Intelligent PSO-Fuzzy MPPT approach for Stand Alone PV System under Real Outdoor Weather Condition

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ABSTRACT

This work depicts a performance analysis of stand alone solar PV systems under real outdoor weather conditions. An intelligent control technique based on the PSO fuzzy optimization approach is applied to extract the maximum point power. Consequently, efficiency and performance of PV system. The designed method is based on combining the fuzzy MPPT approach and particle swarm algorithm to optimize fuzzy gain. The stand alone PV system includes 6 kWp PV arrays, DC-DC boost converter associated to PSO fuzzy MPPT control and resistive load. The photovoltaic PV system has been simulated using MATLAB/SIMULINK. Accorfing to the result, it can be concluded that the proposed technique can quickly convergence to the MPP, higher efficiency, and low oscillation during different situations of real climatic conditions which impprove the effectiveness and validation of the proposed MPPT.

I. Introduction

Renewable energies are manifested as a potential solution to decreasing pollution. Among ways of production (wind, hydro ...), photovoltaic has emerged as the most appropriate and most successful in the production of renewable electricity for the home. Add to that the liberalization of the electricity market, which introduced major changes in the field of energy. Domestic photovoltaic conversion of energy chain is generally single and with lower consumption energy, fewer than 10 kW [2]; [4]. Over the last years, various studies have been conducted on intelligent MPPT approach to extract the maximum power point of the photovoltaic array, such as short-circuit current techniquae [11], Open-circuit voltage strategy [12], Perturb and Observe (P&O) approach [13], Incremental conductance (INC) method [14]. In recent years, intelligent approaches were applied for the MPPT such as Fuzzy logic controller [15][16][17] , neural network [18] and meta-heuristics in which we find genetic algorithms (GA), Ant colonies (ACO), particle swarm optimization (PSO) algorithms, etc.

This work presents an energy conversion chain based on Fuzzy logic MPPT controller under unstable atmospheric conditions (radiation and temperature). In this Fuzzy logic MPPT controller, Particle swarm optimization is used to find the optimum gains of the controller. The PV system includes 6 kWp solar PV panel, DC-DCboost converter, PSO fuzzy MPPT controller and a load.

The manuscript is organized as bellow: section 1 a bref intrduction and some previous research and proposed work in this area section 2 photovoltaic system description and the designed of PSO fuzzy MPPT controller proposed in this work. Simulation results and discussion are presented in Section 3. Conclusion and future scope are montioned in section 4

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II. Photovoltaic system description

The Fig 1 shows the bloc diagram of the stand alone PV system. It consists of the elements: PV generator, PSO Fuzzy MPPT controller, DC-DC boost connected to the resistive load consumption.

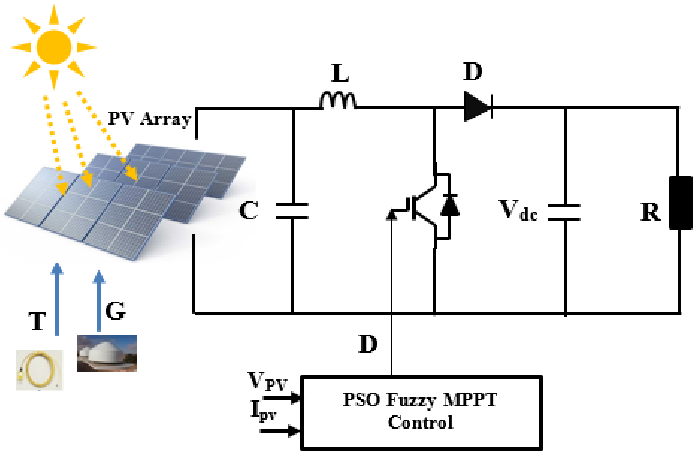

Figure 1. Stand-alone photovoltaic system.

II.1. PV array side

Typical equivalent circuit of a single diode model of PV cell given in Fig.2; a single diode model of PV cell is widely used in the literature compared to the two-diode model [4].

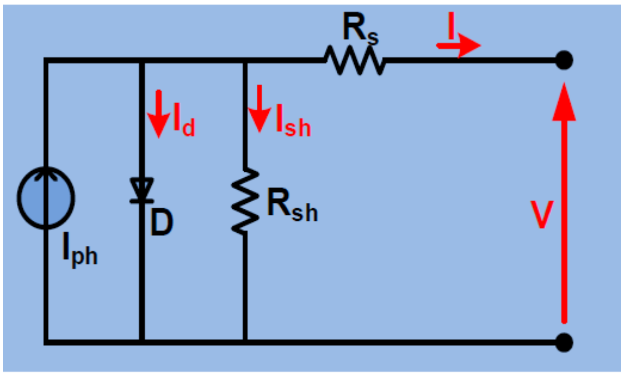

Figure 2. Typical circuit of PV solar cell.

The current-voltage characteristic for a PV cell is given with the equation below [4]:

$$I = I_{ph} - I_s\left(exp^{\frac{V+IR_s}{aV_t n}} - 1\right) - \frac{V+IR_s}{R_{sh}} \quad (1)$$

For a PV panel with Ns series-connected cells and Np parallel connected cells, the current-voltage characteristic is given by [7]:

$$Ipv = NpIph - NpIs\left\{exp\left[\frac{q}{KT}\left(\frac{Vpv}{Ns} + \frac{RsIpv}{Np}\right)\right] - 1\right\} - \frac{Np}{Rsh}\left(\frac{Vpv}{Ns} + \frac{RsIpv}{Np}\right) \quad (2)$$

Where:

- I, I_{ph} and I_s are the current array, the photo generated and the reverse saturation current respectively.
- V , V_t are the array voltage ant the thermal respectively.
- a is the diode ideality factor for single diode model.
- R_s , R_{sh} are cell series and shunt resistance

- N_{ss} , N_{pp} are the number of modules in series and parallel.
- q is the electron charge [$1.60217646*10^{-19}$C].
- k is the Boltzmann constant [$1.3806503*10^{-23}$J/K].
- T is the temperature of the cell; G is the irradiance in W/m^2.

We consider for this study the Solarex MSX-60 PV module as example .The PV array electrical characteristics chosen are summarized in table 1. It consists of 20 modules in series and 5 modules in parallels.

Table 1.Photovoltaic array electrical specifications

Typical peak power (P)	6000 Wp
Voltage at peak power (VMPP)	342 V
Current at peak power (IMPP)	17.5 A
Short-circuit current (ISC)	19 A
Open-circuit voltage (Voc)	422 V
Number of Modules	100

I (V) and P (V) performance of PV Array (6 kWp) under a change in irradiation is given in Fig .3.

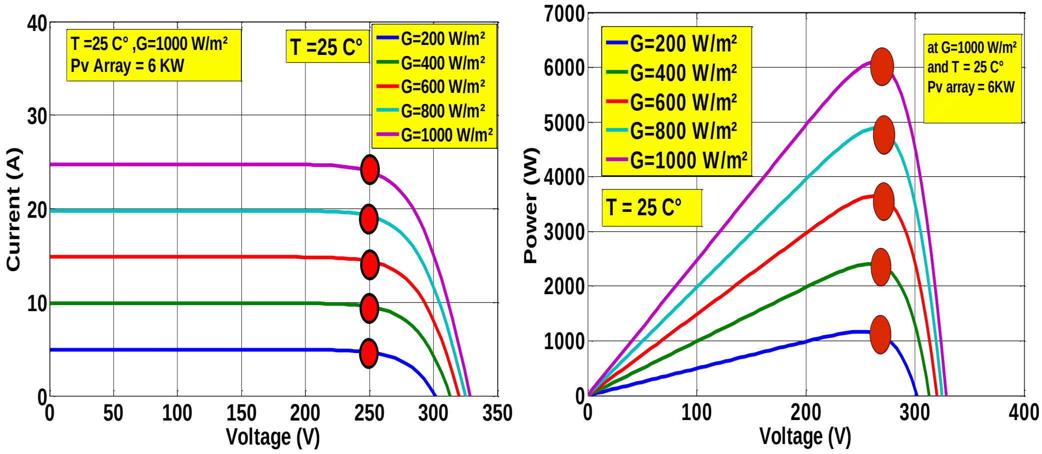

Figure 3. V-I and V-P specific of PV Array (6 kWp) under the change in irradiation

II.2. Boost converter model

The boost converter (DC-DC) connected to a photovoltaic generator using a resistive load is presented in Fig.4 [1]:

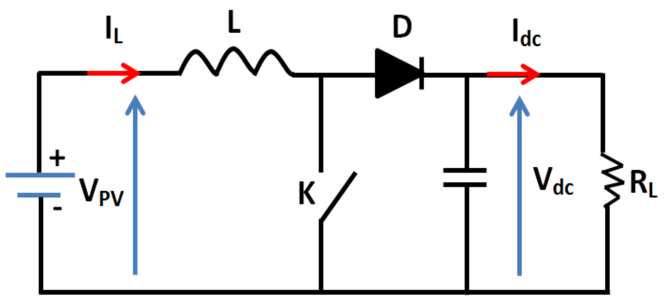

Figure 4. DC-DC Boost converter

The state-space averaged model of the boost converter can be given as the following [1]

$$\begin{bmatrix} \dot{I}_L \\ \dot{V}_{dc} \end{bmatrix} = \begin{bmatrix} 0 & -\frac{1}{L}(1-u) \\ \frac{1}{C}(1-u) & -\frac{1}{C.R_L} \end{bmatrix} \begin{bmatrix} I_L \\ V_{dc} \end{bmatrix} + \begin{bmatrix} \frac{1}{L} \\ 0 \end{bmatrix} V_{pv} \qquad (3)$$

Where u is the duty cycle, V_{pv} is the input voltage to the boost converter, I_L is the inductor current, C is the capacitance, R_L is the load resistance and V_{dc} is the DC link output. Equation (3) can be written as:

The equation (3) can be written as [1]:

$$\begin{cases} \dot{x}_1 = -\frac{1-u}{L}x_2 + \frac{1}{L}u \\ \dot{x}_2 = \frac{1-u}{C}x_1 + \frac{1}{RC}x_2 \end{cases} \quad (4)$$

Where:

$$x = [\dot{I_L}, V_c] \quad ; \quad u: V_e \quad (5)$$

II.3. PSO Fuzzy MPPT Algorithm

The particle swarm optimization (PSO) is a technique inspired by behavior sociological animals that move in swarms, such as fish moving in patches or birds migratory. The PSO is a stochastic algorithm of optimization that moves a swarm of "particles". The movement of each particle is influenced by its velocity vector and a vector position, to reach the global optimum. The quality of its position is determined by the value of the objective function F at that point. There are several optimization criteria. In this work, we will use the quadratic criterion to be minimized following:

$$F = \int_0^t e^2\,dt = \int_0^t (P_o - P_i)^2 dt \quad (6)$$

Where: P_o is PV system output power (load power) and P_i is input power of PV system (PV array power). The movement of each particle in space research is based on its current position and velocity update. Indeed, at iteration k + 1, the position vector is calculated from the equation below [3]; [8]:

$$V_i^{(k+1)} = w \times V_i^{(k)} + c_1 \times rand(x) \times \left(pbest_i - K_i^{(k)}\right) + c_2 \times rand(x) \times \left(gbest_i - K_i^{(k)}\right)$$
$$K_i^{(k+1)} = K_i^{(k)} + V_i^{(k+1)} \quad (7)$$

Fig.5, describes the flow chart of the suggested PSO strategy.

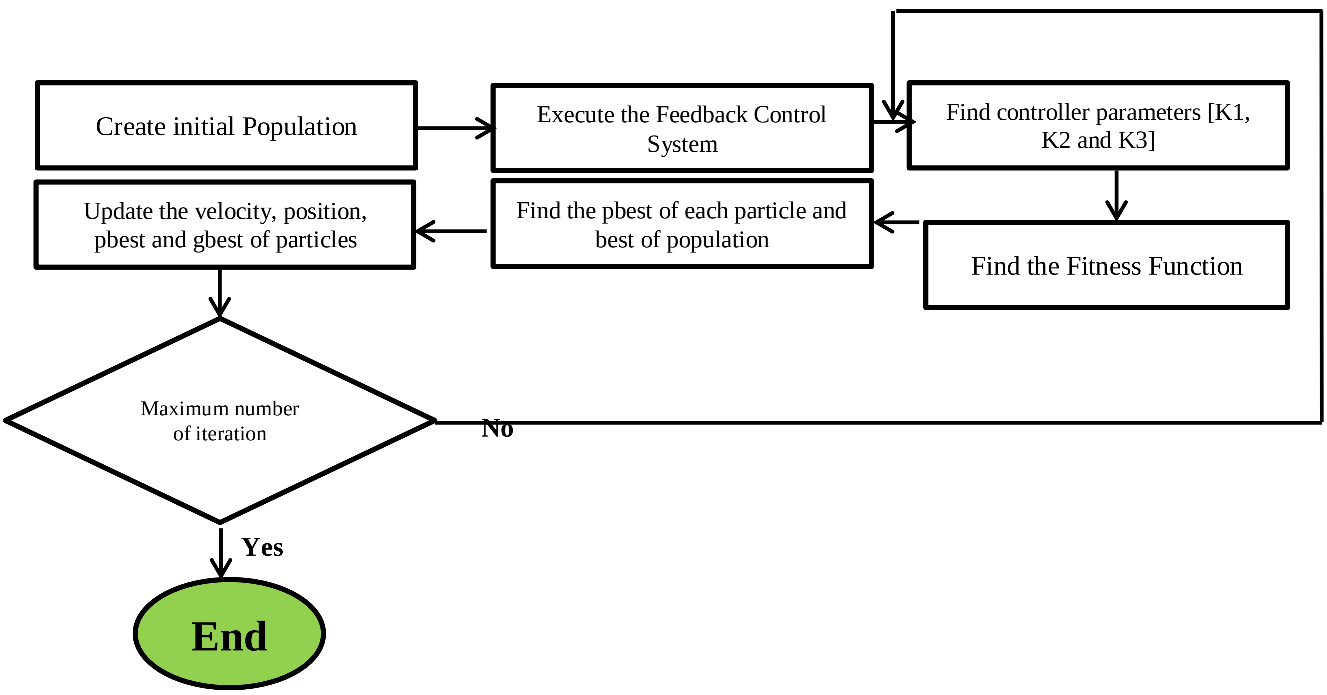

Figure 5. Flow chart of the Proposed PSO Algorithm

1) Fuzzy logic approach

The Fuzzy logic MPPT controllers are more used to be robust in the design and don't require the knowledge of the detailed model. The suggested FLC, is presented in Fig.6, has the error input e(k) and variation of error input de(k) output at sampled discrete times k [5]; [6];[19];[20] .

$$e(k) = \frac{P_{pv}(k) - P_{pv}(k-1)}{V_{pv}(k) - V_{pv}(k-1)} \tag{8}$$

$$de(k) = e(k) - e(k-1) \tag{9}$$

Where: $P_{pv}(k)$ and $V_{pv}(k)$ are respectively output powers and output voltage of the photovoltaic array at the discrete time (k).

The input e(k) shows if the load operation point at the time k is situated on the right or the left of the maximum power point on the PV performance Fig.7, while the input dE(k) presents the direction moving of this point Fig.8. The fuzzy inference is created using Madani's technic, and the defuzzification uses the center of gravity to compute the Duty cycler output D of this FLC Fig.10 , given by [5]; [6]:

$$D = \frac{\sum_{j=1}^{n} u\,(D_j) D_j}{\sum_{j=1}^{n} u\,(D_j)} \tag{10}$$

The control rules are presented in Table 1 with $e(k)$and $de(k)$ as Inputs and $D(k)$ as output.

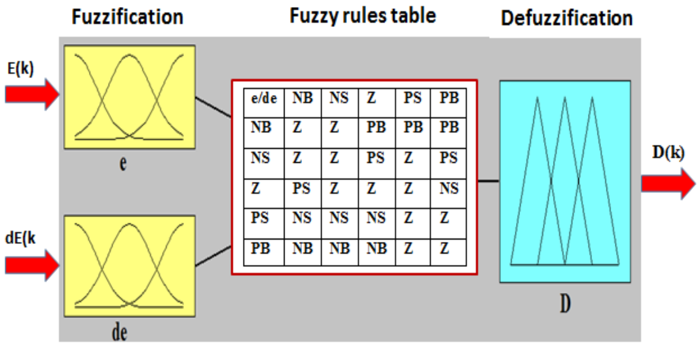

Figure 6. Fuzzy controller configuration

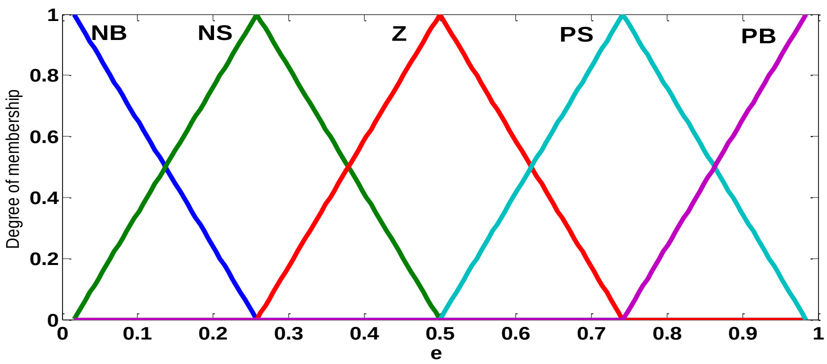

Figure 7. The Membership function of input e(k)

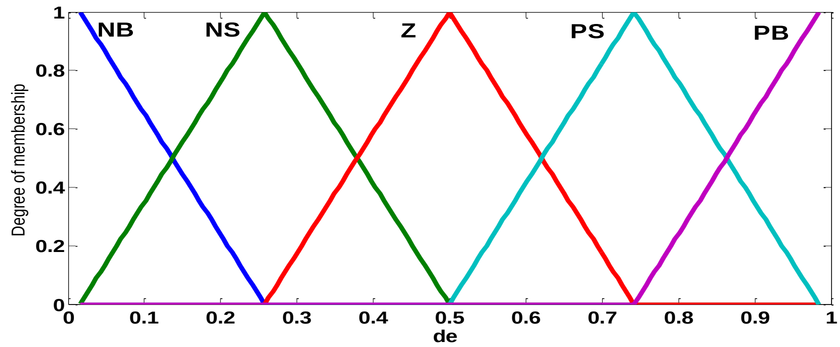

Figure 8. The Membership function of input Δe(k)

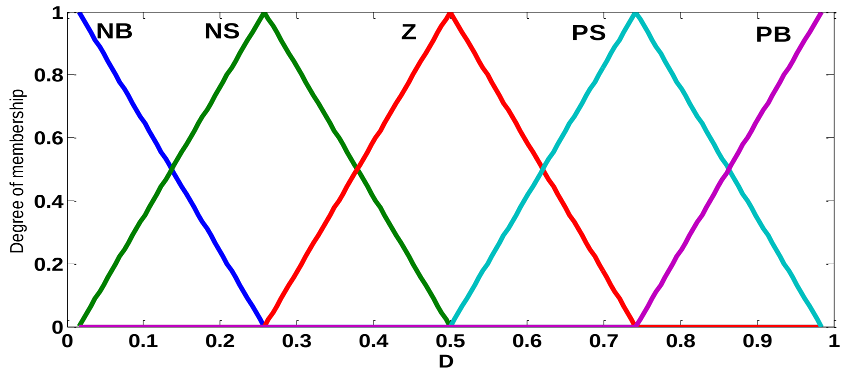

Figure 9. Membership functions of output D (Duty cycle)

Table 2. Fuzzy control rules.

e/de	NB	NS	Z	PS	PB
NB	Z	Z	PB	PB	PB
NS	Z	Z	PS	Z	PS
Z	PS	Z	Z	Z	NS
PS	NS	NS	NS	Z	Z
PB	NB	NB	NB	Z	Z

3D Presentation (e,de and D), is shown in the figure below Fig.10 and the structure of the fuzzy sliding mode MPPT strategy used is presented in Fig.11.

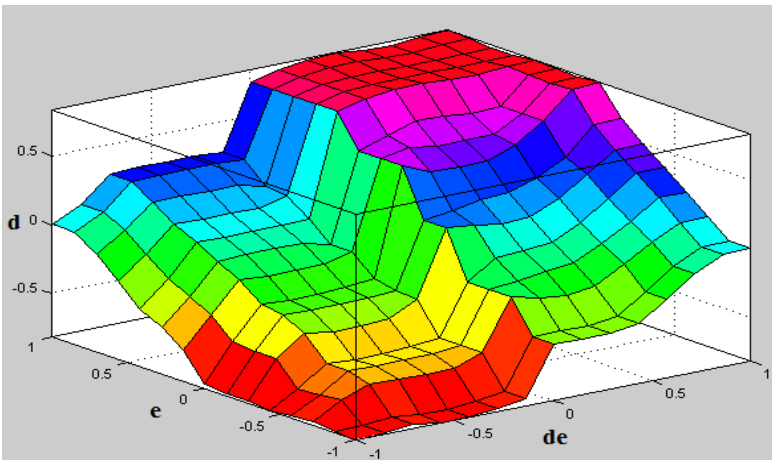

Figure 10. . 3D presentation of (e, de and D)

PSO technique was used to find the optimal gain K1, K2 and K3 fuzzy logic system. It's an interesting way to enhance performance to a fuzzy logic system K1, K2 presents the input gain of fuzzy logic system while K3 prent the gain at output of the fuzzy logic system. The PSO selects the parameters gain of fuzzy logic system that optimizes the power transfer through the DC-DC converter. The system architecture block is shown in Figure 11.

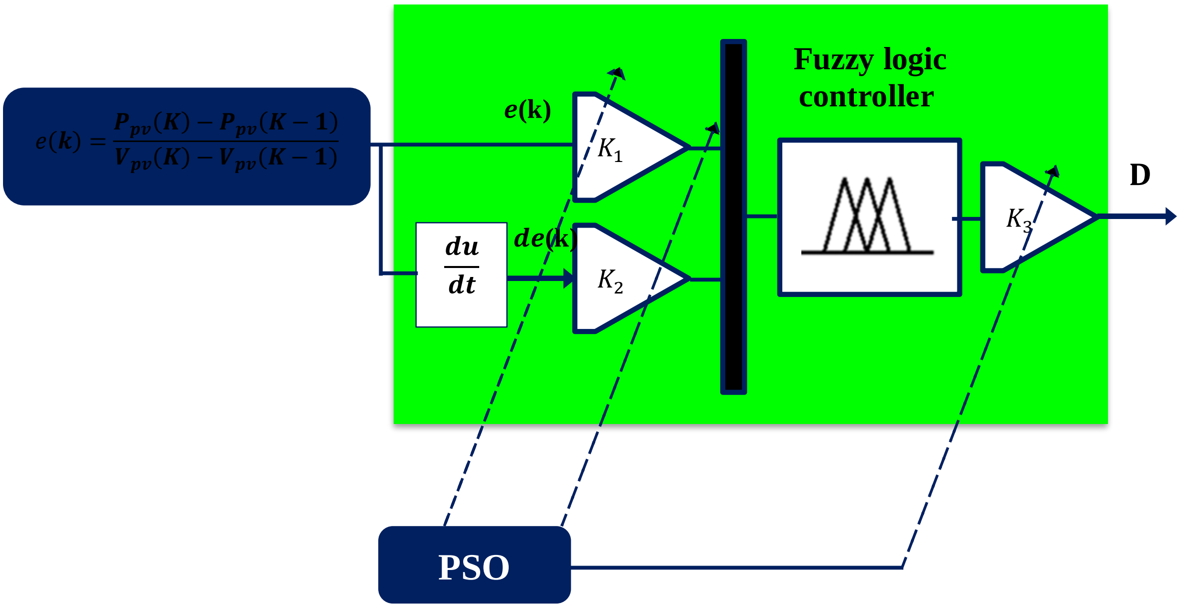

Figure 11. PSO fuzzy MPPT controller Proposed

III. Simulation Results

The stand alone PV system simulations are carried out using Matlab/Simulink as described in Fig.12 within the following parameters. The PV system .It consists of a photovoltaic array, boost converter, PSO fuzzy MPPT controller and resistive load R. The DC-DC-boost converter system specifications are given as follows: Input capacitance: 660 µF, Buck inductance: 85.5 µH, Output capacitance: 440 µF, Switching frequency: 15 kHz. A swarm size of 30 particles and 30 iterations is selected

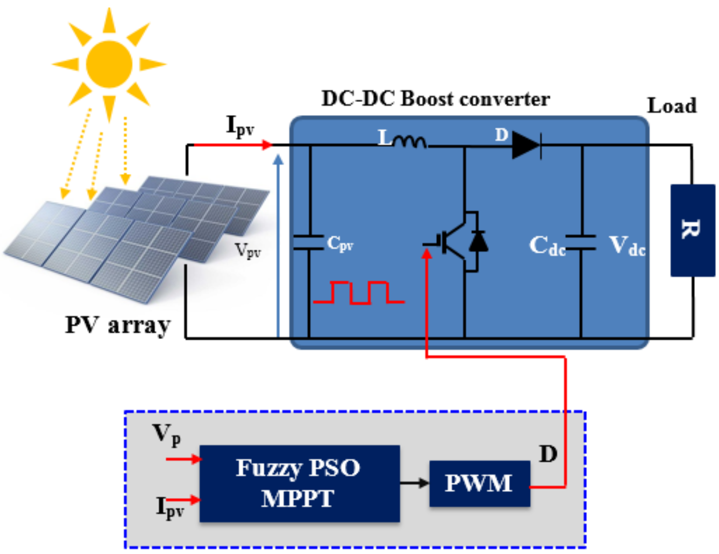

Figure 12. Global PV system implementation

The optimum gains are given in Table 3.

Table 3.Optimal parameters of Fuzzy controller using PSO

Gains	K1	K2	K3
Fuzzy PSO	123456	32.4469	30000

III.1. Abrupt Variation of Irradiation

The proposed MPPT approach is tested under two different profiles, which are abrupt variation of irradiation and real irradiation profile (Ghardaia city southern of Algeria). G=1000 W/m², from t=0 to 0.3s. G=600 W/m², from t=0.3s to 0.4s. G=300 W/m², from t=0.4s to 0.7s and G=800 W/m², from t=0.8s to 1s (see Fig 13).

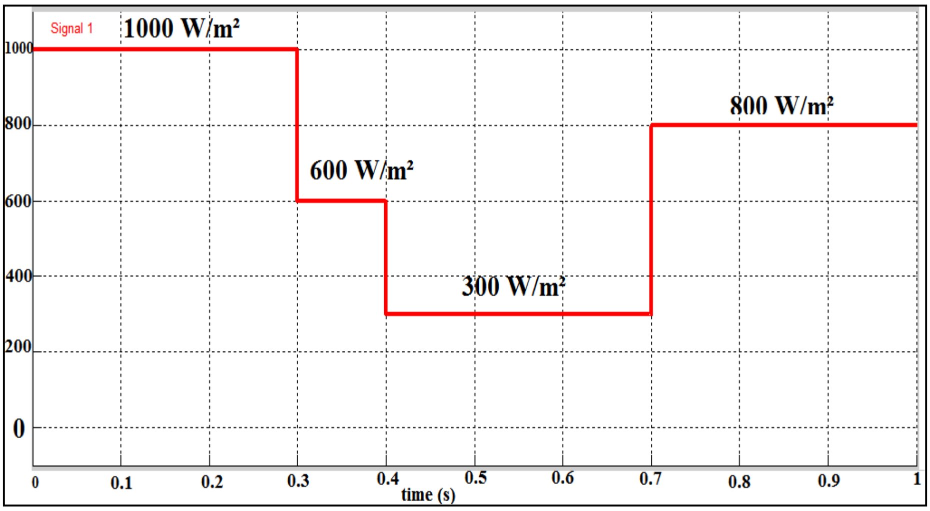

Figure 13. solar irradiation variation

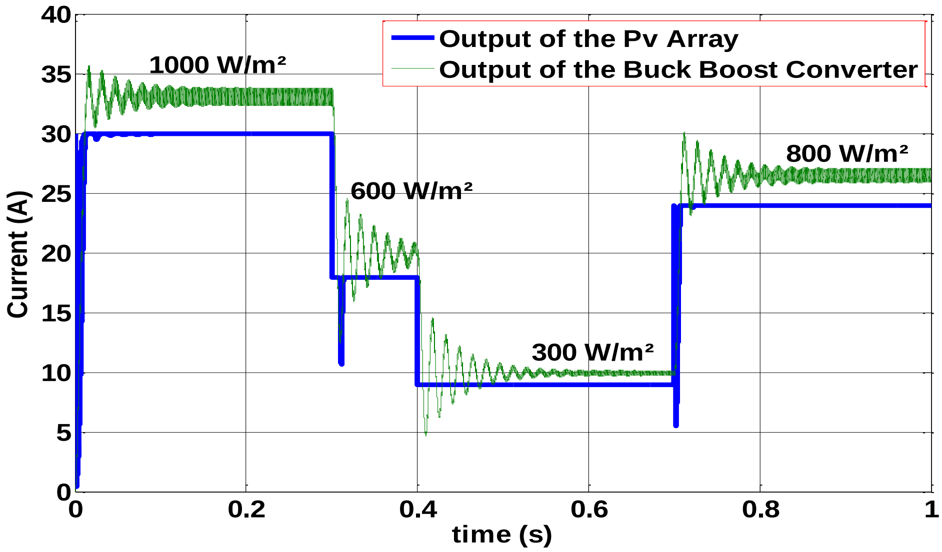

Figure 14. An output current of the PV array and boost converter at constant temperature (T=25 C°)

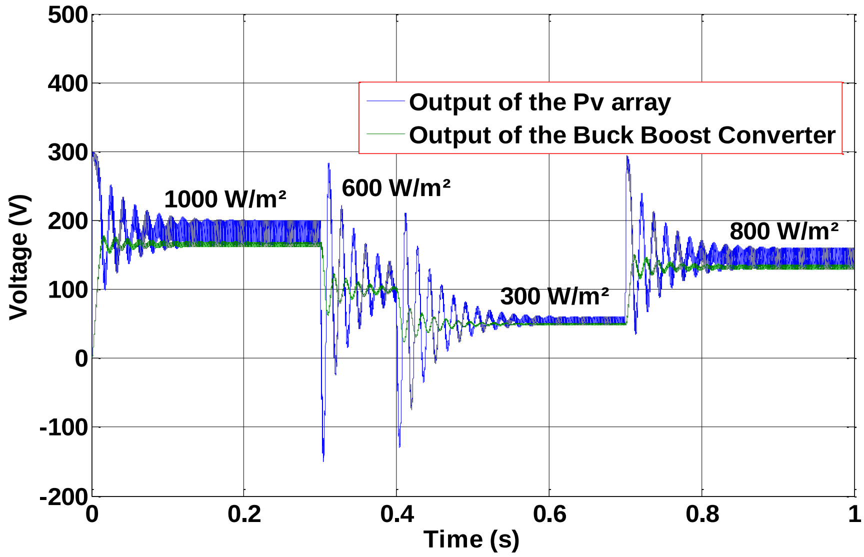

Figure 15. An output voltage of the PV array and boost converter at constant temperature (T=25 C°)

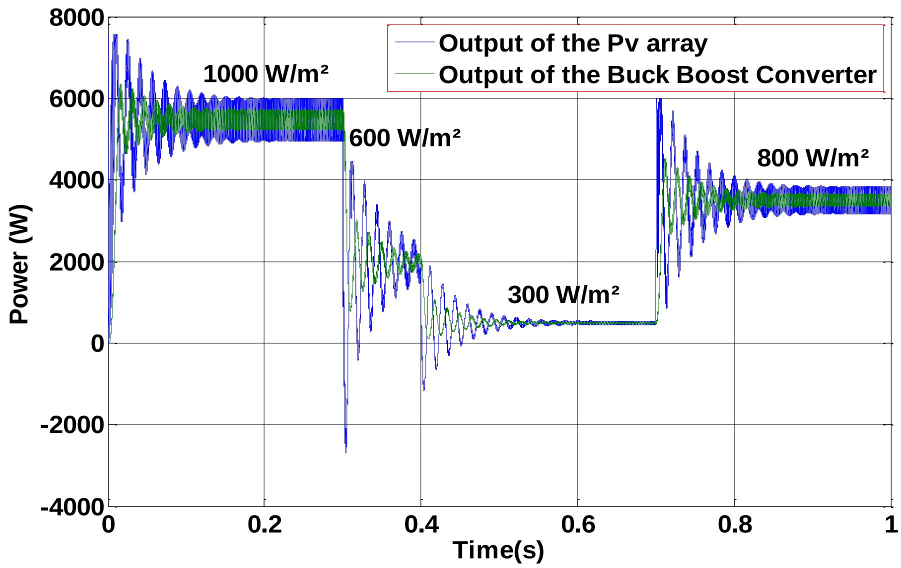

Figure 16. Output power of the PV array and boost converter at constant temperature (T=25 C°)

Simulation is carried out in abrupt variation of irradiation. Fig. 13 presents a variation of solar irradiation from 300 W/m2 to 1000 W/m2.Figures 14, 15, and 16 shows the response of boost input/output current, input/output voltage and input/ output power, and of the abrupt variation of irradiation, respectively. The current varies from 10 A to 30 A, the voltage varies from 40 V to 200 V, and power varies from 1000 W to 6000 W.

III.2. Real solar irradiation profile

As shown in Fig.17, the Irradiance of the location site is variable, passing successively from 0 to 1000 W/m2 in the day and equal to zero at night using cloudy day (14/12/2013) and sunny days (03/05/2013) respectively. An illustration of the relationship between the radiation and the output power of PV panels is shown in Fig.18-20 to explain the effectiveness of the algorithm mentioned. According to the simulation results presented above, all quantities to regulate current (IPVout), voltage (VPVout) and power (PPVout) converge well to references IPV, VPV, and PPV after a time acceptable response t = 0.01s concerning slow dynamics of the profile of the primary source (radiation and temperature).

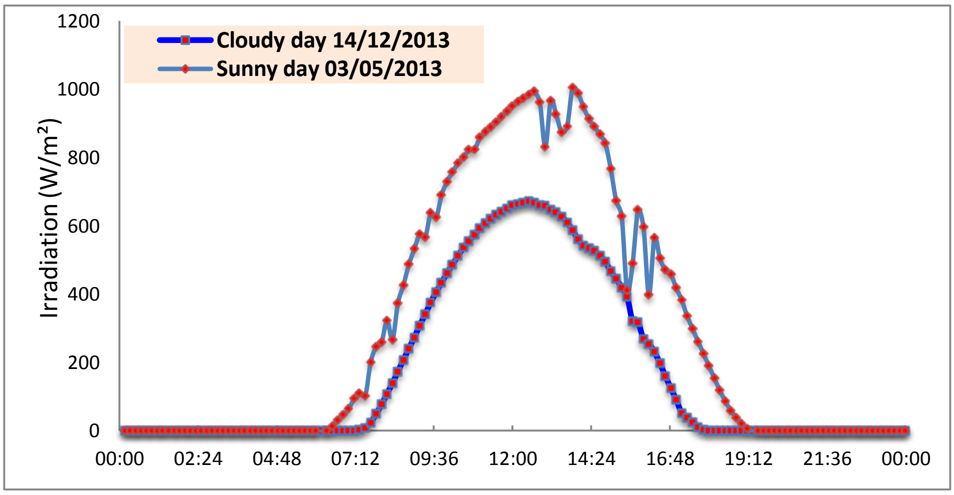

Figure 17. Global solar radiation of studied location (cloudy day and sunny day)

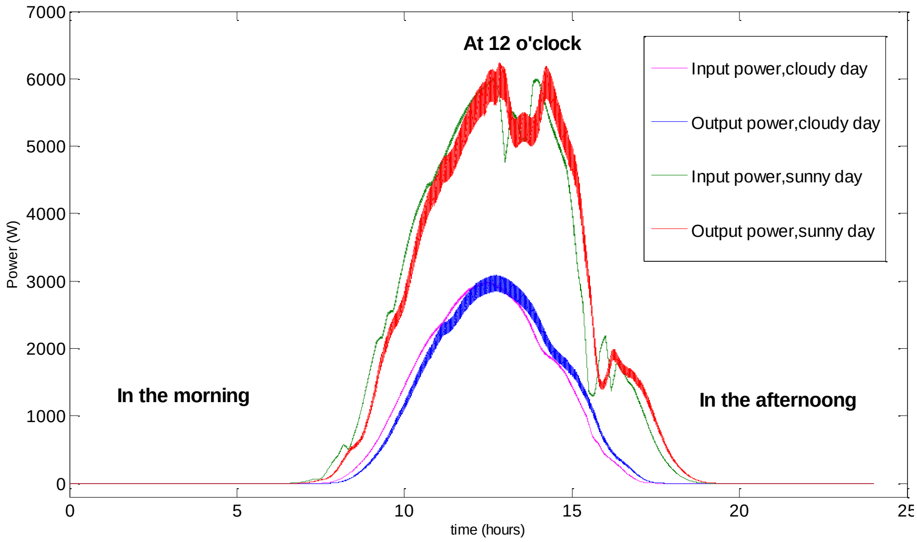

Figure 18. Evolution of input and output power (cloudy and sunny day)

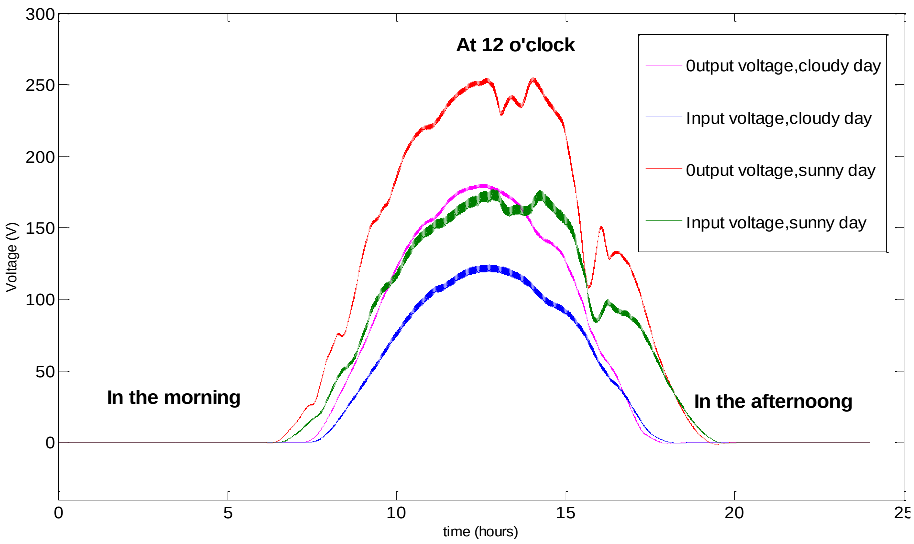

Figure 19. Evolution of input and output voltage (cloudy and sunny day)

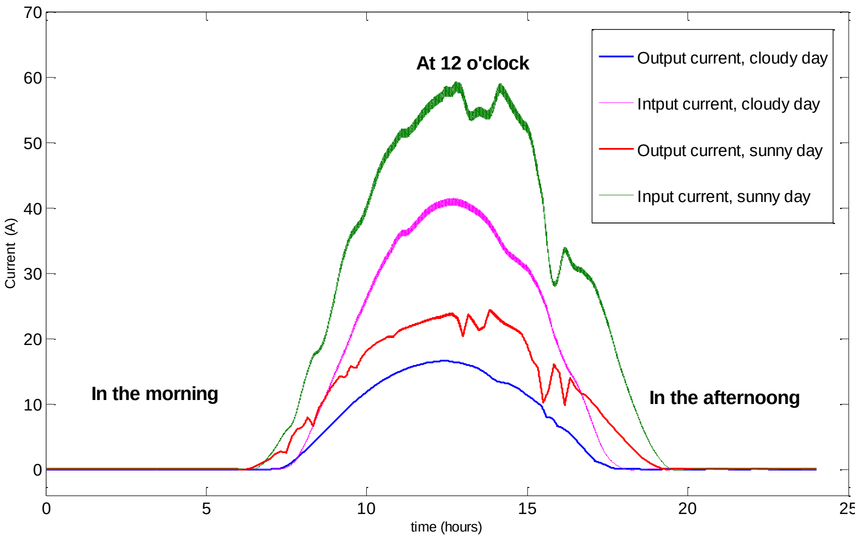

Figure 20. Evolution of input and output current (cloudy and sunny day)

IV. Conclusion

In this paper, PSO-Fuzzy is suggested to track maximum power under real varying environmental conditions of Ghardaia city in Algeria. The grid-connected PV system simulations are carried out using Matlab/Simulink. Particle swarm optimization is used to find the optimum gains of the controller. The results show that the output shows an accurate and fast response. Simulation results confirm the faster tracking of power maxima with low oscillation, reduced response time, as compared to the classical controller.

Acknowledgements

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Nomenclature

Symbol	Description	Symbol	Description
Imp	Current at maximum power point (A)	Vpv	The voltage of the PV module
Iph	Photo-current	I_L	the inductor current
$Isat$	Saturation current of diode	C	The capacitor
m	Ideality factor	R_L	the resistance load
Rs	Series resistance	V_{dc}	DC link voltage output
Rp	Parallel resistance	pbest	the best of a particle i
T	Junction temperature	$gbest$	global best of all particles
K	Boltzmann constant	w, C_1 and C_2	weight parameters
q	Electron charge.		
u	Duty cycle	rand(x)	uniform random number from 0 to 1