Maximum power control for photovoltaic system using intelligent strategies

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ABSTRACT

The power supplied by photovoltaic DC–DC converter is affected by two factors, sun irradiance and temperature. Therefore, to improve the performance of the PV system; a mechanism to track the maximum power point (MPP) is required. Conventional maximum power point tracking approaches, such as observation and perturbation technique present some difficulties in identifying the true MPP. Therefore, intelligent systems including fuzzy logic controllers (FLC) are introduced for the maximum power point tracking system (MPPT). In this paper, we present a comparative study of the PV standalone system which is controlled by three techniques. The first one is conventional based on the observation and perturbation technique, the other are intelligent based on fuzzy logic according Mamdani and Takagi-Sugeno models. The investigations show that the fuzzy logic controllers provide the best results and Takagi-Sugeno model presents the lower overshoot value.

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1. INTRODUCTION

Solar energy is inexhaustible, free and clean and it is considered as the core of renewable energy (RE) in the recent times primarily because of running down of fossil fuels. Among various RE resources, photovoltaic (PV) system plays a very important role either in grid-connected or islanding configurations. However, the PV systems generate intermittent power under fluctuating weather which is the main issue that must be taken in consideration [1], [2]. The power-voltage and current–voltage characteristics are responsible for the power generated from the PV cell. Therefore, to work the PV generation at its peak; the MPPT mechanism is highly significant in PV system [3]-[6]. Numerous MPPT mechanisms have been introduced by many scholars since year 1960. Some well-known MMPT methods are incremental conductance (IC) method, perturb and observe (P&O) method and constant voltage (CV) method [7]-[9]. The method of P&O was extensively used due to its simple control method as well as the minimum number of its input parameters. However, the use of this algorithm leads to a loss in power due to an enormous oscillation in the area of maximum power point (MPP). Others, like IC methods have been proposed by some researchers [7], [8], which somehow could eliminate the oscillations in the area of the MPP. However, this kind of methods need good and accurate sensor to measure either voltage or current. Recently, the MPPT-based Artificial intelligence (AI) is widely used in PV converter with great dynamics and high effectiveness. Various intelligent methods including fuzzy logic and artificial neural network (ANN) have been mentioned in the literature. The fuzzy logic controllers are widely used for the MPP tracking [7]. They are independent of process model, which present an ability to apprehend the problems of nonlinearity and have robust performance to the atmospheric conditions changes. The two most important types of fuzzy inference method are Mamdani's fuzzy inference method and T-S method. In this study, the MPPT is developed using three different techniques to assess their performances. This paper is organized as follows. The description and modeling of the PV system is mentioned in section 2. MPPT based on Perturb and observe (P&O) algorithm is described in section 3. MPPT based on fuzzy logic is explained in section 4. The simulation and results analysis are discussed in section 5. Finally, the conclusion is exposed in section 6.

2. DESCRIPTION AND MODELING OF THE PV SYSTEM

The block diagram of the proposed standalone PV system as shown in Figure 1. The system consists of a PV array (BP Solar SX 150S), a MPPT controller combined to a DC- DC converter (Boost) and a load (resistance).

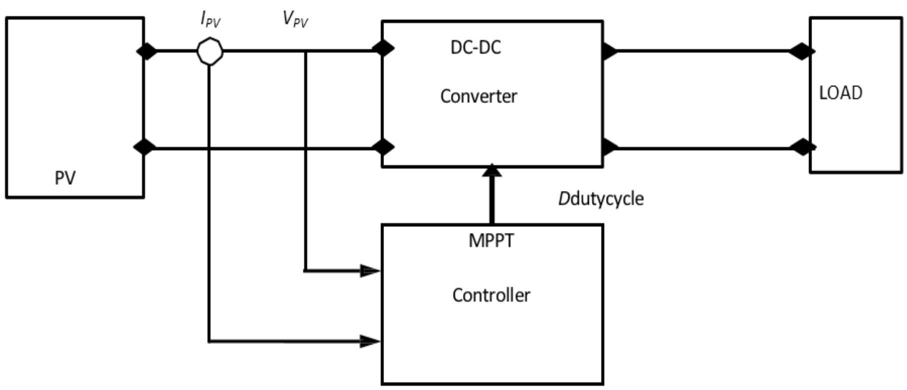


Figure 1. Block diagram of the global PV system

The G and T are in charge of the working point of PV system at the MPP [13], [14]. The cell current, I, which represent the mathematical model of the PV cell can be express as [15]:

$$I = I_{ph} - I_0\left(e^{\left(\frac{q(V+IR_s}{A.K_cT}\right)} - 1\right)\frac{V + IR_s}{R_{sh}} \quad (1)$$

Where Iph is light-generated cell current (A), I_0 is cell reverse saturation current (A), q is electronic charge, A is ideality factor, Kc is Boltzmann's constant, and T is cell temperature (K). According to the equation above, the output power varies according to G (irradiance) and T. The mathematical model can be used to determine the cell output current. Figures below show the electrical characteristics under varying weather G and T of the BP Solar SX 150S according its characteristics as shows in Table 1.

Table 1. PV module characteristics

PV module	BP Solar SX 150S
Maximum power (Pmax)	150 W
Voltage at Pmax (Vmp)	34.5 V
Current at Pmax (Imp)	4.35 A
Open circuit voltage (Voc)	43.5 V
Short circuit current (Isc)	4.75 A
Temperature coefficient of Isc	0.065±0.015%/°C
Temperature coefficient of Voc	-160±20 mV/°C
Temperature coefficient of power	-0.5±0.05%/°C
NOCT	47±2°C

At constant temperature 25°C shows in Figure 3 and Figure 5, the increase in irradiance value leads to an increase in maximum power and a minor increase in open circuit voltage, while the short circuit current varies significantly. This implies that the optimal power generator is almost proportional to the illumination. With a constant irradiation is shown in Figure 2 and Figure 4, the open circuit voltage decreases notably with increasing temperature and the maximum power too. For this case, we can deduce that the voltage changes significantly while the current remains constant. To get a maximum power, it is important to work in the area of MPP of the PV generator. In the next sections, we will compare conventional and intelligent strategies which track the MPP of the PV generator.

BP SX 150S Photovoltaic Module I-V

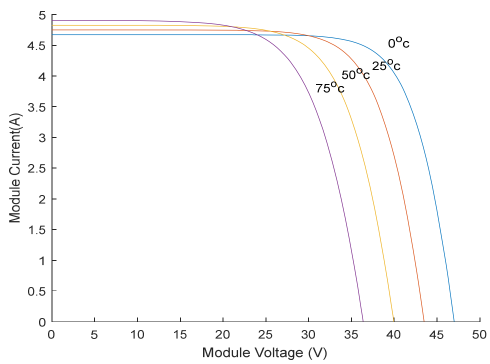


Figure 2. I-V curves at various temperatures

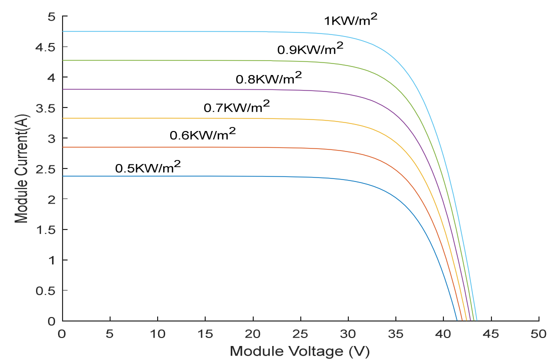


Figure 3. I-V curves at various radiations

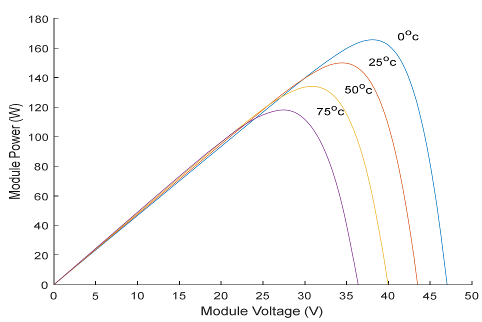


Figure 4. P-V curves at various temperatures

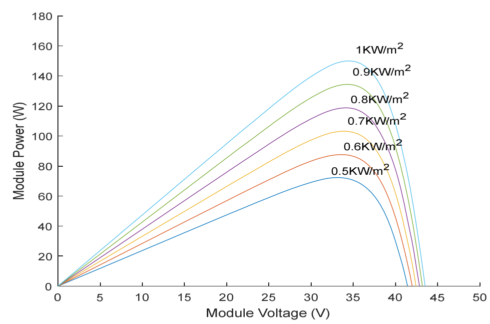


Figure 5. P-V curves at various radiations

3. MPPT BASED ON P&O ALGORITHM

P&O algorithm are widely used in MPPT because of their simple structure and their few measured parameters which are required. As its name indicates, it is based on the system perturbation by increasing or decreasing of VPV, then observing the effect on the output power of the panel. If the current value of the power PPV(k) of the panel is greater than the previous value PPV(k-1) then the direction of perturbation is maintained otherwise it is reversed. With this algorithm the operating voltage VPV is perturbed at each cycle of the MPPT. When the MPP is reached, VPV oscillates around the maximum power point which causes system power losses, depending on the step width of a simple perturbation. If the step width is large, the P&O algorithm will respond quickly to rapid changes in operating conditions with increasing oscillation around the MPP under stable or slowly changing conditions. If the step width is smaller the oscillation around the MPP will be reduced but the system will respond slowly to sudden changes in atmospheric conditions [16], [17].

4. MPPT BASED ON FUZZY LOGIC

Fuzzy logic controller (FLC) is a nonlinear control method. Hence, it can be easily applied for nonlinear characteristics of PV system to track maximum power point. FLC is operated using membership functions instead of mathematical model [13].

4.1. Fuzzy MPPT based on mamdani's inference

Conventional methods of tracking the optimal point of operation have shown their limits to sudden changes of weather and the load connected to the panel, several methods have emerged to try to alleviate these shortcomings and improve the operation of these generators. The approach of Artificial Intelligence in the case of fuzzy logic is implemented to improve control performance and the pursuit of maximum power point by simulation and modeling of a controller based on fuzzy logic [17]. The advent of microcontrollers has enabled the spread of fuzzy control in the pursuit of optimal point during the last decade. The fuzzy controller has the following three blocks: Fuzzification of input variables by using the trapezoidal functions, then these fuzzified variables are compared with pre-defined packages to determine the appropriate response. And finally, the defuzzification converts the obtained area according to fired rules to crisp value which controls the plant. Mamdani's fuzzy inference method is the most commonly seen fuzzy methodology. Mamdani's method was among the first control systems built using fuzzy set theory. It was proposed by Mamdani (1975) as an attempt to control a steam engine and boiler combination by synthesizing a set of linguistic control rules obtained from experienced human operators. Mamdani's effort was based on Zadeh's (1973) paper on fuzzy algorithms for complex systems and decision processes. In this work, each linguistic variable of the fuzzy MPPT controller has five linguistic values: NB (Negative Big), NS (Negative Small), Z (Zero Approximately), PS (Positive Small), PB (Positive Big). The two FLC input variables are the error E and change of error CE at sampled times k defined by:

$$E(k) = \frac{P(k) - P(k-1)}{V(k) - V(k-1)} \tag{2}$$

$$CE(k) = E(k) - E(k-1) \tag{3}$$

Where P(k) is the instantaneous power of the PV 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 Mamdani's inference shows in Table 2, and the defuzzification uses the centre of gravity to compute the output of this FLC which is the duty cycle:

$$d\alpha = \frac{\sum_{j=1}^{n} \left(d\alpha_j \right) - d\alpha_j}{\sum_{j=1}^{n} \mu(d\alpha_j)} \tag{4}$$

Table 2. Fuzzy rules table of mamdani's inference

E/CE	NB	NS	Z	PS	PB
NB	PB	PB	PS	PB	PB
NS	PS	PS	PS	PS	PB
Z	NS	NS	Z	PS	PS
PS	NB	NS	NS	NS	NB
PB	NB	NB	NS	NB	NB

4.2. Fuzzy MPPT based on takagi-sugeno's inference

This method was introduced by Sugeno (1985). The main difference between Mamdani and Takagi Sugeno is that the TS output membership functions are either linear function or constant. Also the difference lies in the consequences of their fuzzy rules, and defuzzification procedures.

A typical rule in a Sugeno fuzzy model has the form :

IF Input 1 = x AND Input 2 = y, THEN Output is z = ax + by + c.

For a zero-order Sugeno model, the output level z is a constant (a = b = 0).The output level zi of each rule is weighted by the firing strength wi of the rule. For example, for an AND rule with Input 1 = x and Input 2 = y, the firing strength is:

$$w_i = AndMethod \quad (F_1(x), F_2(y))$$

Where, F1,2(·) are the membership functions for Inputs 1 and 2. The final output of the system is the weighted average of all rule outputs, computed as (5):

$$Final \quad output = \frac{\sum_{i=1}^{N} w_i z_i}{\sum_{i=1}^{N} w_i} \qquad (5)$$

In this work, the fuzzy MPPT based on Sugeno's inference has been implemented according to the fuzzy rule table below.

Table 3. Fuzzy rules table of Sugeno's inference

E/CE	NB	NS	PS	PB
NB	PB	PB	NB	NB
NS	PS	PS	NS	NS
PS	PS	PS	NS	NS
PB	NB	NS	PS	PB

The two inputs Error And change of error have the same membership functions as shown in Figure 6:

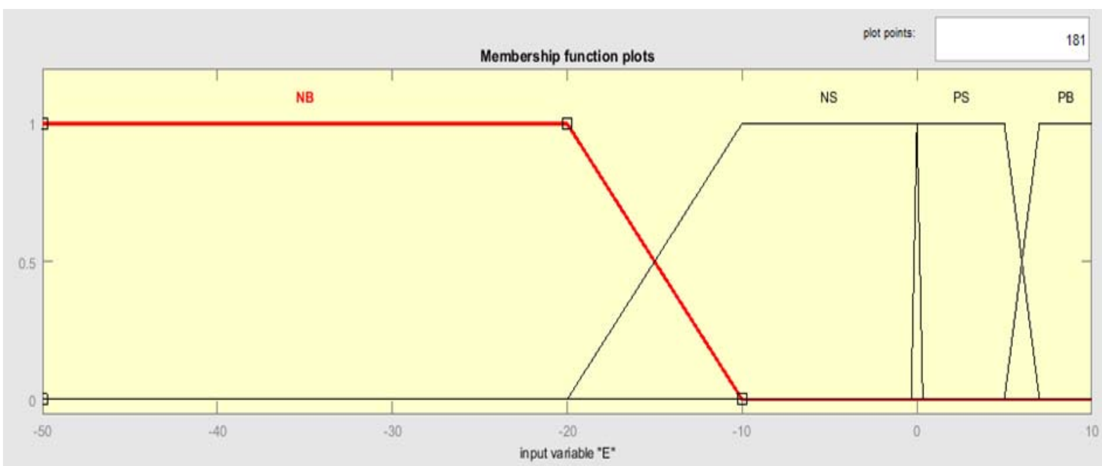


Figure 6. Input error and change of error membership functions

And the output's singletons are respectively as below: NB = -0.08, NS = -0.04, PS = 1, PB = 2.

5. SIMULATION AND RESULTS ANALYSIS

BP Solar SX 150S PV module is chosen for the simulation which has the characteristics above.

The simulation has been done under Matlab/Simlink as shown in Figure 7:

The simulated system has four main blocks: the PV module (BP Solar SX 150S), the MPPT controller which is based on P&O, Mamdani's, and sugeno's model at each simulation, PWM generator, and DC-DC boost converter. The comparison is done under G = 1000 KW/m2 and T = 25 °C.

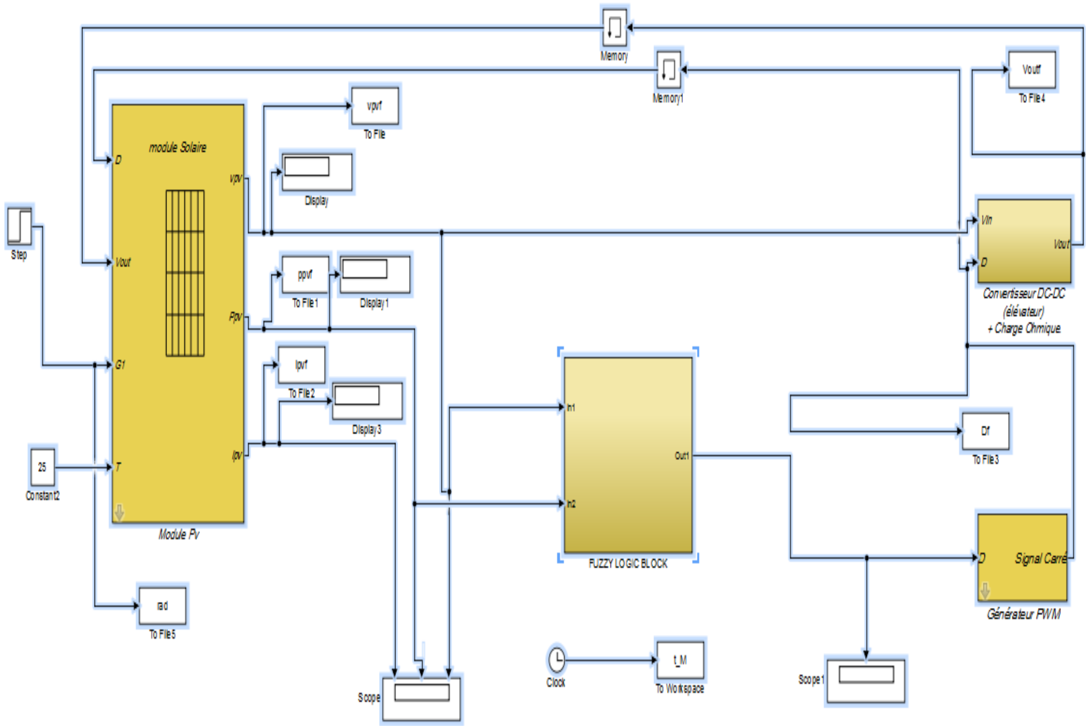
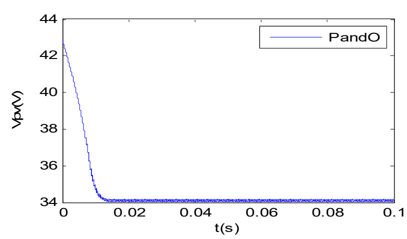


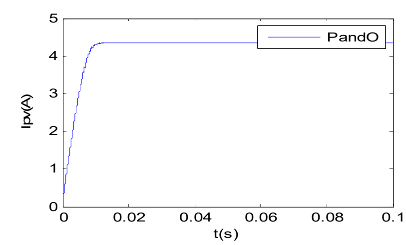
Figure 7. Layout of the simulated system

5.1. MPPT based on P&O algorithm results

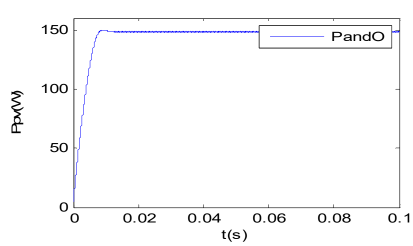
On Figure 8 the obtained results of the P&O algorithm show that the PV voltage is equal to 34 V and the output power on Figure 8 (c) presents a small overshoot.



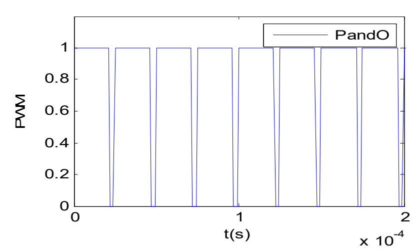
(a)



(b)



(c)

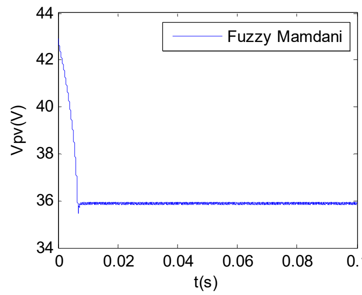


(d)

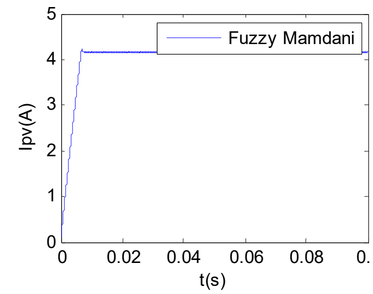
Figure 8. P&O algorithm results: (a) PV's voltage, (b) PV's current, (c) PV's power, (d) PWM signal

5.2. Fuzzy MPPT based on mamdani's inference results

Mamdani's inference results are depicted on Figure 9. We can notice that the output power is nearly without overshoot and the PV voltage presents a small undershoot.



(a)



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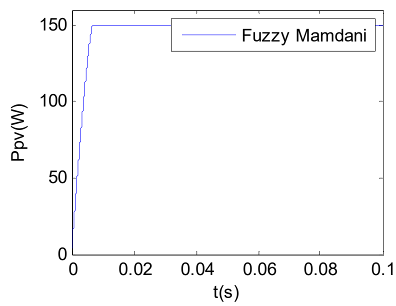
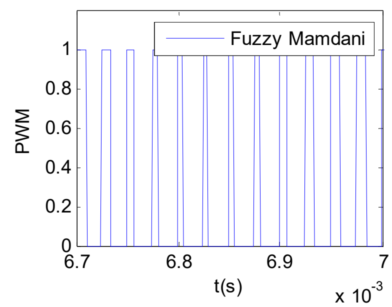


(c)

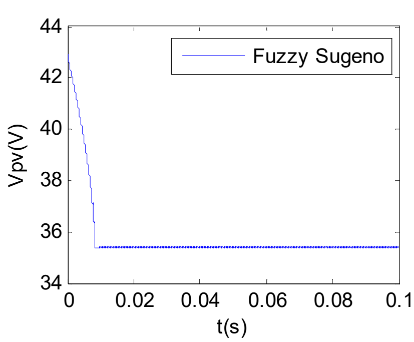


(d)

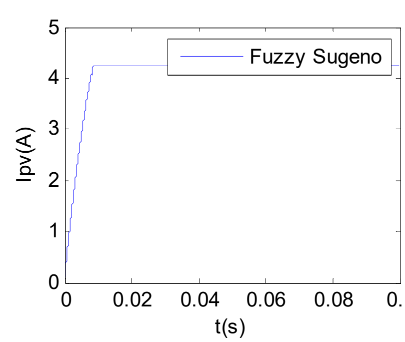
Figure 9. Mamdan's inference results: a) PV's voltage, b) PV's current, c) PV's power, d) PWM signal

5.3. Fuzzy MPPT based on sugeno's inference results

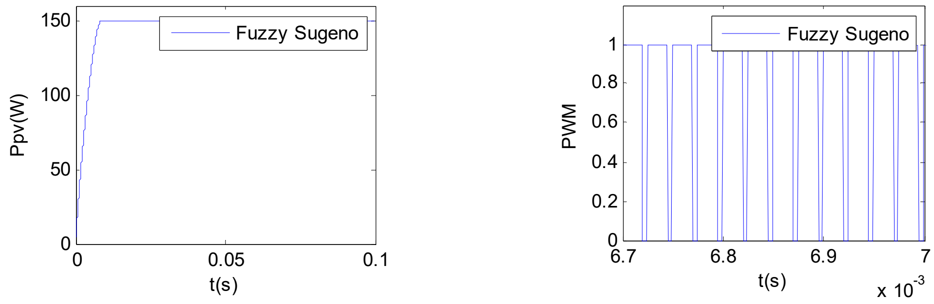
Compared to above results, the output power obtained using sugeno's inference Figure 10 (c) is without overshoot and the PWM signal Figure 10 (d) shows the efficiency of this method.



(a)



(b)

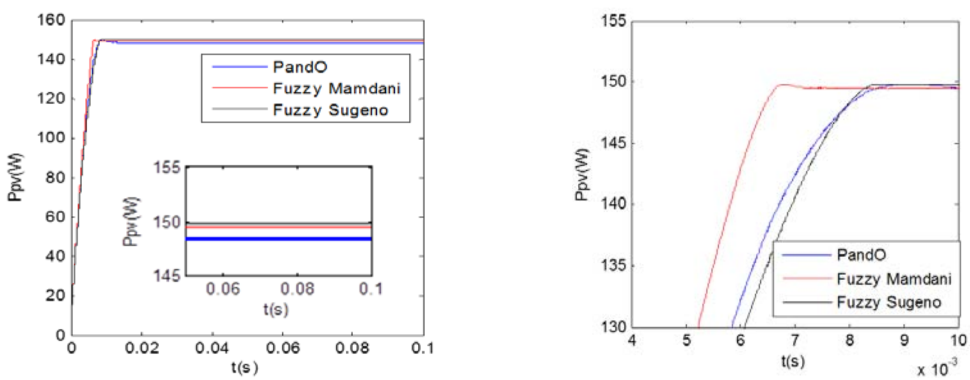


(c) (d)

Figure 10. Sugeno's inference results: (a) PV's voltage, (b) PV's current, (c) PV's power, (d) PWM signal

The comparison of the PV's powers is presented on Figure 11. On Figure 11 (a) we can notice through the zoom that the MPPT based on Sugeno's inference delivers a maximum power in steady state zone and the intelligent controllers are more performance than the conventional controller based on P&O algorithm.

The Table 4 shows the numerical values of the PV power for each strategy.



(a) (b)

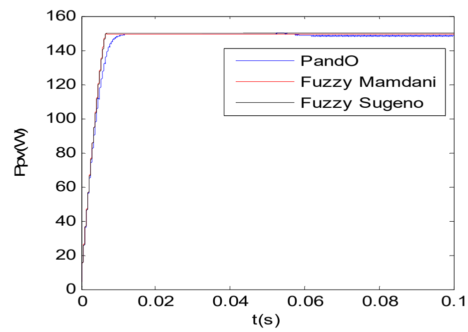
Figure 11. (a) PV's powers for each method, (b) zoom of PV's powers

Table 4. Numerical values of controllers' performances

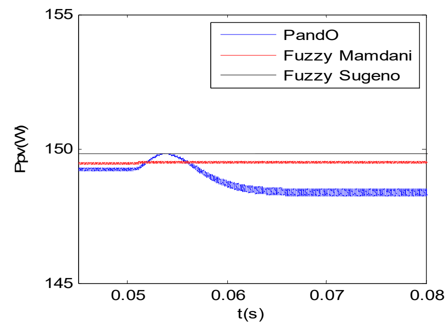
	P&O algorithm	Mamdani's inference	Sugeno's inference
RiseTime (s)	0.0056	0.0050	0.0050
SettlingTime (s)	0.0075	0.0063	0.0064
SettlingMin (W)	134.0605	134.9513	135.2711
SettlingMax (W)	149.8105	149.7950	149.8105
Overshoot	0.9057	0.2234	0.0003
Undershoot	0	0	0
Peak (W)	149.8105	149.7650	149.8105
PeakTime (s)	0.0092	0.0068	0.0293

6. LOAD CHANG

We have increased the load up to 50% to evaluate the robustness of each strategy. The obtained results according to Figure 12 (a) and (b) show that FLCs are more robust than the P&O algorithm because at 0.05s when the system is loaded, they are more stable than P&O algorithm.



(a)



(b)

Figure 12. load change results: (a) PV's powers for each method, (b) zoom of PV's powers

7. CONCLUSION

The PV array has a maximum power point (MPP) which varies with the change of solar irradiation and cell temperature. The controllers by fuzzy logic can provide more effective response than the traditional controller for the nonlinear systems, because there is more flexibility. They are robust and MPP was obtained in shorter time runs as is shown on Table 4. The FLC based on Sugeno's inference presents certain performances compared to Mamdani's inference in terms of settling max, overshoot and peak value.

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