Performances of Meta-Heuristic Algorithms for a PV System Under Partial Shade

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Abstract- Renewable energies are very attractive for the electrical energy production and consequently the power plants installation is growing sharply to meet the energy constant demand in emerging countries. Indeed, these countries then invest too many means to maximize their available natural resources, in particular hydraulic, solar, wind, biomass, etc.., in order to reduce their dependence on fossil fuels. The production of electricity from solar energy as an alternative to fossil fuels continues to be the subject of several research works. However, the problem is that the production of these plants is intermittent because it depends mainly depending on the temperature and the amount of radiation. However, several techniques have been created to ensure operation at the maximum power point of the photovoltaic generator whatever the climatic conditions.

Partial shading which is a non-uniform distribution of irradiation. This phenomenon is a problem that affects the proper functioning of the photovoltaic panel because the power-voltage characteristic causes several maximum points to appear, one of which is global and the others are called partial. However, our optimization algorithm must ensure that we operate at the global point and not at the partial point. So, this work concerns the study of the effect of the non-uniform variation of the level of irradiation known under the name of partial shading on photovoltaic installations and to evaluate the performance and the interest of the use Meta-heuristic algorithms for monitoring the maximum power point compared to those of classical optimization such as DISMC, PSO, CS and GWO. The study validated by numerical simulations taking into account different partial shading scenarios. The analysis of the results proves the best performances a meta-heuristic algorithm, whatever the maximum power point position.

Keywords: Photovoltaic system; Optimization; Algorithms; DISMC; PSO; CS; GWO.

1. Introduction

The need for electrical energy has not stopped growing for several consecutive years, therefore requiring a significant consumption utilizing fossil fuels including coal, natural gas, oil and uranium, etc. [1, 2]. However, the increased consumption of this type of fossil sources for the production of electricity accentuates the emission of greenhouse gases and increases pollution. So, producing electricity based on The use of renewable energies (RE) offers a potential remedy for the world's pressing problem of global warming by enabling clean production [3, 4]. Indeed, renewable energies, in particular photovoltaic panels, face several challenges due to their stochastic nature [5].

Photovoltaic systems consist of renewable energy resources which by nature their availability depends, essentially, on meteorological conditions, in particular irradiation and temperature, however, static power converters are needed because of the topologies of solar conversion systems, and entail utilizing optimization methods to obtain the most power possible [6-8]. So, the main objective is to exploit the photovoltaic energies available to improve the system overall efficiency and profitability in relation to cost and availability. To this end, this work is devoted to analyzing the influence of the shading phenomenon (non-uniform variation of irradiation) on the behavior of photovoltaic panels, given the comparative study of performance that we have carried out, that conventional optimization algorithms do not ensure operation at the point of maximum power in the presence of partial shading, unlike meta-heuristic techniques. Indeed, although the conventional techniques considered give good results under uniform lighting conditions [9, 10].

Since, the extraction of the maximum power that the photovoltaic system generated is a certain requirement; we consider the analysis of the performances of three (03) methods of extraction of the maximum power called meta-heuristics.

The content of this work is structured in three parts represented as follows: The first part deals with the modelling of the photovoltaic cell and the flowcharts of the optimization algorithms. The second part presents the simulation results under three shading profiles and we close this paper with a conclusion.

A PV array is made up with multiple PV modules placed in parallel to enhance current and in series to provide a greater voltage. Under partial shading, several peaks, maximum points both locally and globally are seen in the feature $P_{pv}=f(V_{pv})$ [11]

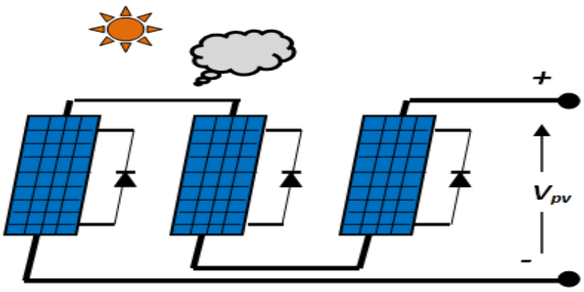

Fig. 1. PV array with some partial shading.

2. Conversion system modelling

Figure 2 shows the conversion system's organizational design studied and the PV system's anticipated MPPT block diagram. The controller determines the output power P_{pv} by measuring V_{pv} and I_{pv} with sensors. These three (03) quantities serve as data for the MPPT control to generate where are obtained through a mathematical model. Thanks to a suitable optimization algorithm such as DISMC, PSO, CS and GWO, the signal (duty cycle) for controlling that supplies the load at its output is the Boost converter [12].

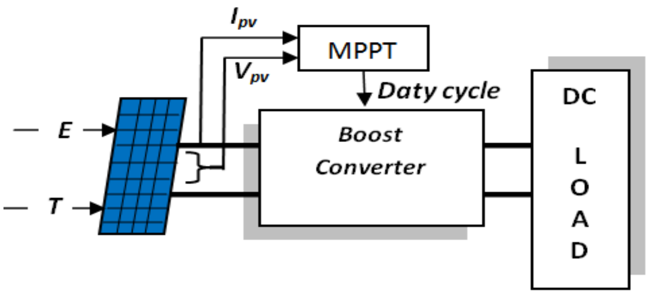

Fig.2. Conversion System.

2.1. Model for photovoltaic cells

For both software and hardware implementations, running and testing the performance of PV systems, modeling a photovoltaic (PV) module is crucial. Because the PV characteristic curve is not linear, it requires proper determination of panel-specific parameters, which are frequently omitted from manufacturer data sheets. The characteristic characteristics should be taken out of the datasheets of the manufacturer in order to obtain the I-V Curve of a PV panel in single diode model. The solar cell's single diode-equivalent electrical circuit is depicted in figure 3 [13, 14].

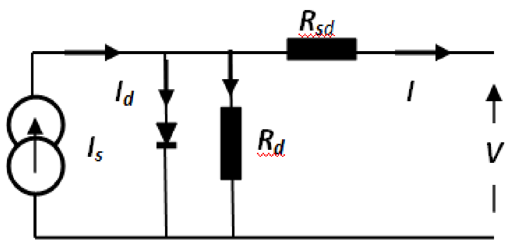

Fig.3. Electrical equivalent of a PV cell.

Where, I_{SC}(A) : short-circuit current of the cell based on temperature and radiation; I(A): cell current; V(V) : cell voltage; I_d(A): diode Current; I_{sh}(A): shunt resistor's current; $R_{sh}(\Omega)$: shunt resistance, which describes the junction currents; $R_s(\Omega)$: serial resistance, which describes the numerous contact and connection resistances

Then, we can conclude [15]:

$$I = I_{sc} - I_d - I_{sh} \tag{1}$$

The short-circuit current is expressed by the following relation for any temperature (T):

$$I_{sc(T)} = I_{sc(Tref)}.(1 + k_i(T_c - T_{ref})) \tag{2}$$

where, I_{sc}(ref): short-circuit current at a reference temperature of 1000W/m^2; T_{ref}: reference cell temperature, which is equal to 25 °C standard temperature;T_{ref} (K) = 25 + 273.15 K; k_i: expression of the temperature coefficient of I_{ph} in (%);

The relationship below illustrates how I_{sc} is expressed:

$$I_{sc}(E) = I_{sc}(E_0).\frac{E}{E_0} \tag{3}$$

where,
E_0: nominal normal sunlight is equal to 1000W/m^2.
Equation (1) is writeable:

$$I = I_{sc} - I_d - \frac{V + I.R_s}{R_{sh}} \tag{4}$$

with,

$$I_d = I_0 (e^{\frac{q}{nkT_c}(V + I.R_s)} - 1) \tag{5}$$

The solar cell's current-voltage equation is constructed with the assumption that it is of high quality:

$$I = I_{sc} - I_0 e^{\frac{q}{nkT_c}(V + I.R_s)} \tag{6}$$

with,
I_0 (A): saturating diode current; q = (1.602×10-19 C): electric charge; n: diode junction non-ideality factor; K:1.381.10^{-23J}/K, Boltzmann constant; T_c (K) : cell's actual temperature; T(K)=273+T (°C) .

2.2. Maximum Power Point Tracking Techniques

The major contribution of this work is to propose an algorithm that takes into account the phenomena of partial shading. In this paper, a comparison analysis is conducted to highlight these algorithms' dynamic performances: DISMC, PSO, CS and GWO.

➢ *Dual Integral Sliding Mode Control (DISMC)*

The components of the DISMC-based MPPT are DISMC, a boost converter, and an MPPT algorithm.

$$\dot{x}_1 = f(x_1) + g(x_1)u_1 \tag{7}$$

$$u_1 = \begin{cases} 0 & \text{when} \quad S_1 > 0 \\ 0 & \text{when} \quad S_1 < 0 \end{cases} \tag{8}$$

where the switching surface, denoted by S_1, is,

$$S_1 = a_1 e_1 + a_2 e_2 + a_3 e_3 + a_4 e_4 \tag{9}$$

The terms e_1-e_4 stand for the error signals, and the phrases a_1-a_4 stand for the sliding surface parameters.

$$\begin{cases} e_1 = \overset{*}{i}_L - i_L \;\; / \;\; \overset{*}{i}_L = A(\overset{*}{V}_{pv} - \beta_{V_{pv}}) \\ e_2 = \overset{*}{V}_{pv} - \beta_{V_{pv}} \\ e_3 = \int (\overset{*}{V}_{pv} - \beta_{V_{pv}})dt \\ e_4 = \int[\int(\overset{*}{V}_{pv} - \beta_{V_{pv}})dt]dt \end{cases} \tag{10}$$

Where, A is the voltage error's magnified gain. Through the calculation of the equivalent control u_{1eq}, the DISMC is applied. The invariance requirement allows for the derivation of this, $\dot{S}_1 = 0$,

$$\dot{S}_1 = a_1 \dot{e}_1 + a_2 \dot{e}_2 + a_3 \dot{e}_3 + a_4 \dot{e}_4 = 0 \tag{11}$$

then,

$$u_{1eq} = 1 - A_1 \frac{i_{C_{in}}}{V_{dc}} - \frac{V_{pv}}{V_{dc}} + A_2 \frac{e_2}{V_{dc}} + A_3 \frac{e_3}{V_{dc}} \tag{12}$$

with, $A_1 = (\frac{A\beta L}{C_{in}} + \frac{a_2 \beta L}{a_1 C_{in}})$, $A_2 = \frac{a_3 L}{a_1}$ and $A_3 = \frac{a_4 L}{a_1}$

According to the existence and stability criteria, parameters are empirically determined A_1, A_2, and A_3 [16-18]. By comparing the control signal $v_{control1}$ with the ramp signal v_{ramp1}, the control law of the DISMC is determined using PWM method.

$$\begin{cases} v_{control1} = (V_{dc} - V_{pv}) - A_1 i_{C_{in}} + A_2 e_2 + A_3 e_3 \\ v_{ramp1} = \beta V_{pv} \end{cases} \tag{13}$$

➢ *Particle Swarm Optimization (PSO)*

A stochastic optimization method called PSO algorithm was developed in part as a result of observations of the behavior of birds [19]. PSO is a meta-heuristic approach to global search that relies on the shared and self-organizing behavior of particles belonging to the same group. With the help of this method, which is controlled by displacement rules (in the space of solutions), these particles can gradually shift from their random positions to an ideal local position.

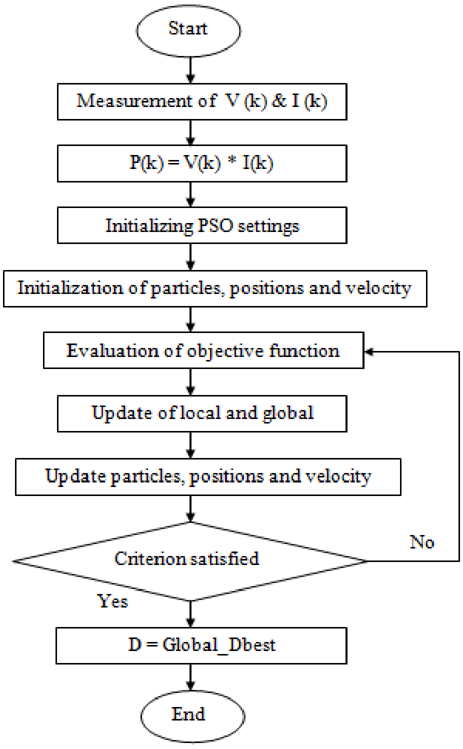

Fig.4. PSO algorithm [20].

Figure 4 depicts the flowchart of the traditional PSO method. The following equations carry out this procedure [21, 22]:

$$V_i(t+1) = w*(V_i(t) + c_1 * rand_1 * (PBest_i(t) - D\_fitness_i(t)) + c_2 * rand_2 * (GBest_i(t) - P_i(t))) \quad (14)$$

With,

$$P_i(t+1) = P_i(t) + V_i(t+1) \quad (15)$$

And,

$$D = PSO(V, I) \quad (16)$$

With, P: gear position; V: speed; PBest: best particle position that corresponds to Local_DBest; GBest: the particle group's ideal placement in relation to Global_DBest; rand: variable at random; D: duty cycle; c1: local knowledge weight; c2: global knowledge weight; w: inertia weight.

➢ *Cuckoo Search (CS)*

The CS algorithm is based on "Cuckoo" bird behavior. The peculiar behavior of some cuckoo species known as obligate brood parasitism, depositing their eggs in other birds' nests (known as host birds), as previously noticed. The latter is achieved by growing the eggs in a number of separate nests. To make the algorithm work with optimization issues, some real-world behavior must be simplified. Cuckoos adopt paths or directions when looking for host bird nests that can be predicted by specific mathematical functions. Levy's flight, which simulates the footprints of the search for the cuckoo's nest, is one of the most popular models. It was merged in the following manner to create new cuckoos from existing cuckoos:

Each cuckoo lays one egg at a time in a nest that is chosen at random.

• Future generations inherit the nests with the best eggs, or quality solutions, ensuring that good solutions are sustained over time.

• When the host bird finds eggs deposited in their nest, it will either abandon the nest or destroy the cuckoo's eggs. The number of nests is always set, and the number of eggs that the host bird discovers will have a probability P_a ($0< P_a <1$).

• Recent nests are obtained using Lévy's law of flight which is given as follows [23-25]:

$$X_j^{i+1} = X_j^i + \alpha \oplus \text{Lévy} \quad (17)$$

For the multidimensional issue, the $\oplus$ operator denotes multiplication by input. For MPPT, this is as follows:

$$V_j^{i+1} = V_j^i + \alpha.\ \text{Lévy} = V_j^i + s \quad (18)$$

Where,

$$s \approx K.\left(\frac{u}{|v|^{\frac{1}{\beta}}}\right)(V_{best} - V_j) \quad (19)$$

V_j: indicates the tension of the i^{th} iteration cycle's j^{th} particle; β: index power law; K: steps per second.

The distribution is followed by u and v:

$$u \approx N(0, \sigma_u^2) \quad (20)$$

$$v \approx N(0, \sigma_v^2) \quad (21)$$

$$\sigma_u = \left(\frac{\Gamma(1+\beta).\sin(\pi+\beta/2)}{\Gamma(\frac{1+\beta}{2}).\beta.(2^{(\frac{\beta-1}{2})}}\right)^{\frac{1}{\beta}} \quad (22)$$

$$\sigma_v = 1 \quad (23)$$

Γ : Gamma function integral.

All particles launch Lévy flights at each cycle iteration until they locate the G_{MPP}. If all particles move toward a single solution, the tracking procedure will end. The CS algorithm's flowchart is depicted in Figure 5.

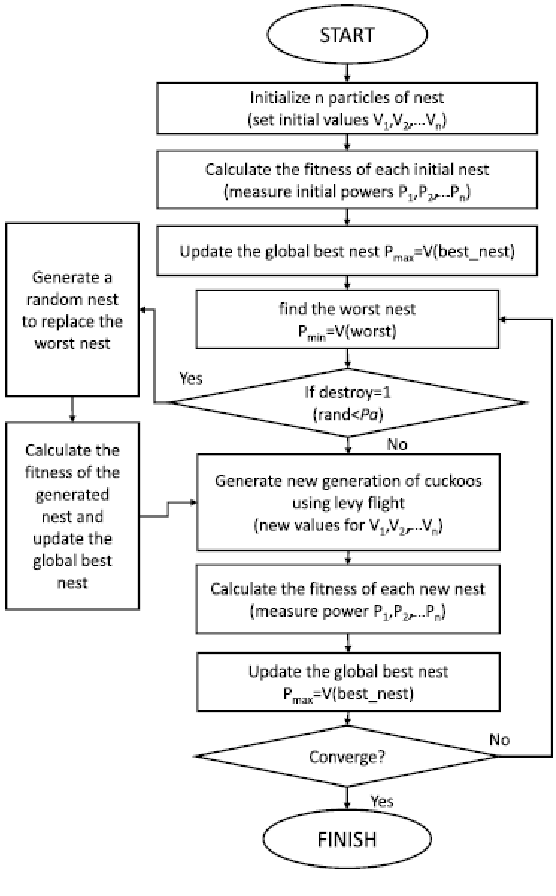

Fig.5. Algorithm flowchart for the CS [26].

➢ *Grey Wolf Optimization (GWO)*

The GWO algorithm was created to mimic the social structure of gray wolves, particularly their hunting behavior. There are four wolf populations used by the GWO: α the finest solutions are wolves that lead the hunt. β and δ the best second and third wolves, respectively, the wolves and, can aid the α wolves in making decisions. ω wolves are wolf followers [27, 28].

The GWO algorithm's flowchart is depicted in Fig. 6.

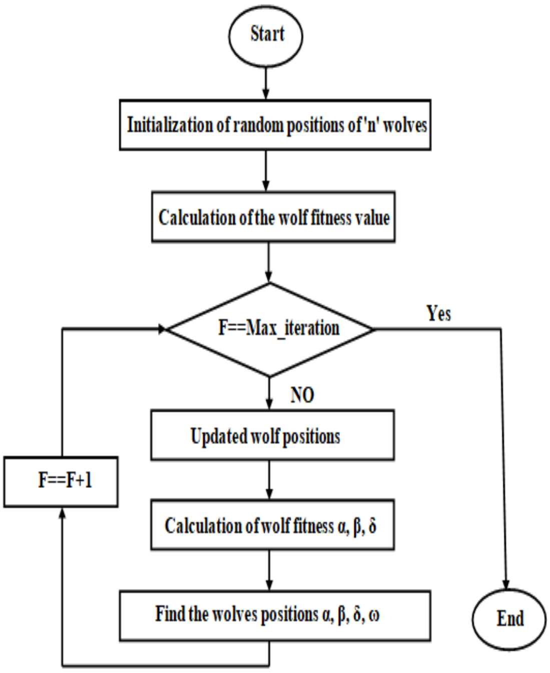

Fig.6. GWO algorithm [29].

The GWO is based on the following primary phases:

- Identification of the prey's location and encirclement of it.
- Continue to hound the target until it stops moving. In order to converge to the best places, the wolf positions are modified.
- Game attack.

$$\vec{e} = \left|\vec{c}.\vec{x}_p(t) - \vec{x}_p(t)\right| \quad (24)$$

$$\vec{x}(t+1) = \vec{x}_p(t) - \vec{a}.\vec{e} \quad (25)$$

Where x_p is the position vector of the prey, x defines the position vector of the gray wolf, and t is the current iteration; a, c, and e represent the coefficient vectors. The following is an estimation of the vectors a and c:

$$\vec{a} = 2\vec{b}.\vec{r} - \vec{b} \quad (26)$$

$$\vec{c} = 2.\vec{r}_2 \quad (27)$$

Where r_1, r_2 are random vectors in the interval and the components of b decrease linearly from 2 to 0 [0, 1].

3. Simulation outcomes and analysis

Under the influence of the sun, the functioning of the entire system is examined, while taking the shading phenomenon into account. Realizing that, under these circumstances, the statistical feature $P_{pv}=f(V_{pv})$ presents, in essence, several MPPs, only one of which is considered to be a global MPP and the rest to be partial.

3.1. 1st shading profile

Figure 7 depicts the simulation findings. Under the first shading profile, there is a global peak (P_G) and two (02) partial peaks (P_{P1} and P_{P2}) of maximum powers. Moreover, Figure 8 shows that under this condition, only the advanced algorithms PSO, CS and GWO detect the global maximum power (P_G=114W). But it is also interesting to note that the rhythm P_{pv} for CS and especially PSO have too many oscillations before extracting the maximum point.

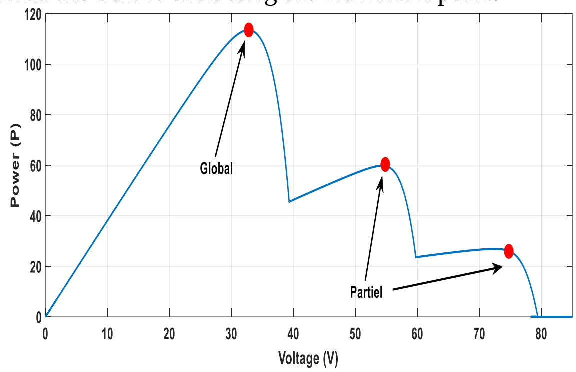

Fig.7. First shading profile.

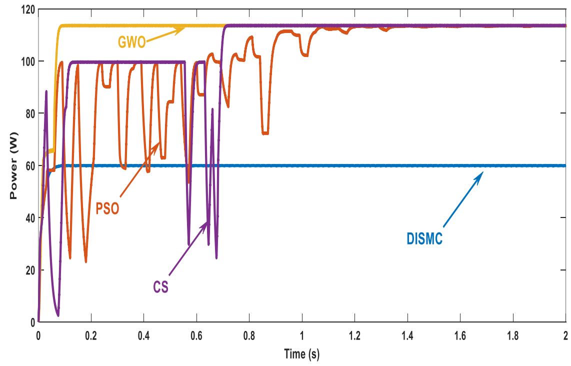

Fig.8. PV powers.

3.2. 2nd shading profile

Figure 9 illustrates the characteristic $P_{pv}=f(V_{pv})$ as a result of this second shading profile. It is characterized by a global peak (P_G) and three (03) partial peaks of maximum power.
Moreover, Figure 10 shows that under this condition, only the advanced algorithms PSO, CS and GWO detect the global maximum power (P_G=116W). But it is also interesting to note that the rhythm P_{pv} for CS and especially PSO have too many oscillations before extracting the maximum point.

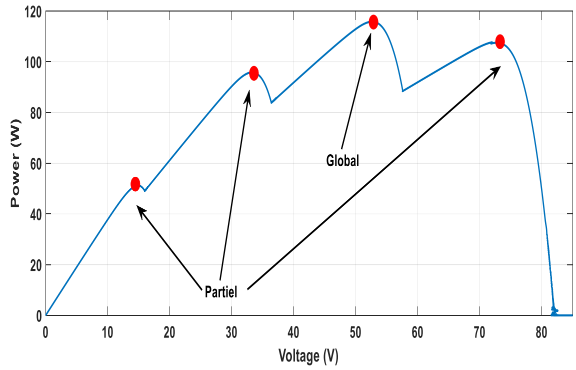

Fig.9. Second shading profile

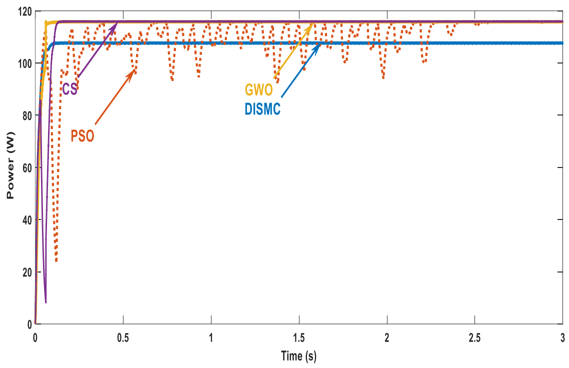

Fig.10. PV powers.

3.3. 3rd shading profile

Figure 11 illustrates the characteristic $P_{pv}=f(V_{pv})$ as a result of this third shading profile. It is characterized by a global peak (P_G) and one (01) partial peak of maximum power. Moreover, Figure 12 shows that under this condition, all the algorithms DISMC, PSO, CS and GWO detect the global maximum power (P_G=100W). But it is also interesting to note that the rhythm P_{pv} for CS and especially PSO have too many oscillations before extracting the maximum point.

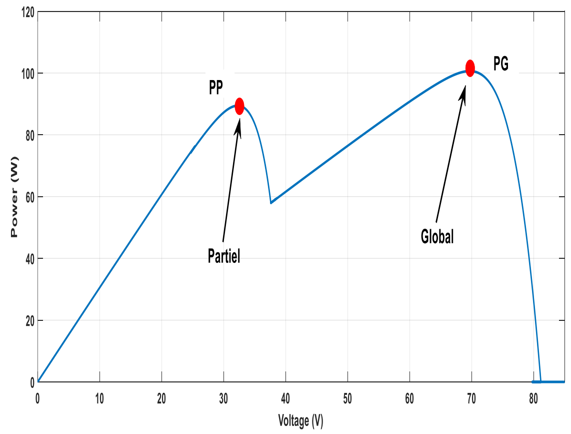

Fig.11. Third shading profile

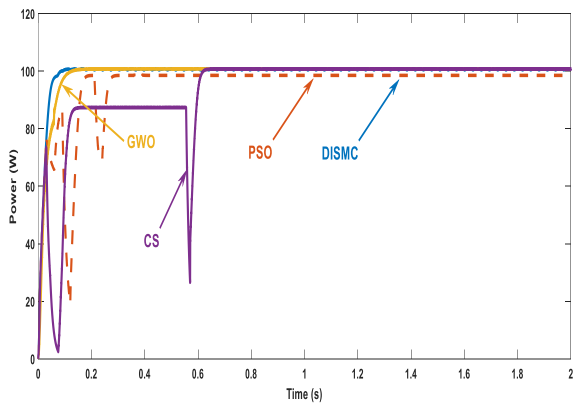

Fig.12. PV powers.

And, for the comparative analysis, the superposition of the waveforms of the powers, obtained by the algorithms of the four . Table 1 lists the four examined algorithms' MPPT efficiency, maximum power point, and response time (T_r).

Table 1. Comparison of algorithms

Shady		1st shading profile	2nd shading profile	3rd shading profile
P_{Max} (W)	DISMC	60	107,8	100,8
	PSO	113,5	115,75	99
	CS	113,6	115,85	100,74
	GWO	113,6	115,75	100,75
T_r (s)	DISMC	0,07	0,1	0,075
	PSO	1,028	0,94	0,27
	CS	0,68	0.09	0,62
	GWO	0,06	0,06	0.12
MPPT yield (%)	DISMC	52,63	92,93	99,80
	PSO	99,56	99,78	98,01
	CS	99,64	99,87	99,74
	GWO	99,64	99,78	99,75

The table shows that the DISMC technique is trapped in the partial point, so the power losses are significant. The GWO-based simulation result offered the shortest response time. Comparing the proposed MPPT to the technical PSO and CS, The GWO demonstrates that the proposed MPPT definitely follows the global point with faster convergence. System efficiency is raised as a result of the reduction of oscillation-related power loss in GWO-based systems.

However, for the DISMC, despite its better performance, its inability to detect the global point results in a significant loss of power.

At the same time GWO offered the best response time and it clearly follows the global point with faster convergence than other meta-heuristic techniques.

It can be seen that with the GWO algorithm the system operates on the global maximum point, which proves the economic and technical advantage of this installation.

4. Conclusion

It is evident that the GWO algorithm allows the system to run at the global maximum power point, demonstrating both the technical and economic benefits of this installation. Compared to the other three approaches, GWO-based MPPT ensures faster tracking speed and speedy oscillation disappearance PSO, DISMC, and CS.
It has been shown that the proposed MPPT based on GWO gives faster tracking speed and consequent damping of oscillations compared to the other three methods, namely PSO, CS and DISMC and regardless of the partial shading profile it allows to 'reach global maximum power point.

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