Le 3ème Séminaire International sur les Energies Nouvelles et Renouvelables
The 3rd International Seminar on New and Renewable Energies
Unité de Recherche Appliquée en Energies Renouvelables,
Ghardaïa – Algérie 13 et 14 Octobre 2014

Optimal Fuzzy Logic Controller Based on PSO for the MPPT in Photovoltaic System

Ayat Rhma[#1], Mabrouk Khemliche[*2]
Automatic Laboratory- LAS, Electrical Engineering Department, University of Sétif1
Sétif, Algeria
ayat.rahma@yahoo.fr
Automatic Laboratory- LAS, Electrical Engineering Department, University of Sétif1
Sétif, Algeria
Mabroukkhemliche@yahoo.fr

***Abstract*— Fuzzy logic control (FLC) systems have been tested in many technical and industrial applications as a useful modeling tool that can handle the uncertainties and nonlinearities of modern control systems. The main drawback of the FLC methodologies in the industrial environment is challenging for selecting the number of optimum tuning parameters. The present paper proposes an approach combined from FLC and particle swarm optimization algorithm (PSO) used to finding the optimum membership functions (MFs) of a fuzzy system using PSO algorithm with the aim of achieving the accurate and acceptable desired results. For improving and optimizing the performance of a photovoltaic system to deliver the maximum power available. It is clearly proved that the optimized MFs provided better performance than a fuzzy model for the same system, when the MFs were heuristically defined.**

Keywords*- *PV system, MPPT, Fuzzy logic control (FLC), Membership functions (MFs), Particle swarm optimization (PSO)

I. Introductin

With the ceaseless deterioration of living environment and the rapid reduction of traditional energy, developing clean and renewable new energy has been gradually attacked much attention and promotion by more and more governments.

To overcome the problem of low energy conversion efficiency of PV modules and to get the maximum possible efficiency, it is necessary to provide PV systems with MPPT controllers in order to draw the maximum electrical power from the PV modules under varying atmospheric conditions. In the photovoltaic system, DC/DC is adopted to connect photovoltaic array and load, through adjusting the duty ratio, so as to make the output power reach the highest point.

In order to get a maximum of solar energy utilization efficiency by approaching the maximum power point of PV panel, many scholars elaborate various optimal control algorithms since the seventies, starting with simple techniques such as the P&O technique and the incremental conductance technique based MPPT [1] to more improved power based MPPT such as fuzzy logic control

In this paper, intelligent control technique using FLC is associated to an MPPT controller in order to improve energy conversion efficiency. This fuzzy logic controller is then improved by using PSO.

II. Maximum Power Point Tracking (MPPT)

To improve efficiency, PV system must operate on maximum power point (MPP) so necessary to determine it.

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

To overcome this problem, it is necessary to add an adaptation device, an MPPT controller with a DC/DC converter between the source and the load, Fig. 8 [8].

The characteristics of a PV system vary with temperature and irradiance, Fig. 3, 4, 5, 6. Therefore, an MPPT controller is also required to track the new modified MPP in its corresponding curve to arrange PV system operate at peak power point so that maximum power can be delivered to load. Whenever, a variation in temperature and/or irradiance occurs.

III. PV Modelling

PV systems are a device that converts solar into electrical energy. It consists of several solar cells. Each cell is associated with each other either in series or parallel to form a series of PV that is generally referred to as "PV modules" [4].

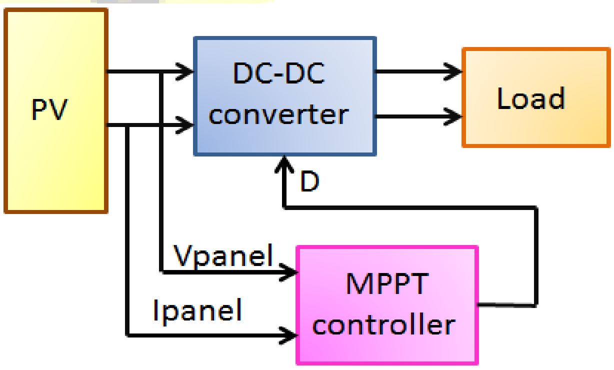

Fig. 1 Photovoltaic system.

The proposed PV system consists of three main blocks as is shown in Fig. 1: PV panel, power converter, and MPPT controller. The following sections will describe the modeling of the PV panel and power converter [5].

The general model of solar cell can be derived from an equivalent circuit who have a photo current source, a diode, an equivalent parallel resistor (Rp) and an equivalent serial resistor (Rs) which can be shown as in Fig. 2 [6].

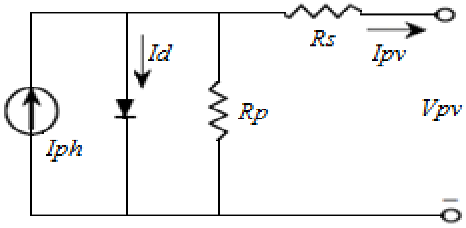

Fig. 2 Equivalent circuit of photovoltaic cell.

The PV system equivalent circuit is described by the following equation:

$$I_{pv} = I_{ph} - I_d - \frac{V_{pv} + R_s \cdot I_{pv}}{R_p} \quad (1)$$

Where *Vpv* and *Ipv* represent the output voltage and current of the PV, *Iph* is the Photocurrent.

Note that:

$$I_{ph} = I_{sc}\frac{G}{1000}\left[1 + a\left(T - T_{ref}\right)\right] \quad (2)$$

*I*sc is the PV module light-generated current in the nominal condition.

$$I_d = I_0 \cdot \left(e^{\frac{V_{pv} + R_s \cdot I_{pv}}{V_T}} - 1\right) \quad (3)$$

I_0 represent the saturation current of the diode.
The thermal voltage, *VT* has the function as shown in (4):

$$V_T = \frac{nKT}{q} \quad (4)$$

Where n is ideality factor of the diode, *q* is the electronic charge, *K* is the Boltzmann's constant, and T is the cell temperature.

From equation (1) we notice that the output current of the PV module *Ipv* depends on the photocurrent itself *Iph*, which itself depends on the solar insulation *G* and temperature *T* of the cells consequently the power which a module can deliver depends on *G* and *T* . [2, 3].

We have simulated the behavior of the generator under various constraints.

We vary the illumination between 200W/m² 1000W/m² and a constant temperature of 25°C. The influence of illumination on the I = f (V) and P = f (V) is shown in Figs. 3 and 4.

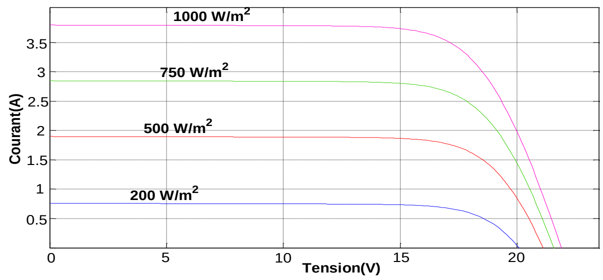

Fig. 3 The I-V characteristic of PV panel for a constant temperature of 25°C.

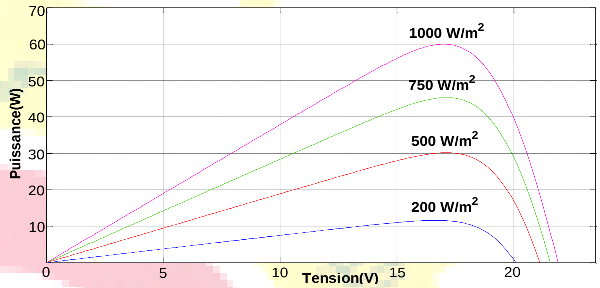

Fig. 4 The P-V characteristic of PV panel for a constant temperature of 25°C.

By varying the temperature between 25°C and 100°C under an irradiance of 1000W/m², we can see the influence of temperature on the characteristics I = f (V) and P = f (V) as is shown in Figs. 5 and 6.

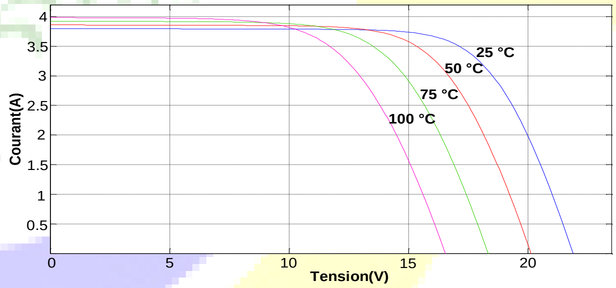

Fig. 5 The I-V characteristic of PV panel under a constant irradiance of 1000W/m².

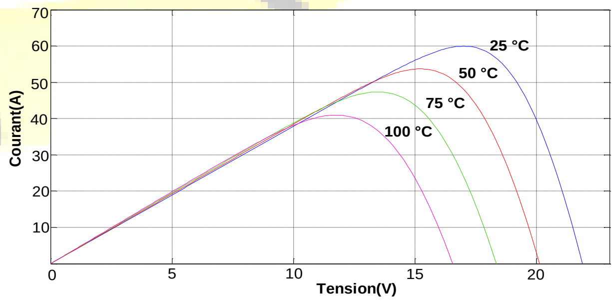

Fig. 6 The P-V characteristic of PV panel under a constant irradiance of 1000W/m².

IV. Fuzzy Logic Controller

Recently fuzzy logic controllers have been introduced in the tracking of the MPP in PV systems [13]. They have the advantage to be robust and relatively simple to design as they do not require the knowledge of the exact model. On the other hand, the designer needs complete knowledge of the PV system operation. The proposed fuzzy logic controller based MPPT has two inputs and one output.

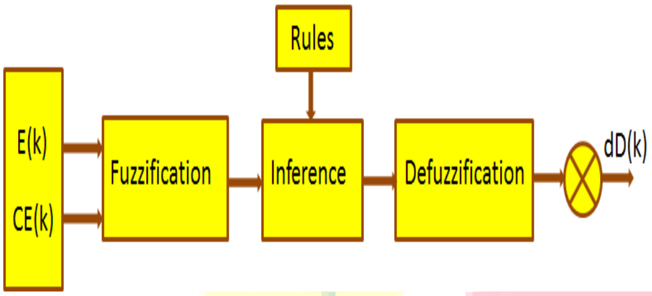

Fig. 7 General diagram of fuzzy controller.

The two input variables are the error E and change of error CE at sampled times k defined by [3]:

$$E(K) = \frac{P_{ph}(k) - P_{ph}(k-1)}{V_{ph}(k) - V_{ph}(k-1)} \quad (5)$$

$$CE(K) = E(k) - E(k-1) \quad (6)$$

where *Pph (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 (The control rules are indicated in **Table 1**) [7]., and the defuzzification uses the centre of gravity to compute the output which is the duty cycle:

$$D = \frac{\sum_{j=1}^{n} \mu(D\,j) - D\,j}{\sum_{j=1}^{n} \mu(D\,j)} \quad (7)$$

To simulate this fuzzy logic controller and to track the maximum power point of the PV array , a boost chopper as a DC–DC converter, as illustrated in Fig. 8 and described by equations (8) – (10), is used [9].

$$I_L = I_i - C1\frac{dV_i}{dt} \quad (8)$$

$$I_0 = (1-D)I_L - C2\frac{dV_0}{dt} \quad (9)$$

$$V_i = (1-D)V_0 + R_L I_L + L\frac{dI_L}{dt} \quad (10)$$

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

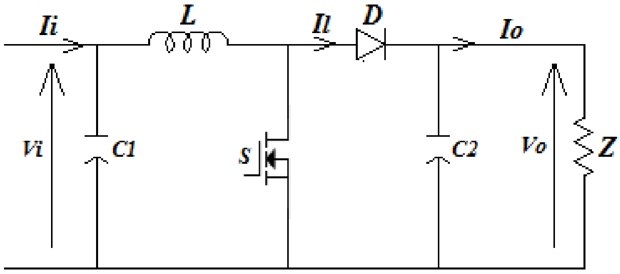

Fig. 8 Basic circuit of the boost chopper.

V. Particle Swarm Optimization Algorithm

PSO (Particle swarm optimization algorithm) is the evolutionary optimization algorithm inspired by the social behavior of bird flocking and fish schooling [10]. It was firstly proposed by R. EBERHART and J. KENNEDY in 1995. As an alternative to genetic algorithms (Goldbeg, David, 1989) and differential evolution (Storn, Price, 1997), PSO proved itself to be able to find better solutions for many optimization problems [11].

In this method, several cooperative particles are used, where the position and velocitie of each particle are initialized within the solution space in a random way, using upper and lower bounds .

The optimized particle in the swarm deliveries information to other particles, and all particles follow the optimized particle in the solution space, searching with their own flying experiences, and schooling to the optimized direction of fitness function. And the whole searching process follows the current optimal solution to achieve the goal [12].

In each generation, a new location of a particle is calculated based on its previous location and velocity, The flowchart of a basic PSO algorithm is illustrated in Fig. 9.

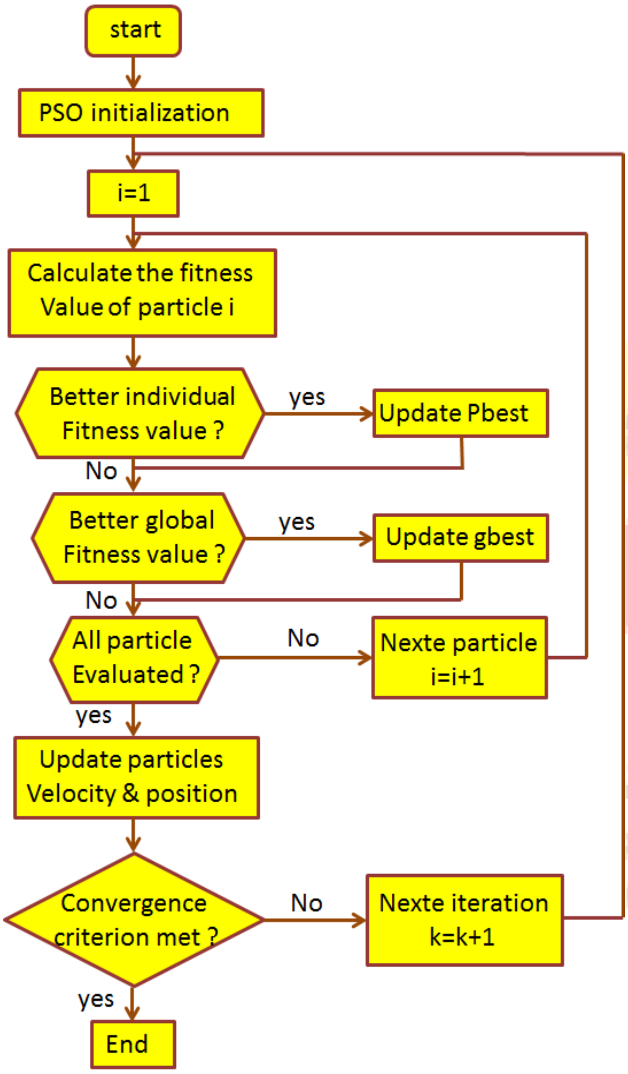

Fig. 9 Flowchart of a standard PSO.

The velocity and position update can be described using the following equations (11), (12):

$$V_i^{k+1} = wV_i^k + c_1 r_1 (pbest_i - S_i^k) + c_2 r_2 (gbest_i - S_i^k) \quad (11)$$

$$S_i^{k+1} = S_i^k + V_i^k \quad (12)$$

Where:

Si is the position of particle *i*, ***Vi*** is the velocity of particle *i*, ***K*** indicates iteration number, ***w*** is the inertia weight, ***pbesti*** is used to store the best position that the *ith* particle has found, ***gbest*** is used to store the best position of all the particles, ***C1*** ,***C2*** are the acceleration coefficients, and in order to maintain diversity of particles ***r1*** and ***r2*** are random variables uniformly distributed inside (0, 1) which provides randomness to the movement of the swarm.

VI. Fuzzy Logic Controller Optimized By PSO Algorithms

In order to optimize the FLC presented in the previous section, PSO technique was used to find the optimal MFs of the inference engine, it's an interesting way to give better performance to a fuzzy logic system.

PSO is an iterative algorithm that represents possible solutions to a given problem with a series of multidimensional vectors. Each dimension of each particle represents one parameter of a solution to be optimized.

In the design of the proposed optimal FLC, two inputs E(k), CE(k) and one output D are used. Each variable is described with five MFs, the coding scheme of this MFs is shown in Fig.10.

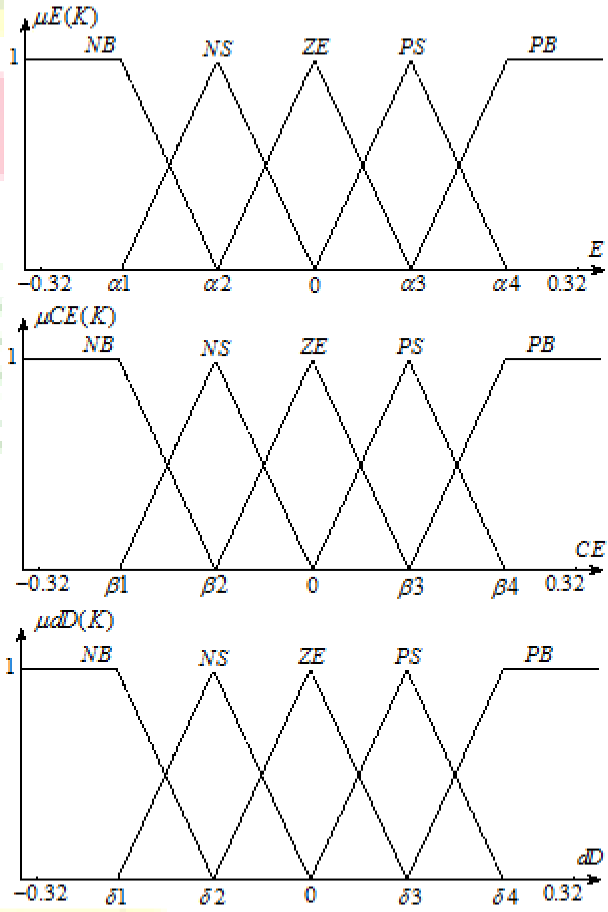

Fig.10 Membership functions coding.

In this case, the dimension number of each particle in PSO algorithm is 12: αi, βj, γk (i, j, k=1,2,3,4), who they are respectively initialized as 50 groupes of random numbers among the interval of [-0.32,0.32] by selecting $\alpha i \le \alpha i+1$; $\beta j \le \beta j+1$ and $\gamma k \le \gamma k+1$.

The objective function to be minimized is defined by the integral of the squared error as:

$$J = \int e^2 dt \tag{13}$$

Where: $e = P_{\max} - P$ (14)

P is the desired power and Pmax is the maximum power delivered by the module under the standardized conditions (T = 25 °C/G =1000 W/m^2). This choice was made with an aim of improving the response time and reducing the fluctuations.

The stop criterion is carried out when the maximum number of generations reaches 50 that is where the fitness function is at its minimum, it can be noticed that PSO algorithms have made the system to converge gradually towards an optimal solution represented by the best individual of the last population. The obtained optimal solution gives the shape of the MFs shown in Fig. 12.

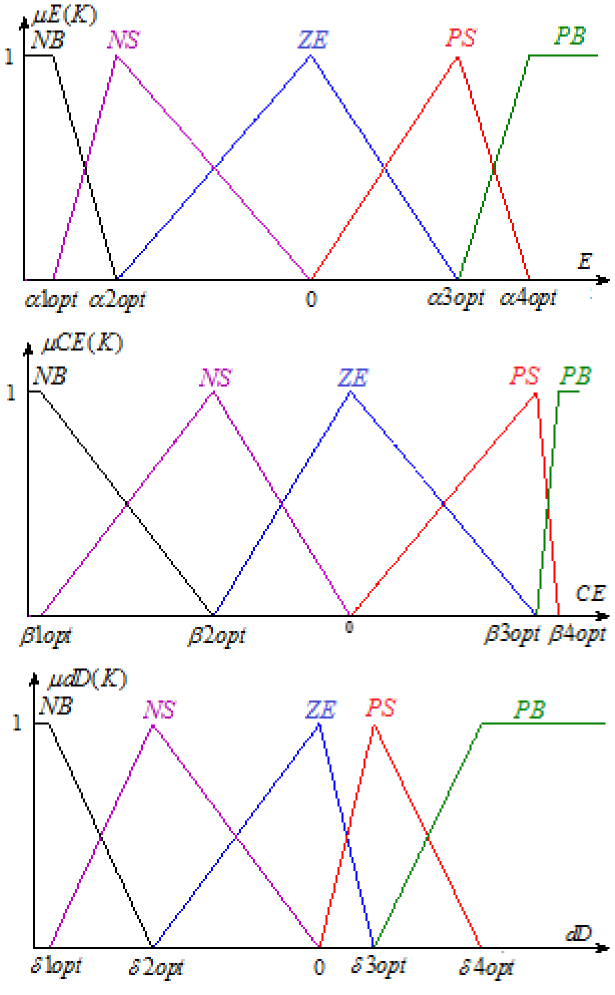

Fig. 12 Optimal FLC membership functions.

$$\begin{cases} \alpha 1opt = -0.27019 & \alpha 2opt = -0.20313 \\ \alpha 3opt = 0.1543 & \alpha 4opt = 0.22894 \end{cases}$$

$$\begin{cases} \beta 1opt = -0.43313 & \beta 2opt = -0.19117 \\ \beta 3opt = 0.26083 & \beta 4opt = 0.29156 \end{cases}$$

$$\begin{cases} \delta 1opt = -0.30232 & \delta 2opt = -0.18626 \\ \delta 3opt = 0.060944 & \delta 4opt = 0.18133 \end{cases}$$

Same series of tests as above were carried out to validate the new optimized fuzzy logic MPPT controller. The simulations were performed using the PV system of Table II. Some of the obtained simulation results are illustrated in Figs. 13–15. The results show that the OFLC has much better performances than the FLC.

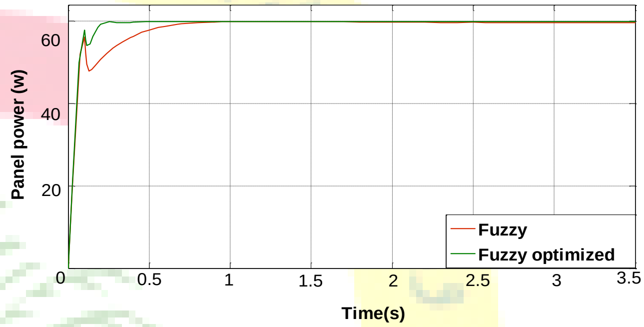

Fig. 13 Variation of the panel power under standard conditions: temperature (25 °C) and sunlight (1000 W/m^2).

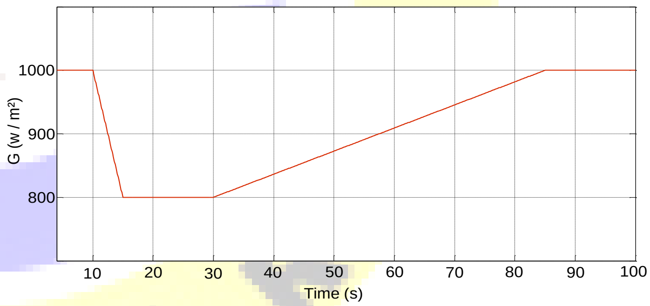

Fig. 14 Variation curve of irradiance in the experiments.

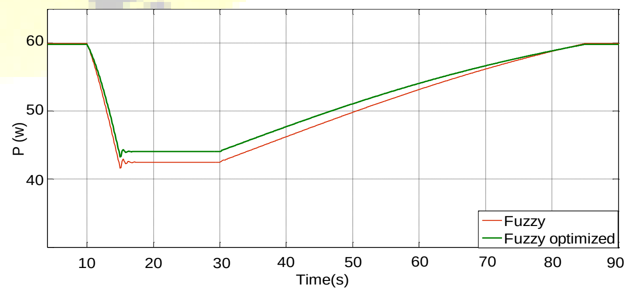

Fig. 15 The Tracking result between the Fuzzy and PSO-Fuzzy.

VII. CONCLUSION

Intelligent control techniques for the MPPT were investigated in this paper to improve the efficiency of PV systems, under different conditions.

PSO algorithm was used to obtain the best subsets of the MFs of the proposed fuzzy logic based MPPT controller as they are very difficult to be achieved by the designer.

According to the results of the simulation, the FLC with PSO algorithm has better performance in compare with a conventional FLC controller without PSO algorithm, he achieved very good performances, good robustness, fast responses with no overshoot.

This means that these controllers are able to maintain very rapidly the operating point of the PV systems at the maximum power point hence improving the amount of energy effectively extracted from the PV modules, so increasing the efficiency of the PV system.

TABLE I. FUZZY RULES TABLE.

CE(k) \ E(k)	NB	NS	ZO	PS	PB
NB	ZO	ZO	NB	NB	NB
NS	ZO	ZO	NS	NS	NS
ZO	NS	ZO	ZO	ZO	PS
PS	PS	PS	PS	ZO	ZO
PB	PB	PB	PB	ZO	ZO

TABLE II. CHARACTERISTIC OF PV MODULE.

Isc| (T=298k)	3.8 A
Pmax (w)	60 w
Rp	30 Ω
Rs	15.10-3 Ω
q	1.602.10-19 C
k	1.381.10-23 J/k
a	0.65.10-3
n	1.2

TABLE III. PARAMETERS OF PSO ALGORITHM

Population Size	50
Number of Iteration	50
C1,C2	1.5
w	0.5
Fitness	J

VIII. REFERENCES

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