Analysis of Genetic and Cuckoo Search Algorithms for MPPT in Partial Shaded

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Received: 01.03.2024 Accepted:30.03.2024

Abstract- The exploitation of solar energy through photovoltaic technology has become crucial for electricity production. To maximize this production, optimizing solar radiation is essential. However, various challenges for example fixed structures, structures, and winds carrying sand particles can diminish light intensity, thereby reducing efficiency. These conditions may result in multiple maximum power points appear on the static characteristic of maximum power as a function of photovoltaic voltage. curve. Consequently, more efficient metaheuristic algorithms for maximum power point tracking are needed to ensure optimal operation, particularly during inclement weather and instances of partial shading, such as non-uniform irradiation. This work provides a comparative analysis of metaheuristic approaches specifically Cuckoo Search and Genetic Algorithm, used for tracking the maximum power point in photovoltaic systems under partial shading conditions.

Keywords: Photovoltaic, Shading; Optimization metaheuristic; Cuckoo Search; Genetic algorithm.

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1. Introduction

The increasing utilization of photovoltaic systems for electricity generation relies on the deployment of photovoltaic (PV) connected in series and parallel configurations. These solar panels harness sunlight to produce usable electrical power. However, to maximize this power, it is crucial to adjust the system's internal resistance to match that of the load perceived by the source. Photovoltaic generators incorporate DC/DC power converters that adjust their operating cycle based on climatic conditions to enhance the optimization of maximum power point tracking (MPPT). These MPP tracking devices are equipped with algorithms specifically designed for this purpose. Among the most common algorithmic methods are Perturbation and Observation (P&0), hill climbing, INcremental Conductance (INC), short circuit current tracking, open-circuit voltage tracking, and ripple correlation techniques [1-6].

Some algorithms have been tailored to reduce hardware requirements and enhance performance [7-11]. Unfortunately, these methods are reliable only when the photovoltaic generator (PV) is exposed to uniform irradiation, where only one peak appears in the photovoltaic supply voltage characteristics. Conversely, in the presence of non-uniform partial shading, bypass diodes generate multiple peaks, among which only one is global and must be targeted to ensure optimal system efficiency [12]. Consequently, the presence of multiple peaks reduces the effectiveness and efficiency, thereby complicating the process of maximizing the performance of conventional MPPT techniques. Since partially shaded conditions are common, it is crucial to implement more advanced algorithms capable of detecting the global peak independent of shading profile and weather conditions. Previous proposals suggest two stages for tracking global power: state space analysis to locate the global peak. This approach is rapid and accurate but requires additional sensors and is system-specific, making it complex. Recently, artificial intelligence methods have been employed to maximize power. However, in this study, global power point tracking is accomplished using a genetic algorithm (GA) and the Cuckoo Search (CS). The results obtained with this approach are analyzed and discussed under various partial shading profiles, demonstrating the superiority and effectiveness of this method.

The objective of this work is to investigate and carry out an extensive comparative analysis of two distinct algorithms aimed at tracking the ultimate maximum power point of a photovoltaic (PV) system under partial shading (PS). The aim of this research is to provide a thorough understanding of their performance in dynamic PS conditions. By conducting a thorough evaluation and comparing these algorithms, our aim is to make a substantial contribution to the wider field of MPPT technologies within the context of solar energy. Our goal is to provide an equitable evaluation of their individual advantages and disadvantages. We employ Matlab/Simulink for validation purposes, and a comprehensive analysis of the findings is outlined in the complete research report.Validation using Matlab/Simulink.

2. System Structure and Modeling

Figure 1 depicts the system configuration under investigation, comprising a photovoltaic generator (GPV), Boost converter, a power load circuit, and MPPT control unit aimed at optimizing power extraction from the GPV across varying operational scenarios.

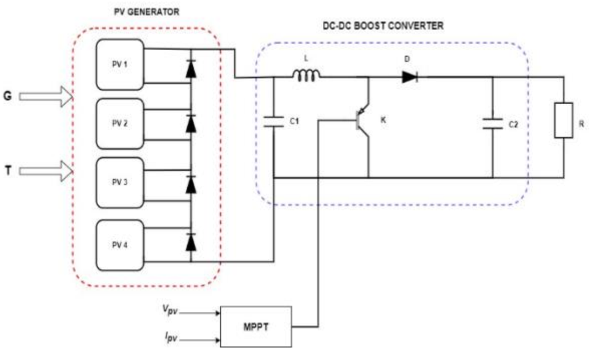

Fig. 1. System structure.

The output power characteristics of a photovoltaic panel are contingent upon its output voltage. Maximizing the available power from the PV generator involves operating the generator at the voltage level capable of producing this maximum power. To maintain a consistent output, the converter regulates the DC-DC link voltage through pulse width modulation (PWM).

2.1 Modeling Photovoltaic System

Modeling the parameters of the photovoltaic system is essential to prepare for the simulation and performance analysis phase [13-14]. The single-diode model is considered (See Figure 2) because of its advantages: simplicity of design and ease of analysis of performances. Modeling the single diode circuit PV panel requires four parameters.

The modeling of photovoltaic parameters is drawn from the references [13, 14]. The utilization of the single-diode model (refer to Figure 2) is favored due to its inherent benefits, including its straightforward design and the simplicity it offers in analyzing photovoltaic performances. This model necessitates four key parameters to effectively represent the single diode circuit of the photovoltaic panel.

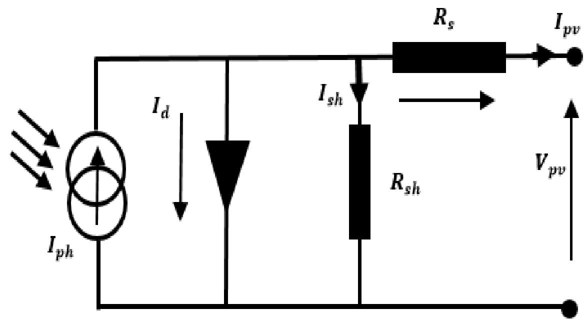

Fig. 2. Equivalent diagram of a PV cell.

$$I_{pv} = I_{ph} - I_0\left[e^{\left(\frac{q(V_{pv}+I_{pv}R_s)}{nkT}\right)} - 1\right] - \frac{V_{pv}+I_{pv}R_s}{R_{sh}} \qquad (1)$$

Where,

I_{ph}: photocurrent; I_0: diode saturation current; I_{pv}: terminal current; V_{pv}: voltage across the output terminal; R_s: module series resistance; R_{sh}: modules hunt resistance; N_s: number of cells in one module; k : Boltzmann's constant ; n: diode ideality factor ; T : absolute temperature; q: elementary charge.

MatLab/Simulink software is employed in this work for programming PV cells and GPVs. The I-V and P-V characteristics are illustrated in Figure 3. One can clearly observe that the MPP varies significantly with variations in irradiance level. Similarly, it can be noted that the open-circuit current magnitude increases with higher irradiance levels.

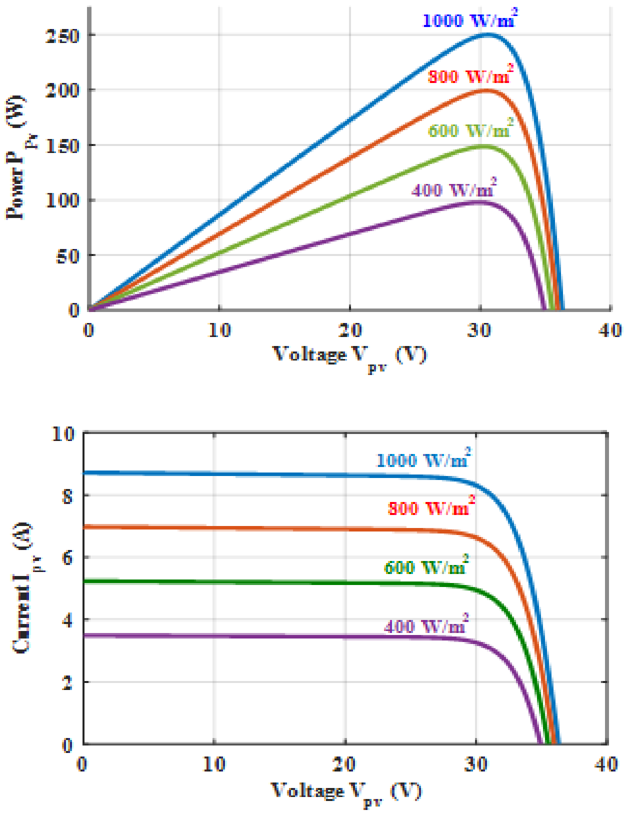

Fig. 3. $I_{pv}=f(V_{pv})$ and $P_{pv}=f(V_{pv})$ with irradiation variable.

2.2 Modeling the DC-DC Boost Converter

The DC-DC converter plays a crucial role within a PV system, particularly in managing the duty cycle. Figure 4 illustrates the components of the Boost converter, comprising a switch, diode (D), inductor (L), capacitor (C_2).

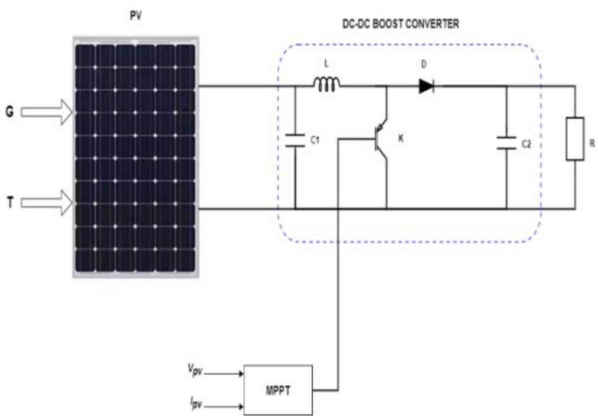

Fig. 4. Boost converter circuit.

The IGBT boost controller switch is controlled by a duty cycle (α) and the DC voltage of the DC-DC boost converter is [15]:

$$\frac{V_{out}}{V_{in}} = \frac{1}{1-\alpha} \tag{2}$$

Where, V_{out} represents the output voltage, V_{in} denotes the input voltage of the boost converter sourced from the photovoltaic array, and (α) refers to the duty cycle generated by the MPPT controller to increase the input voltage using PWM.

The converter employed in this paper has been designed based on the parameters provided in Table 1:

Table 1. Boost system parameters.

System Parameters	Value
DC link capacitor	C_{in}=4ms
Capacitor output	C_{out}=500ms
Input inductor	L=40ms
Switching frequency	f_s=100KHz

2.3 MPPT Control with Genetic Algorithm

GA-based optimization is a dynamic heuristic search approach involving the generation, systematic evaluation, and refinement of potential solutions until reaching a predefined termination condition. The search process of a genetic algorithm revolves around three important operators: selection, crossover, and mutation. Selection entails choosing a chromosome from the actual population generation based on its fitness for inclusion in the subsequent generation's population [16]. The crossover operator combines two chromosomes to generate a new chromosome (offspring). Meanwhile, the mutation operator preserves genetic diversity across population generations, introducing stochastic variability to expedite convergence [17].

The procedural steps for implementing the genetic algorithm are outlined as follows:

Step 1: Specify the cost function (CF) and determine the parameters used in the design.
Step 2: Create the initial population.
Step 3: Assess the population using the CF.
Step 4: Verify convergence. If criteria are met, halt; otherwise, proceed.
Step 5: Commence the reproduction process by applying genetic operators.
Step 6: Advance to the next generation. Return to step 3.

Genetic algorithms (GAs) are optimization algorithms devoid of gradients, operating in parallel, employing a performance measure for assessment, and a multitude of potential solutions to explore a global optimum. GAs exhibit proficiency in navigating intricate and irregular solution landscapes, showcasing their versatility across a range of formidable optimization tasks [18].

The flowchart depicting the Genetic Algorithm and the parameters employed in this study are illustrated in Figure 5 and detailed in Table 2, respectively.

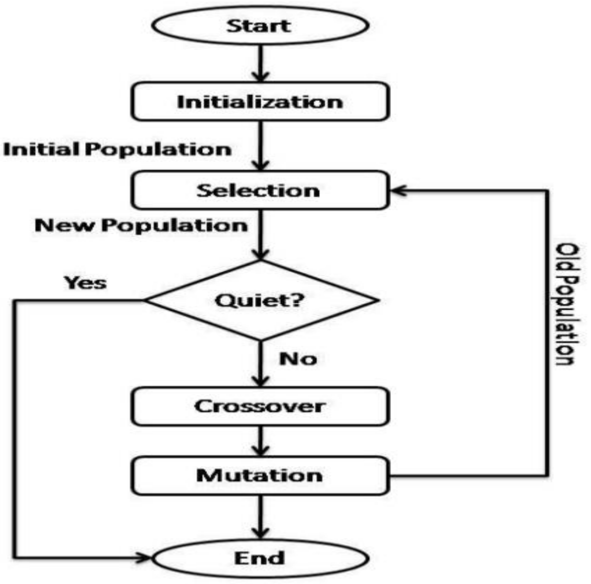

Fig. 5. Flow chart of Genetic Algorithm.

Table. 2 .Parameters system of GA

Dimension of Problem	Value
Population Size	100
Max_Iteration	130
Crossover Probability	0.08
Mating	Single point crossover

2.4 Cuckoo Search Algorithm

Figure 6 illustrates the flowchart depicting the search mechanism utilized by the CS-based tracker [19]. Initially, the number of utilization cycles is assigned randomly.

Subsequently, each cycle is applied to the PVPS, and the system's current and voltage are measured to estimate the PVPS power [20]. This power represents the fitness value. The utilization cycle associated with the best fitness function is selected as the current best nest (d_{best}). Then, Levy flight is applied for generate new nests [21]. The fitness of the new nests is evaluated using the PVPS, followed by a random destruction of the least fit nest with a probability, mimicking the behavior of a host bird discovering and eliminating cuckoo eggs. The new nest replaces the destroyed one through a Levy flight, after which the photovoltaic power is measured, and the current best nest is identified. The CS-based tracker continues until the termination criterion is met, at which point it ceases operation and provides an optimal duty cycle corresponding to the global power [22].

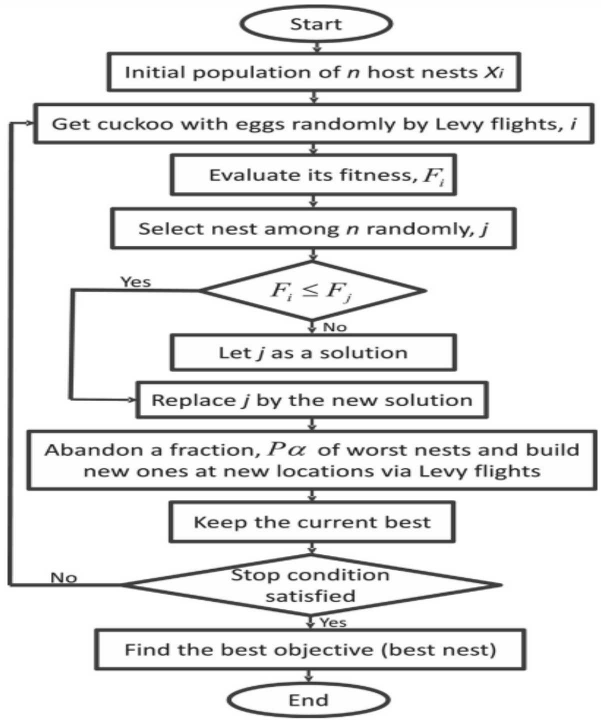

Fig. 6. Algorithm of the Cuckoo Search [19].

3. Simulation and Results

This section focuses on assessing the performance and efficacy of the GA technique employed to regulate the overall maximum power point achievable by a PV array in the presence of PS. To this end, simulations were conducted to test the system's behavior under four different shading profiles, as shown in Table 3 and Figures 7. Their respective specifications are indicated in Table 3. The simulation results obtained, particularly the photovoltaic voltage and power, as well as the duty cycle, are presented in Figures 8 and 9. It is noteworthy that the first profile corresponds to the absence of shading, while the other profiles were chosen to have a different number of maximum power peaks, corresponding to the 2nd and 3rd profiles, respectively. The objective is to ensure that the MPPT can extract the overall maximum power for each case. However, the results confirm our intention, showing that the system operated exactly at the desired performance level in each test.

Table 3. Profiles type and specifications

Profils	G (W/m^2)	PG (W)
Profil 1	**[1000,1000,1000, 1000]**	**250**
Profil 2	**[1000,1000,1000, 450]**	**160**
Profil 3	**[900 900 750 300]**	**125**
Profil 4	**[850 600 400 200]**	**78.7**

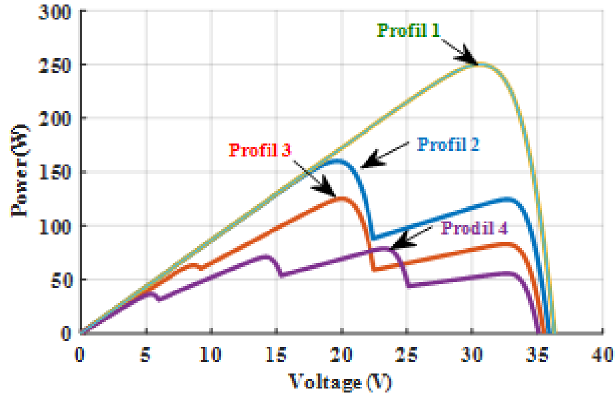

Fig. 7. Organigramme de la P&O

Table 4. Tableau de comparison

		Ppv_max	Duty Cycle	MPP Track	Track Time	Efficiancy (%)
Profil 1	CS	249.8	0.52	Success	0.18	99
	GA	249.18	0.4925	Success	0.25	97
Profil 2	CS	159.819	0.599	Success	0.25	99
	GA	159.01	0.5358	Success	0.53	96
Profil 3	CS	125.01	0.5982	Success	0.2	99.9
	GA	125.8	0.5358	Success	0.28	98
Profil 4	CS	78.621	0.53775	Success	0.2511	99
	GA	78.552	0.501	Success	0.2598	97

The results article are evaluated under PS conditions, as presented in comparison table 4. The simulation results in this article have demonstrated that the average tracking efficiency in the case of CS and GA algorithms is 99% and 98.5%, respectively, with an average response time of 0.21 s and 0.251 s, respectively. Therefore, the Cuckoo Search algorithm is more effective and faster compared to the Genetic Algorithm

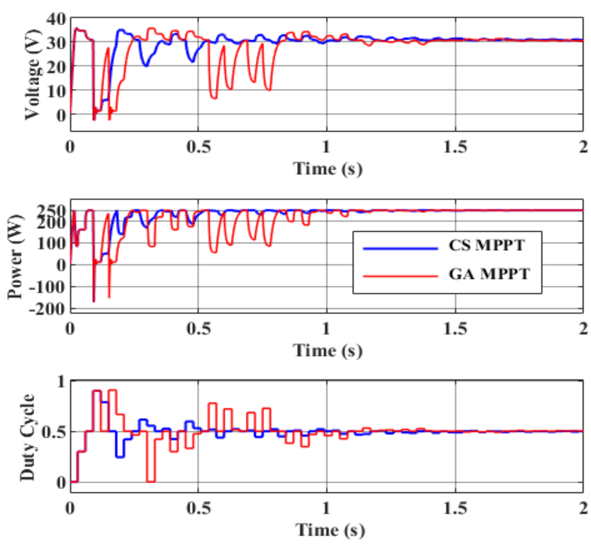

Fig. 8. Results in uniform profiles

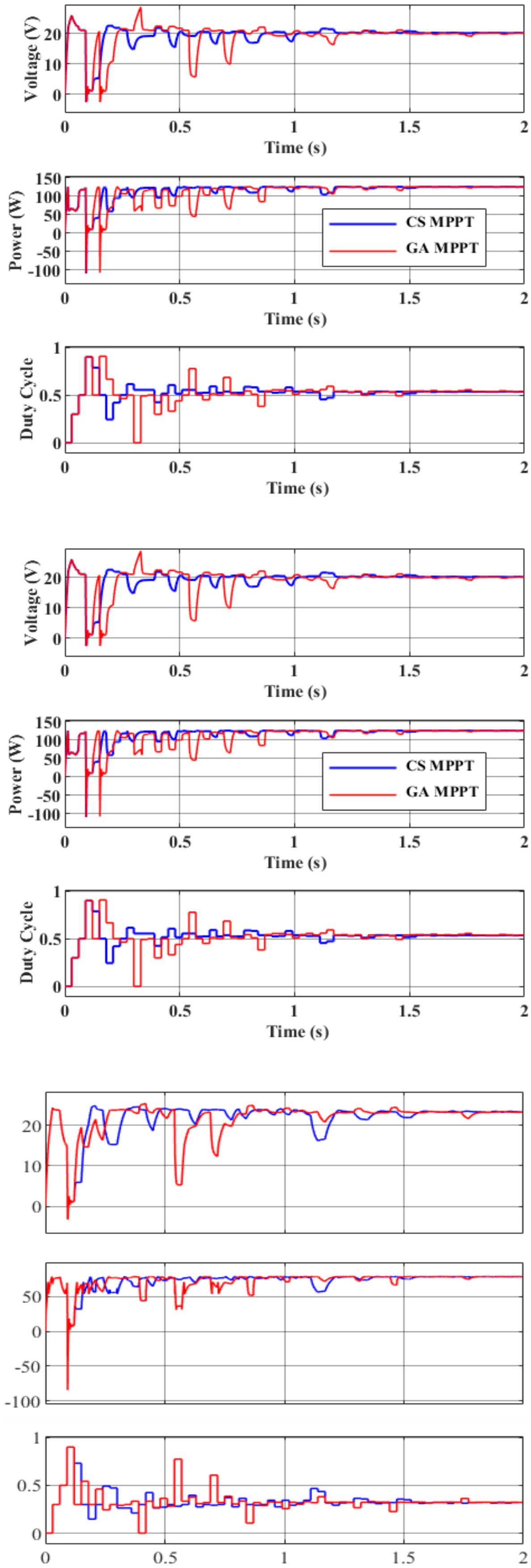

Fig. 9. Results in shading profiles

4. Conclusion

Detecting the MPP is highly efficient for a uniformly shaded photovoltaic panel system. The results indicate that the Cuckoo Search algorithm easily detects the global MPP compared to the Genetic Algorithm. MatLab/Simulink simulations are performed to evaluate the MPPT method utilizing the Cuckoo Search algorithm across a range of operating conditions. The simulation results demonstrate that this approach is effective and accurate, exhibiting a high convergence rate in the search space of photovoltaic conversion system properties, regardless of weather conditions, particularly uniform or non-uniform variations in solar irradiation.

In conclusion, the use of metaheuristic algorithms, such as the Cuckoo Search algorithm and Genetic Algorithm, demonstrates significant value in tracking the global power point under non-uniform shading conditions. While both approaches offer distinct advantages, particularly in terms of convergence speed and exploration of the search space, the Cuckoo Search algorithm stands out for its ability to more effectively exploit potential solutions. Consequently, integrating the Cuckoo Search algorithm into the design of solar power tracking systems can lead to enhanced performance, ensuring better adaptation to variable environmental conditions, especially in the presence of non-uniform shading. However, as future prospects following this work, it would be highly valuable to validate it experimentally by testing the system under the adopted profiles using a photovoltaic emulator.

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