Design of a Particle Swarm Optimized Photovoltaic system during various partial shading conditions

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Abstract. This work discusses an enhanced photovoltaic system using the Particle Swarm Optimization algorithm. The proposed method has been evaluated under several scenarios of partial shading, and the results obtained are contrasted with the Perturb and Observe technique. Hence, it has shown its effectiveness in locating the global maximum power point whatever the meteorological conditions, especially in inhomogeneous conditions. This technique makes it possible to enhance the effectiveness of the photovoltaic system studied because it makes it possible to minimize the loss of power in the case of non-homogeneous irradiation conditions.

1 Introduction

Solar photovoltaic energy is considered the greatest reliable sustainable energy source that respects the environment. For this reason, several studies have been effectuated aiming to optimize the production of this energy. But the main drawback of this is its dependence on different parameters, such as irradiation, cell temperature, shading as well as the overall aging of the photovoltaic components.

Among the techniques for optimizing PV energy, Maximum Power Point Trackers (MPPT) plays the primary role. Indeed, MPPT algorithms enhance the efficiency of PV systems.

The usefulness of these MPPTs is thought to the non-linearity of the photovoltaic generators' characteristics, and the fact that these characteristics have a single maximum power, as illustrated in Figure 1. In other hand, we can conclude from Figure 1.a that there is only one value of the load (i.e. optimal load) for which the operating point coincides with the Point of the Maximum Power (points B), otherwise, the operating point will be further from the Point of the Maximum Power (points A, C, and D).

On the other hand, a decrease or an increase in irradiation leads to a modification of the characteristics of the photovoltaic generators, as described in Figure 1.b. This leads to the modification of the position of the MPP and thus the position of the operating points (A', B', C', and D'). Which requires the use of an MPPT to track the MPP.

These algorithms differ from each other from the simplest, like the Perturb and Observe [1] method, the Incremental Conductance technique, and the optimization technique based on the Hill Climbing (HC) method [2], [3].

In the literature, other methods can be considered complex methods, among these techniques, we find trackers based on Fuzzy Logic (FLC) [2], [4]. The FLC technique allows overcoming the restrictions observed in classical methods (P&O and I&C) concerning the choice of the incrementation step in the case of unstable meteorological conditions. Neural networks are used in particular in tracking the maximum power point [5] and make it possible to obtain significant results.

The integration of neural networks in fuzzy controllers makes it possible to adjust the internal parameters of fuzzy controllers. These techniques, used in [6], [7] for example, improve the efficiency of PV systems, but on the other hand, require significant computation time. These complex trackers based on soft computing techniques have better yields, but they necessitate some requirements when implemented in reconfigurable circuits. Therefore, the main difficulty is to build high-performance algorithms that do not require large hardware requirements.

The presented techniques present high efficiency in standard conditions, but thanks to the unstable nature of meteorological conditions, this efficiency can make remarkable decreases. In the apparition of Partial Shading Conditions (PSC), this decrease becomes important since this phenomenon influences the characteristics of the photovoltaic generator, resulting in the appearance of several maxima in these curves as shown in Figure 2.

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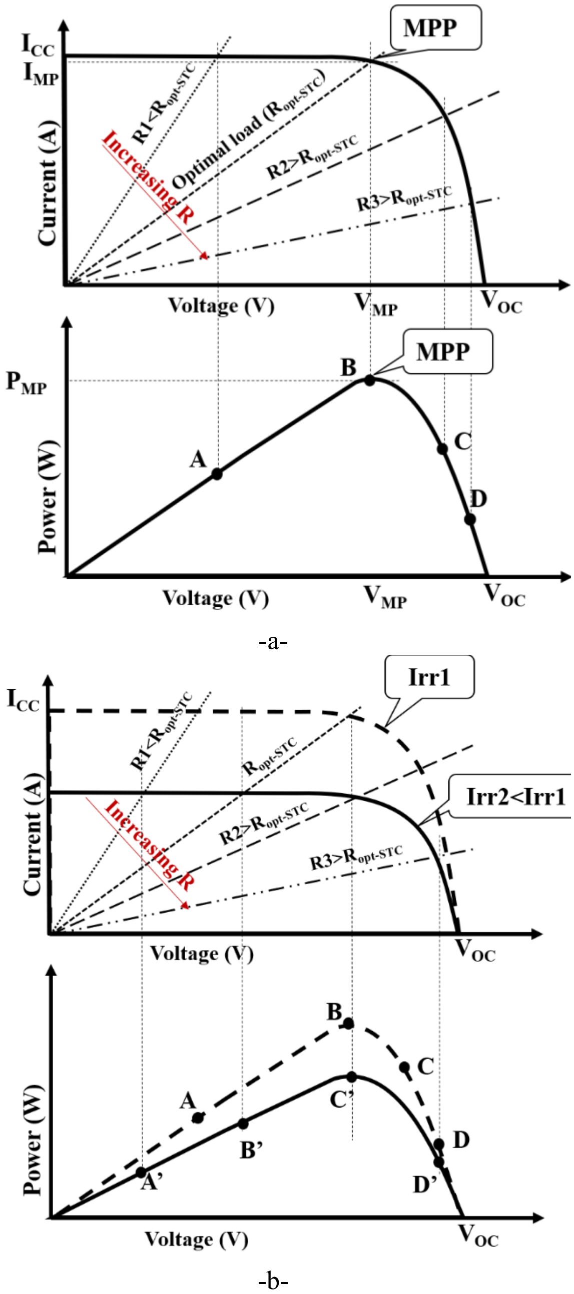

Fig. 1: Direct connection betwixt a PV model and a linear load

These conventional MPPT techniques often do not make it possible to track the true MPP (global MPP) since they cannot differentiate between local (points A, C, and D in Figure 1.a) and global MPPs (point B).

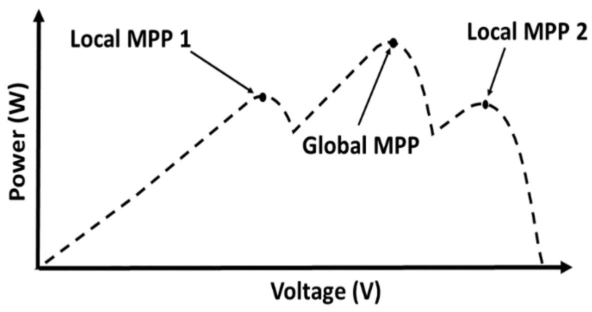

Fig. 2. Characteristics of photovoltaic generators

Among the most efficient techniques, the technique based on the β parameter demonstrates its effectiveness, especially in the detection of PSC [8]. This technique allows the detection of the existence of the PSC phenomenon, and thanks to a linear equation makes it possible to make the functional point in the proximity of the true MPP (Global-MPPT). However, an instantaneous change in weather conditions disrupts the operation of this technique.

Several other advanced Evolutionary techniques have been used to localize the global MPP, among which are the Artificial Bee Colony Optimization technique, and the Genetic Algorithm.

In this work, an MPP tracker based on the PSO technique is implemented on a PV system. This system consists of a photovoltaic array built from the storage of 4 PV modules, a Boost-type converter, and the presented MPPT-PSO. The studied photovoltaic system is summarized in Figure 3.

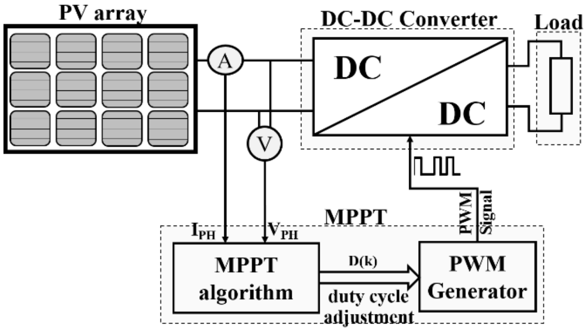

Fig. 3. PV system studied.

2 Modeling of the Studied photovoltaic System

2.1 Modeling a PV array

A PV generator is conceived by the arrangement in series and parallel of PV cells, to furnish the desired voltage (parallel connection) and the output current (cells in series) values.

➢ **Modeling of photovoltaic cells**

In the literature, we found several equivalent models of a photovoltaic cell, but the most commonly utilized is the single diode model as described in Figure 4. It includes a source of current, one diode, a series, and parallel resistance. The resistances are used to model the power dissipation through the internal resistances of the PV cell during its operation.

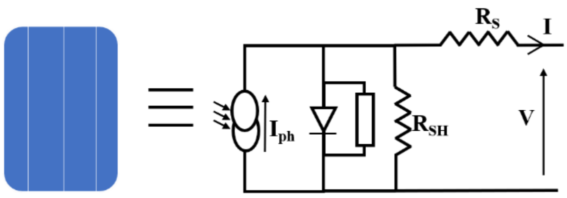

Fig.4 : Photovoltaic cell model.

From Figure 4, the generated current by the photovoltaic cell can be presented by (1) [9].

$$I = I_{ph} - I_{S0}.(e^{\frac{V+IR_S}{\alpha V_T}} - 1) - \frac{V + IR_S}{R_P} \quad (1)$$

With,

- I_{ph}: the photo-current of the cell
- Is0: the inverse PV cell diode saturation current
- A: The factor of the ideality of the diode
- T: Cell temperature
- V: The PV cell voltage
- I: The generated current of the cell

➢ **Modeling of a Photovoltaic Array:**

A photovoltaic generator consists of several photovoltaic cells arranged in series and/or in parallel. In this paper, the BP365TS module with 65.25 W of maximum power, which contains NS=18 cells mounted in series, has been selected to ratify the system.

The I(V) characteristic of such generator PV (made up of NS ×NP cells) is represented by equation (2).

$$I = N_P(I_{ph} - I_{SO}(e^{\frac{V+IR_S}{\alpha V_T N_S}} - 1) - (\frac{V + IR_S}{N_S.R_P})) \quad (2)$$

To meet the needs of consumers, PV arrays are designed to generate remarkable voltages. These arrays are made by the arrangement of PV generators in series and/or in parallel. In the present work, a PV array designed from the series arrangement of four PV modules (BP365TS) is used, Figure 5 illustrates the diagram of the PV used array.

As shown in Figure 5, anti-return diodes are used when making the PV generator. These diodes contain bypass diodes in parallel and blocking diodes in series. Blocking diodes are used in photovoltaic generators to prevent reverse currents, and bypass diodes are used to eliminate the creation of hot spot phenomena that can damage PV cells and allow PV generators to operate with high reliability throughout their lifespan.

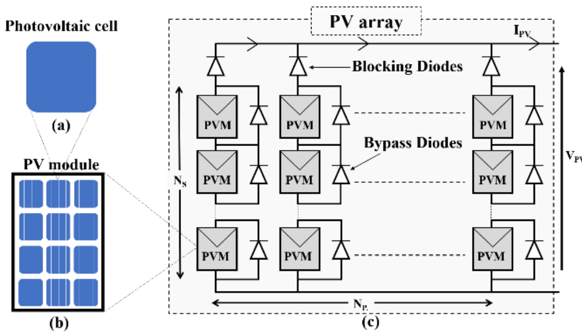

Fig. 5. Photovoltaic array.

2.2 Modeling of a boost converter

The DC-DC converter is an important component in the electronic domain, its part is to transfer a DC voltage into a same type voltage but with a different level [10]. Figure 6 presents the equivalent circuit of a boost converter[11].

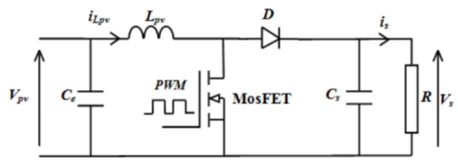

Fig. 6. Boost converter

The values of the parameters constituting the Boost converter must verify the conditions of the relations (3) and (4).

$$L \geq \frac{(1-D)^2.D.R}{2fc} \quad (3)$$

$$C \geq \frac{V_0.D.R}{\Delta V_0.f.R_{min}} \quad (4)$$

Where ΔV0 is the ripple voltage.

By respecting the conditions mentioned in (3) and (4), the values used in the DC-DC converter are described in Table1.

Table 1. Parameter of the boost DC-DC converter used

Parameter	Value
Switching-frequency	50 KHz
Inductance, L	1.148 mH
Input Capacity, C_{in}	10 µF
Output Capacity, C_{out}	468 µF
Load, R	23 Ω

2.3 Algorithm Perturb and Observe

The Perturbation and Observation method consists of perturbing (increasing/decreasing) the PV voltage with a predetermined voltage value V_{ref} to reach MPP. The PV power $P_s(k)$ is then evaluated for each iteration, this value is then compared to P_s (k-1). If the output P_s (k) is superior to the output P_s (k-1), the variation of the next perturbation will be maintained in the previous orientation, otherwise, it will go in the observed orientation. The diagram of this technique is shown in Figure 7.

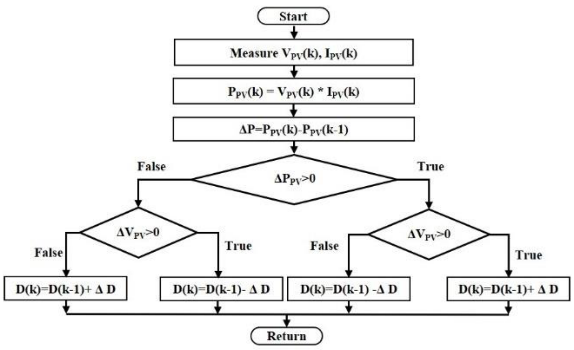

Fig. 7: Perturb and Observe flowchart

2.4 Modeling of the Particle Swarm Optimization method

The PSO method is a metaheuristic approche commonly utilized in the optimization of complex systems. This technique is inspired by the living world

[12], [13], it is an evolutionary algorithm that uses an ensemble of candidate solutions to locate the optimal solution to the problem under study.

Mathematically, this method can be modeled according to two main factors, the velocity defined by equation (5) and the position of the particle defined by (6) [13]. The principle of this method is described in Figure 8.

$$\vec{v_i}(k+1) = \omega.\vec{V_i} + C_1 r_1\left(\overrightarrow{p_{best}} - \vec{d_i}\right) + C_2 r_2\left(\overrightarrow{g_{best}} - \vec{d_i}\right) \quad (5)$$

$$d(k+1) = d_i(k) + v_i(k+1) \quad (6)$$

With;

- $v_i(k)$: The i[th] instantaneous particle velocity.
- $d_i(k)$: The i[th] particle.
- $\overrightarrow{P_{best}}$: Best position through the particle (i).
- $\overrightarrow{G_{best}}$: Best position (global position).
- ω : The inertia coefficient.
- $c_{1,2}$: The acceleration parameters.
- $r_{1,2}$: Random parameters on the interval [0,1] applied to the i[th] particle.

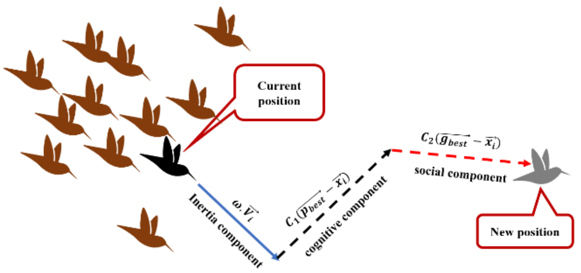

Fig. 8. Principle of the PSO technique.

In the present work, the PSO algorithm is utilized to regulate the duty cycle value used to control the PWM generator. Equation (7) shows the relationship to determine this relationship.

$$d(k) = G_{best}(k) \quad (7)$$

The parameters used during the implementation of the studied PSO technique are described in Table 2.

Table 2. The PSO main parameters.

PSO parameter	Value
Inertia-Weight(w)	0.4
Personal-coefficient(c1)	1.2
Global-coefficient(c2)	2
Number of particles N	10

A minimum number of particles (N=10) is used to avoid computational complexity per iteration, this number is necessary to cover the entire search space for each iteration. The number of iterations is also chosen to avoid unnecessary additional computational complexity. The inertia weight (w=0.4) is chosen in order to avoid delayed convergence (large inertia weight) and local trapping (low weight). This value is fixed after several trial and error tests. Finally, the values of the acceleration coefficients are chosen so that (c2 >> c1). This condition is used so that the particles are more strongly attracted toward the best global position.

3 Results and discussion

The photovoltaic generator is exposed to various partial shading situations for examining the efficiency of the presented method. Fig 9, 10, and 11 present the results obtained for the following scenarios:

- Scenario 1: Instant change of irradiation.
- Scenario 2: (1000 – 1000 – 1000 – 1000) W/m2.
- Scenario 3: (500 – 800 – 1000 – 1000) W/m2.

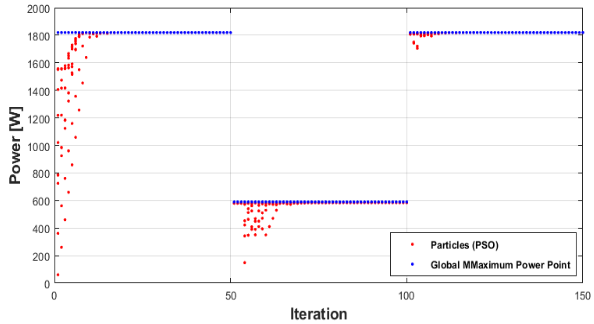

Fig. 9. Instant change of irradiation (scenario 1).

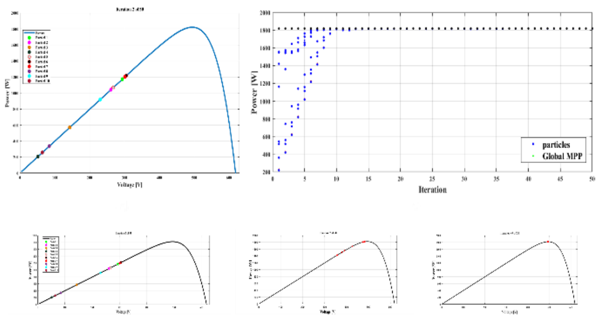

Fig. 10. Results obtained for scenario 2 (a, b, and c: Position of swarm particles, d: History of particle positions)

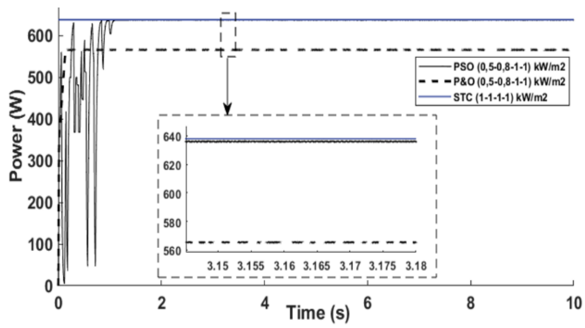

Fig. 11. Comparison between PSO and Perturb and Observe technique (scenario 3).

The obtained results prove the efficiency of the PSO approche compacted to the conventional methods since it allows to follow the true MPP with zero oscillation. In contrast to the Perturb and Observe technique, which does not differentiate betwixt maxima local and global, the PSO method allows for localization of the global MPP among a set of local maxima.

4 Conclusion

In this work, an MPPT relying on the PSO algorithm is presented and implemented in a PV system. The PSO is utilized to surmount the problem of locating the global MPP among local maxima that occurred in the presence of PSC. The obtained results prove the efficiency of the presented approach, with a 12.6% improvement in performance over the Perturb and Observe controller.

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