoltaic generator.

The input $E(k)$ 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 $CE(k)$ expresses the moving direction of this point.

The fuzzy inference is carried out by using Madani's method, (**Table 1**), and the defuzzification uses the centre of gravity to compute the output of this FLC which is the duty cycle:

$$D = \frac{\sum_{j=1}^{n} \mu(D_j) - D_j}{\sum_{j=1}^{n} \mu(D_j)} \tag{6}$$

The control rules are indicated in **Table 1** with E and CE as inputs and D as the output.

Table 1: Fuzzy rule table

E ↓ \ CE →	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

These two variables and the control action D for the tracking of the maximum power point are illustrated in figure 8 [7].

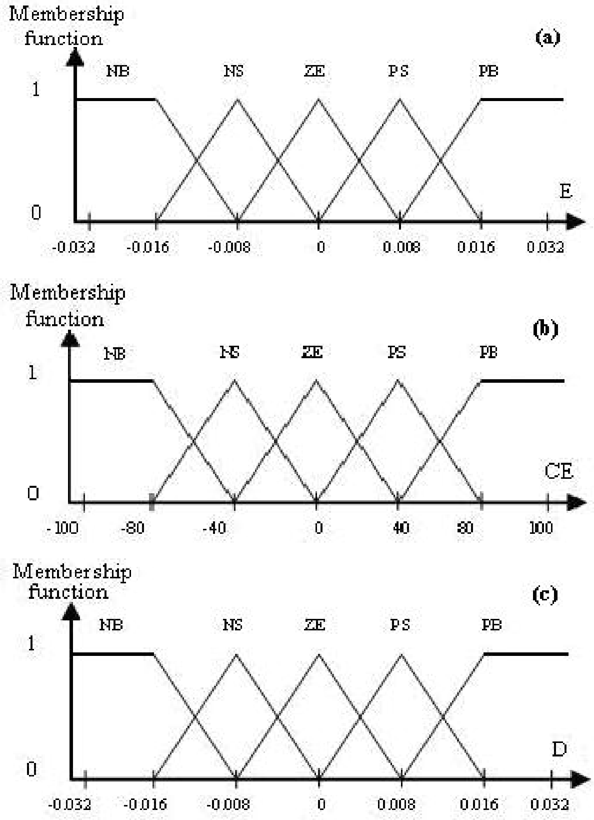

Fig. 8: Membership functions of
(a) error E - (b) change of error CE - (c) duty ratio D

5. SIMULATION OF THE P&O AND FUZZY LOGIC MPPT CONTROLLERS AND RESULTS

Figure 3 shows the functional diagram of the simulated photovoltaic system. The DC-DC converter is the boost chopper of figure 6. The previous MPPT controllers P&O and FLC were simulated under the following tests:

- Constant temperature with a rapid and slow increase in the insolation from 500 to 1000 W/m^2;
- Constant temperature with a rapid and slow decrease in the insolation from 1000 to 800 W/m^2;
- Constant insolation with a rapid and slow increase in the temperature from 20°C to 30°C;
- Constant insolation with a rapid and slow decrease in the temperature from 40°C to 20°C.

Figures 9 to 17 show the respective results of these tests.

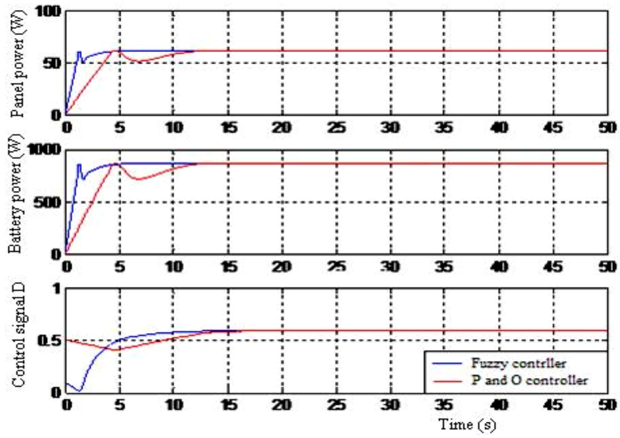

Fig. 9: Variation of the panel power, battery power and the duty ratio D, under standard conditions: temperature (25 °C) and solar insolation (1000 W/m^2)

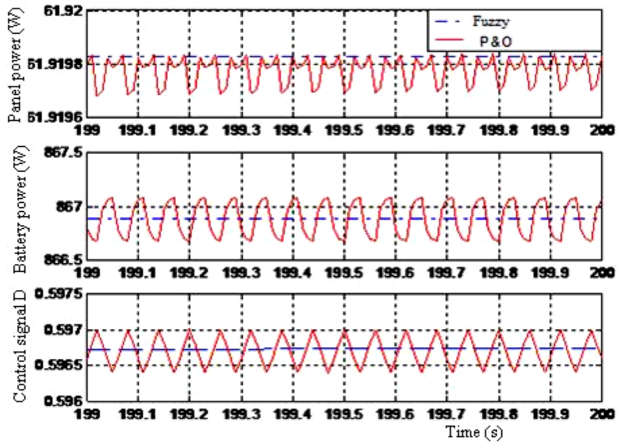

Fig. 10: Wave shape in steady state of the panel and battery power and of the duty ratio signals for a sampling rate of 100 Hz (T = 25 °C and S = 1000W/m^2)

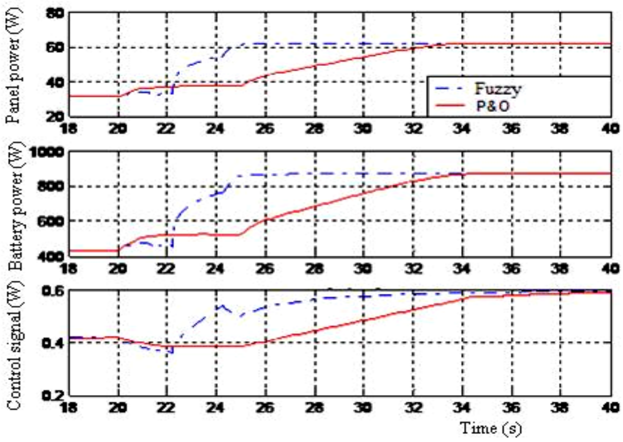

Fig. 11: Fuzzy and P&O controller responses:
for a fast solar insolation increase (500 W/m^2 to 1000 W/m^2 in 5 s at 25 °C)

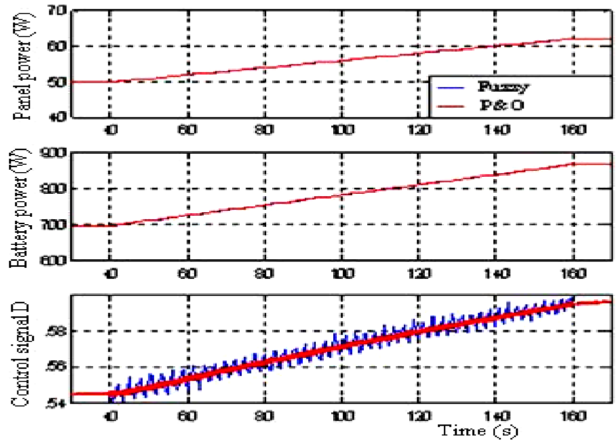

Fig. 12: Fuzzy and P&O controller responses: for a slow (120 s) solar insolation increase (800 W/m^2 to 1000 W/m^2 at 25 °C)

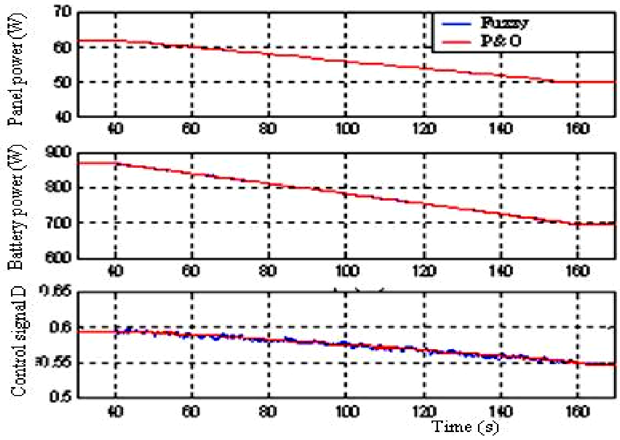

Fig. 13: Fuzzy and P&O controller responses: for a slow (120 s) solar insolation decrease (1000 W/m^2 to 800 W/m^2 at 25 °C)

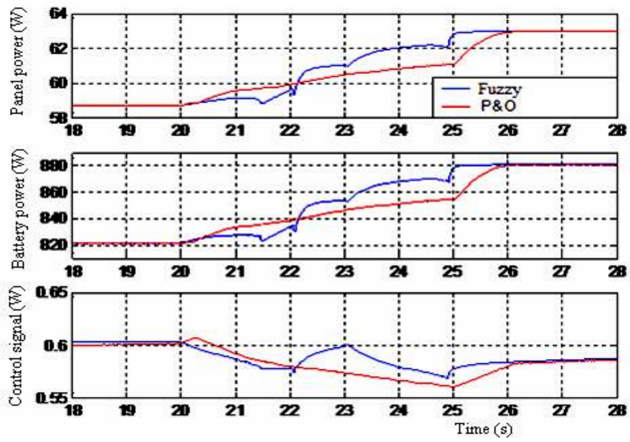

Fig. 14: Fuzzy and P&O controller responses: for a fast temperature decrease (40 °C to 20 °C) at 1000 W/m^2 of solar insolation

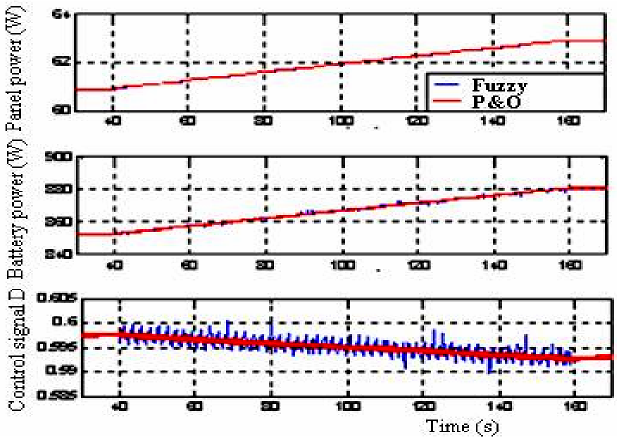

Fig. 15: Fuzzy and P&O controller responses: for a slow (120 s) temperature increase (20 °C to 30 °C) at 1000 W/m^2 of solar insolation

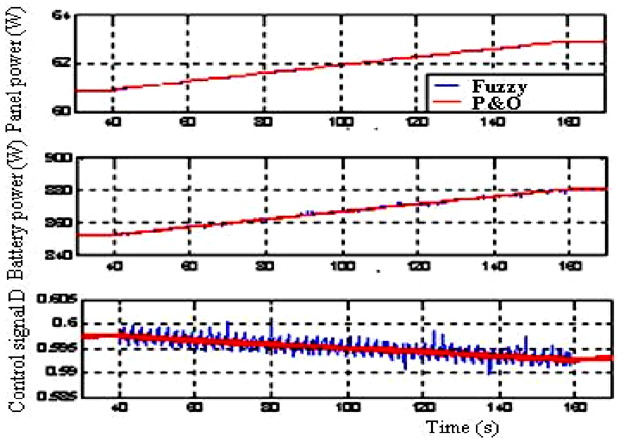

Fig. 16: Fuzzy and P&O controller responses: for a slow (120 s) temperature decrease (30°C to 20°C) at 1000 W/m^2 of solar insolation

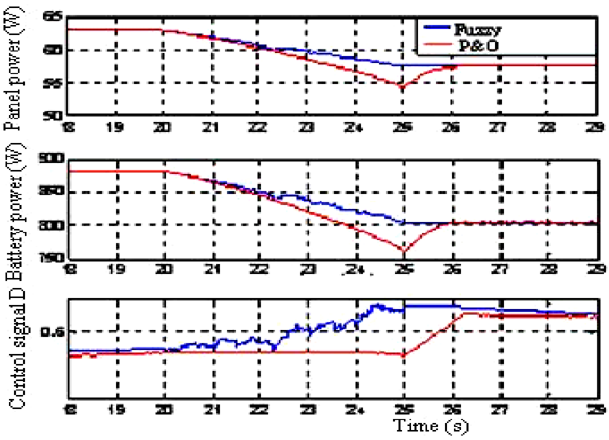

Fig. 17: Fuzzy and P&O controller responses: for a fast (5 s) temperature increase (20 °C to 45 °C) at 1000 W/m^2 of solar insolation

6. CONCLUSION

Obviously, it can be deduced that the fuzzy controller is faster than the P&O controller in the transitional state (Fig. 11, 13, 14, 17), and presents also a much smoother signal with less fluctuations in steady state (Fig. 10).

In this work, the aim was to control the voltage of the solar panel in order to obtain the maximum power possible from a PV generator, whatever the solar insolation and temperature conditions.

Since quite a few control scheme had already been used and had shown some defects, it was necessary to find and try some other methods to optimize the output, fuzzy logic controller seemed to be a good idea.

The controllers by fuzzy logic can provide an order more effective than the traditional controllers for the nonlinear systems, because there is more flexibility.

A fast and steady fuzzy logic MPPT controller was obtained. It makes it possible indeed to find the point of maximum power in a shorter time runs compared to the well known P&O controller.

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