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Study and Improve Photovoltaic Systems Performance based on Fuzzy metaheuristics MPPT Optimization

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***Abstract*— Maximum power point tracking (MPPT) methods are used to maximize the PV array output power by tracking every moment the maximum power point . In order to optimize the photovoltaic power generation, the MPPT is integrated in the bloc control of DC/DC converter.This paper presents a comparison study between conventional perturb and observe (P&O) algorithm, fuzzy logic controller and the optimization of this last using particle swarm optimization for the maximization of the photovoltaïc generator power.The particle swarm optimization algorithm based on the quadratic error criterion to be minimized is introduced in order to obtain the optimal parameters of membership functions and gains of fuzzy logic controller. The obtained simulation results for a photovoltaic system show the effectiveness and superiority of the optimized fuzzy logic controller using PSO algorithm compared to the fuzzy logic controller not optimized and P&O algorithm.**

***Keywords*— Fuzzy PSO MPPT Controller; boost converter; Photovoltaic system.**

I. Introduction

Smart tools are increasingly used in the design, modeling and control of complex systems such as robots, biological processes, road vehicles, etc. The term intelligent tools of soft computing techniques such as fuzzy logic, artificial neural networks and metaheuristics. Fuzzy logic introduced by Zadeh in the sixties is a very powerful tool for the representation of terms and vague knowledge [1]. Metaheuristics, including in particular the method of simulated annealing, evolutionary algorithms, tabu search method, the algorithms of ant colonies ... appeared in 1990 .This type are stochastic optimization algorithms and progressing towards an optimum sampling by an objective function whose purpose is solving difficult optimization problems. Since the early 1990s, these smart technologies are entering the engineering sciences. The goal of the researchers is to design artificial systems that retain the important mechanisms of natural systems.

II. Mathematical model of the PV system

The stand-alone PV system comprises a photovoltaic panel; a -Boost converter and à load to controls the operation point of the PV panels and MPPT controller.

A. Photovoltaic generator model

An accurate equivalent circuit for the PV cell is shown in Fig.1; the output current from the photovoltaic generator is given by equation 1: [1][2].

$$I = I_{PV} - I_0 \cdot \left[\exp\left(\frac{q.(V_{PV} + I.R_S)}{n.K.T} \right) - 1 \right] - \frac{V_{PV} + R_S.I}{R_{sh}} \quad (1)$$

The panel's parameters, changing with solar irradiance G (W/m²) and temperature T (°K), can be estimated by the following relations:

$$\begin{cases} I_L = \left(\frac{G}{G_{ref}} \right) . \left(I_{L,ref} + \mu_{Isc} . (T_C - T_{C,ref}) \right) \\ I_0 = I_{0,ref} . \left(\frac{T_C}{T_{C,ref}} \right)^3 \exp\left[\left(\frac{q.\zeta.G}{K.A} \right) . \left(\frac{1}{T_{C,ref}} - \frac{1}{T_C} \right) \right] \\ \gamma = \gamma_{ref} . \left(\frac{T_C}{T_{C,ref}} \right) \end{cases} \quad (2)$$

Where I_{pv} and V_{pv} are the cell output current and voltage.

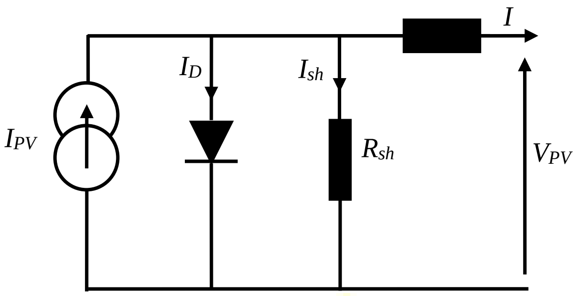

Fig1. Photovoltaic generator model

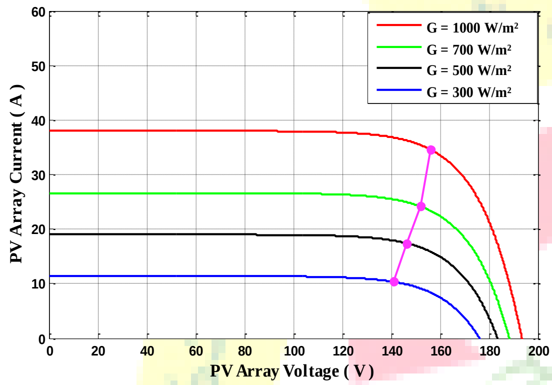

Fig 2. I (V) Characteristic

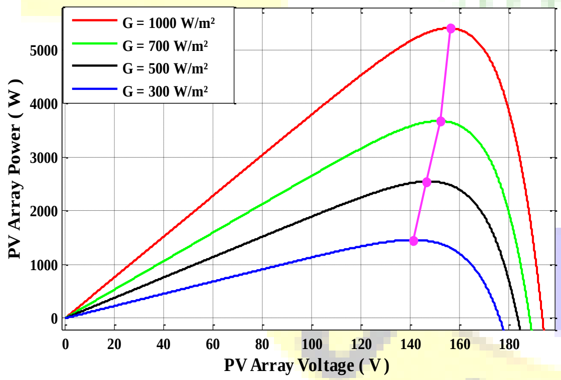

Fig.3 P (V) Characteristic

B. *Boost converter model*

The dynamic model of the solar subsystem written in terms of voltage and current between input and output of the boost converter can be expressed as: [1][2]

$$\begin{cases} L\dfrac{di_L}{dt} = -(1-D).V_{bus} + V_{PV} \\ C\dfrac{dV_{bus}}{dt} = (1-D)i_L - \dfrac{V_{bus}}{R} \end{cases} \quad (3)$$

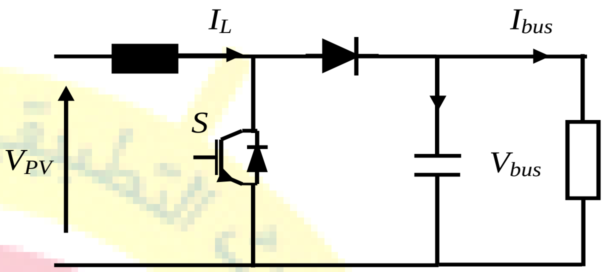

Fig.4 Boost converter.

III. MPPT ALGORITHM

A. *Perturbation and observation method*

The perturbation and observation method has been widely used because its simple feedback structure and fewer measured parameters witch are required [3].It operate by periodically perturbing (incrementing or decrementing) the array terminal voltage and comparing the PV output power with that of the previous perturbation cycle. If the power is increasing the perturbation will continue in the same direction in the next cycle, otherwise the perturbation direction will be reversed. The flowchart of this method is represented by figure 1.

The P&O method presents, in some cases, two drawbacks:

- By forcing the operating point to operate near the MPP, oscillations around the MPP appear

in steady state as shown in figure 5. Such a drawback gives rise to the waste of some amount of available energy.

- It can confuse; it moves the operating point far from the MPP instead of close to it under rapidly changing atmospheric conditions.

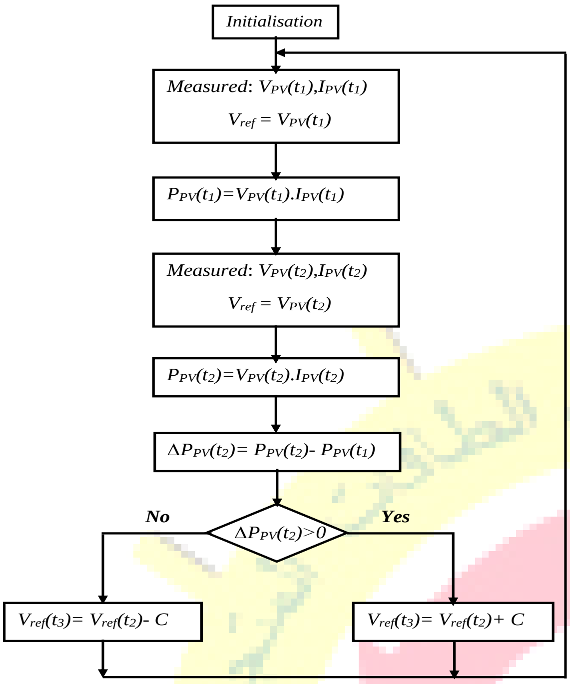

Fig. 5: Flowchart of the P&O method

B. Fuzzy MPPT algorithm

Recently, the fuzzy logic control was used in the MPPT maximum power point tracking systems; this command offers the advantage of being robust and relatively simple to develop and control it does not require knowledge of the exact model regulate. The establishment of a fuzzy controller is realized in three stages, which are: fuzzification, inference and defuzzification [4][5]. The proposed fuzzy logic controller based MPPT has two inputs (error and change of error) and one output (duty cycler).

Where:

$$E(k) = \frac{P_{PV}(k+1) - P_{PV}(k)}{V_{PV}(k+1) - V_{PV}(k)} \quad (4)$$

$$dE(k) = E(k+1) - E(k) \quad (5)$$

$$\begin{cases} X_E = K_E.E(k) \\ X_{dE} = K_{dE}.dE(k) \end{cases} \quad (6)$$

Where P_{PV} *(k)* is the instant power of the photovoltaic generator.

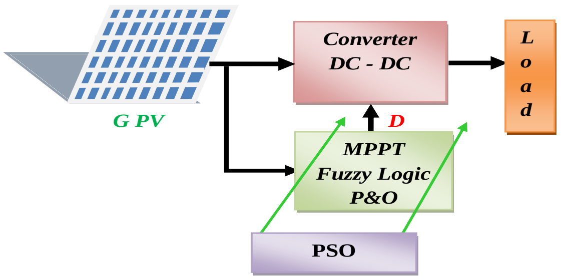

Fig 6. General diagram of adaptive fuzzy Mppt controller

The fuzzy inference is carried out by using Madani's method, and the defuzzification uses the centre of gravity to compute the output, which is the duty cycle:

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

TABLE 1: FUZZY CONTROL RULES

E dE	NB	NB	NS	Z	PS
NB	Z	Z	PB	PB	PB
NS	Z	Z	PB	PB	PB
Z	PS	Z	Z	Z	NS
PS	NS	NS	NS	Z	Z
PB	NB	NB	NB	Z	Z

C. Fuzzy Logic Controller Optimized By metaheuristics Algorithms

The method of Particle Swarm Optimization (PSO) is a swarming particle. These particles coexisted and evolving in the search space, based on their experience and knowledge shared with the neighborhood [6][7]. Each particle has two parameters, the position and velocity (*x (t), v (t)*), the population is flying in a search space based on the following two equations [8][9]:

$$x(t+1) = x(t) + x(t+1) \quad (8)$$

$$v(t+1) = W.v(t) + C_1.r_1.(pbest - x) + C_2.r_2.(gbest - x) \quad (9)$$

Where *(pbest)* is the best solution that has achieved so far, *(gbest)* is the overall best value from all particles in current generation, *where* c_1 and c_2 are the social and cognitive accelerations for the local best and global best positions, respectively, r_1,r_2 are the two normally distributed random numbers between 0 or 1.

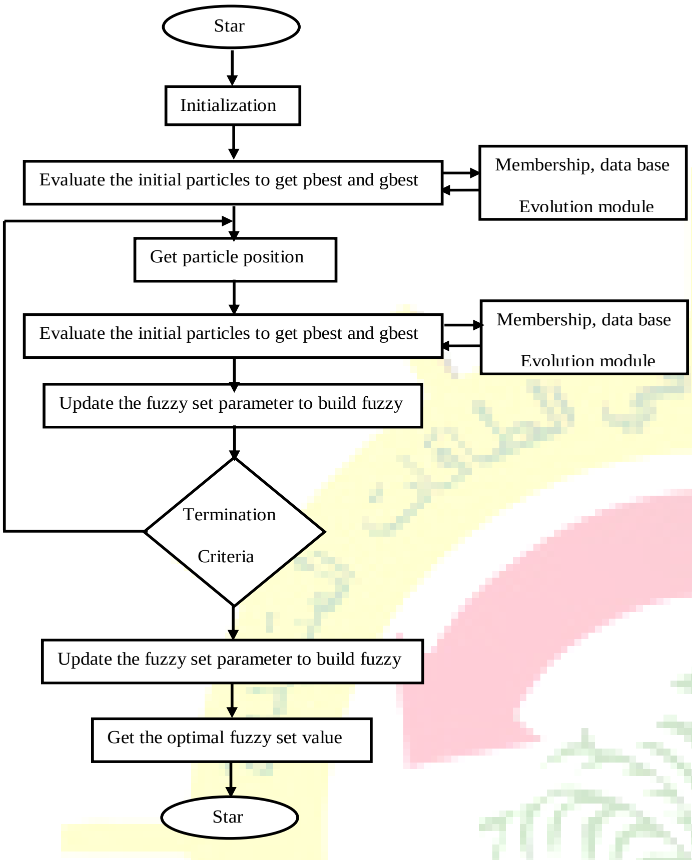

Fig 7. Flow chart of the proposed algorithm for designing the membership functions (MFs)

1) A fuzzy gain scheduling (the scaling factors)

This section has addressed tuning fuzzy scaling factors for PV control system by particle swarm optimization (PSO), a stochastic global search method with good convergence characteristics. This optimization method has been applied to tune the input and output scaling factors controller whose rules are obtained from expert knowledge [7][10]. The PSO objective function has been defined to minimize overshoot and the fitness function.

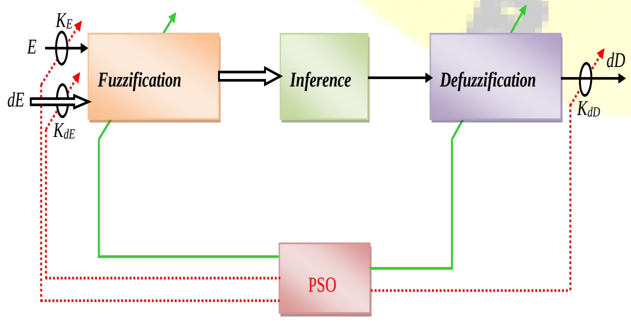

Fig 8. Bloc diagram for the PSO-Fuzzy control system

2) Tuning of the membership functions distribution and the scaling factors

This section has addressed tuning fuzzy triangular function membership of fuzzy system controller by particle swarm optimization (PSO).
Membership function includes normal type, triangular, rectangular, Gaussian and other forms [8][9]. In this paper the triangle membership function is used. Traditional triangular membership functions are shown in Fig. 9.
In order to improve the performance of the fuzzy controller, the PSO algorithm is used to find the optimal membership function.

Establishment of the variable

Two inputs E(k), CE(k) and an output dD are used in fuzzy controller design.

Each input (E , CE) and output (dD) variable are described by five membership functions as follows:

(a) The error *E(k)*: d_1, d_2, d_3, d_4 are changing in the interval [-1, 1].
(b) The error variation *CE(k)*: d_5, d_6, d_7, d_8 are changing in the interval [-1, 1].
(c) The duty cycler *dD*: d_9, d_{10}, d_{11}, d_{12} are changing in the interval [-1, 1].
The Relations between particle P_i (i=1…12) and the distance between the peak of each tow memberships function (d_i) are designated by the following equations:

$$\begin{cases} P_1 = (d_1 + d_2).(A_{min}) \\ P_2 = d_2.(A_{min}) \\ P_3 = d_3.(A_{max}) \\ P_4 = (d_3 + d_4).(A_{max}) \end{cases} \quad (10)$$

$$\begin{cases} P_5 = (d_5 + d_6).(B_{min}) \\ P_6 = d_6.(B_{min}) \\ P_7 = d_7.(B_{max}) \\ P_8 = (d_7 + d_8).(B_{max}) \end{cases} \quad (11)$$

$$\begin{cases} P_9 = (d_9 + d_{10}).(C_{min}) \\ P_{10} = d_{10}.(C_{min}) \\ P_{11} = d_{11}.(C_{max}) \\ P_{12} = (d_{11} + d_{12}).(C_{max}) \end{cases} \quad (12)$$

The pattern of membership function is shown in Fig.9. The PSO containing 20 particles are used to obtain the optimal solution.

Applying the following fitness function to select:

$$J = \int_0^t e^2 dt \qquad (13)$$

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

Where, P is the ideal power and P_{max} is the maximum output power of the module under standard conditions.

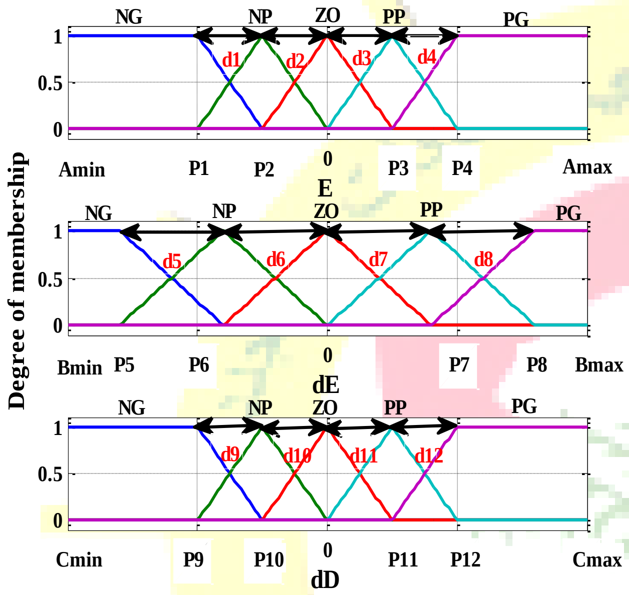

Fig 9. The membership functions of fuzzy input and output variables

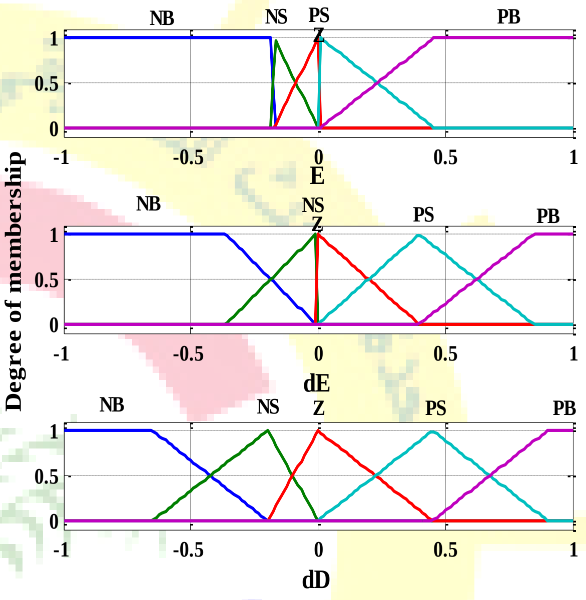

Fig. 10 Optimized membership function

The above process enables the system gradually achieve the optimal solution.

The above method allows the solution gradually achieving the system. In the last iteration, the best of particle Swarm represents the optimal solution. The parameters of the optimal solution are obtained tuning of the membership function, as shown in Fig. 10.

IV. SIMULATION RESULTS

To verify the efficiency of the proposed fuzzy rule method (FRMs) and a particle swarm optimization (PSO) algorithm. The following parameters are used for the PSO algorithm (Table II).

TABLE II PSO PARAMETERS

Size =20	**Swarm size**
Max (iter) =50	Maximum number of iterations
Dim =12	Dimension of the problem
C1=1.2	Cognitve acceleration
C2=1.4	Social acceleration
W=0.9	Inertial weight

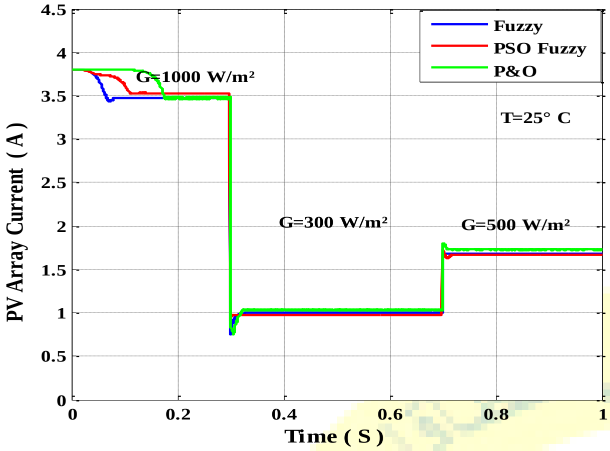

Fig .11 The Tracking result between the PSO-Fuzzy tuning of PV Current characteristics

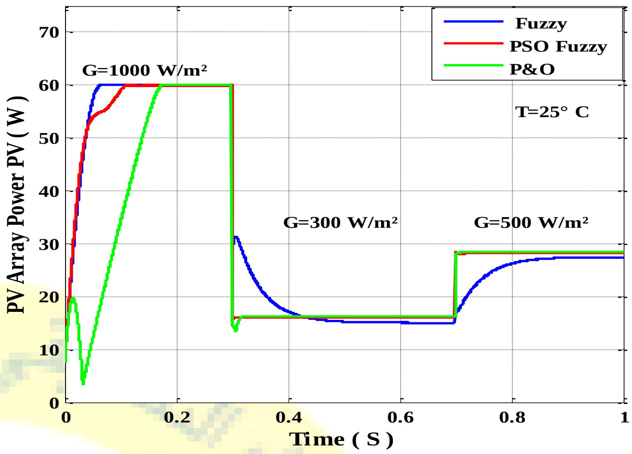

Fig .13 The Tracking result between the PSO-Fuzzy tuning of PV power characteristics

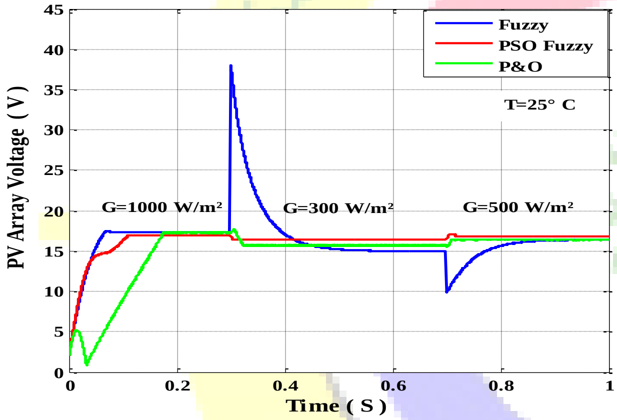

Fig .12 The Tracking result between the PSO-Fuzzy tuning of PV Voltage characteristics

Fig. (11-13) shows the different parameters of the photovoltaic system in steady state for irradiance values ranging from 300 W/m² to 1000W/m² at the temperatures T=25°C.

We see a good response from the tracking system from the point of maximum power and a drawback of this technique is oscillation of (V_{pv}, I_{pv}).

V. CONCLUSIONS

The PV array output power delivered to the load can be maximized using MPPT control method. In this paper, comparative study between P&O, Fuzzy and fuzzy PSO method was presented. The improved tracking performance of this presented method was verified trough simulation. An adaptive approach evolutional particle swarm optimization is proposed to design and tuning the adaptive fuzzy controller based on scaling factors and triangular membership adjusting automatically. He improved the transient and reduced fluctuations in the static state and the PV array output power remains in the maximum power point.

According to the results of the simulation, the Fuzzy PSO tracking algorithm shows better performance than Fuzzy and P&O method; he achieved very good performances, good robustness, and fast responses.

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