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Maximum power point tracking of partially shading PV system using cuckoo search algorithm

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ABSTRACT

This paper presents a cuckoo search (CS) algorithm for determining the global maximum power point (GMPP) tracking of photovoltaic (PV) under partial shading conditions (PSC). The conventional methods are failed to track the GMPP under PSC, which decrease the reliability of the power system and increase the system losses. The performance of the CS algorithm is compared with perturb and observe (P&O) algorithm for different cases of operations of PV panels under PSC. The CS algorithm is used in this work to control directly the duty cycle of the DC-DC converter without proportional integral derivative (PID) controller. The proposed CS model can track the GMPP very accurate with high efficiency in less time under different conditions as well as in PSC.

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1. INTRODUCTION

It is known that the world's electricity consumption will increase annually it is expected that further growth will be due to the increase in the number of population and the increasing demands of the modern way of lifestyle [1, 2]. Therefore, there is a need to develop renewable energy sources to ensure sustainability high power supplies to the consumer, as well as to reduce local and global room pollution. The main problems in the practical use of Pa V power generation system (PGS) are the relatively low efficiency of conversion of primary energy (from 9 to 17%) and the pronounced dependence of the solar cell's energy characteristics on external climatic conditions [3-5]. Solar panels consist of several series-parallel connected solar modules and are designed for direct conversion of solar energy into electrical energy with the necessary values of constant voltage and current.

The power characteristics of solar cells have a nonlinear convex shape with an extremum, so to obtain the maximum available power it is advisable to operate them at the maximum power point (MPP). On the other hand, the generated power of solar panels depends on the operating conditions: the intensity of solar radiation, ambient temperature [6]. Changing in one or all of these conditions will lead to change in the position of MPP. So the search and tracking of MPP in real operating conditions are one of the ways to improve the operational efficiency of the solar panel. With no Shading, many conventional methods of having been developed for MPPT, the most common methods among them are a constant voltage MPPT, perturb and observe (P&O) and its numerous modifications, and incremental inductance method [7-11]. Under partial shading, the P-V characteristic has many local peaks and one global peak [12-14]. The conventional methods are failed to track the GMPP. Recently, the researchers have worked how to track the GMPP under PSC using soft computing techniques.

Among them are the fuzzy logic control (FLC) [15], artificial neural networks (ANN) [16], Genetic algorithm (GA) [17], particle swarm optimizations (PSO) [18] and ant colony optimizations [19]. They test the performance of their algorithms under dynamic changes of the solar irradiance of the PV panel. Although the very high cost of implementation the ANN and fuzzy logic, they capable of tracking the GMPP with lower oscillation in power as compared to P&O algorithm. The major difference between the proposed CS and other techniques is that the proposed algorithm is used to control the duty cycle directly without using the without Proportional Integral Derivative (PID) controller [20].

In this paper, the CS algorithm is introduced to track the GMPP of the PV under fast variation of solar irradiance as well as partial shading condition. The proposed algorithm is compared with the P&O algorithm in different test cases and the efficiency of both of them are measured in each test case. Section two describes the modeling of single diode PV cell. The effect of PSC on PGS is explained in section three. Section four describes the CS and P&O and its applications in PSC. Simulation results of the developed model are explained in the sixth section.

2. SINGLE DIODE PV MODEL

A single diode equivalent circuit is the most common mathematical model of PV arrays that available in the literature. Figure 1 illustrates the equivalent circuit of the PV cell that used in the proposed model.

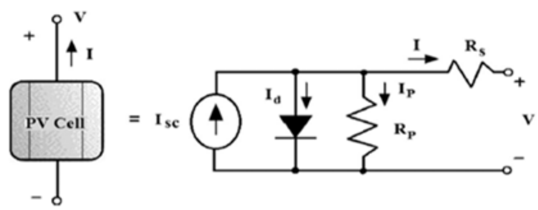


Figure 1. The equivalent circuit of a solar cell

The output current of the PV cell is calculated by the following equations [21]:

$$I = I_{sc} - I_D - I_p \tag{1}$$

$$I = I_{sc} - I_0 \cdot \left[\exp\left(\frac{q(V + I \cdot R_S)}{n \cdot k \cdot T} \right) - 1 \right] - \frac{V + I \cdot R_S}{R_p} \tag{2}$$

Where, V, I - is the value of output voltage and current of the PV cell; I_o- reverse saturation current of the diode; R_S и R_p series and parallel resistance of the solar cell; n is the ideality factor; T- is the absolute temperature of the PV cell; $k=1.38\cdot10^{-23}$ j/k Boltzmann constant.

A PV module consists of a large number of identical solar cells connected in series and in parallel, which allows increasing its voltage and output power. The main electrical parameters of the PV module that used in this work are summarized in Table 1.

Table 1. Specifications of PV Module

Parameter	Value
Maximum power rating P_{max}	249 w
Rated voltage V_{MPP}	30V
Open circuit voltage V_{OC}	8.3A
Short circuit current I_{SC}	8.83A
Rated current I_{MPP}	36.8V
Temperature coefficient of I_{sc}	(0.065±0.015) % / °C
Temperature coefficient of power	-(0.5±0.05) % / °C

3. PV MODULE UNDER PSC

In real operations, the PV modules are often subject with PSC, which resulted from clouds; trees; buildings; towers. As an example to show the effect of the shading on the PV module, four PV panels are connected in series. This configuration is named "4s1p" connection, as shown in Figure 2. To simulate that model in Matlab, PV output current is supplied to DC voltage controlled source as shown in Figure 3. The P-V and V-I for these cases are shown in Figure 4.

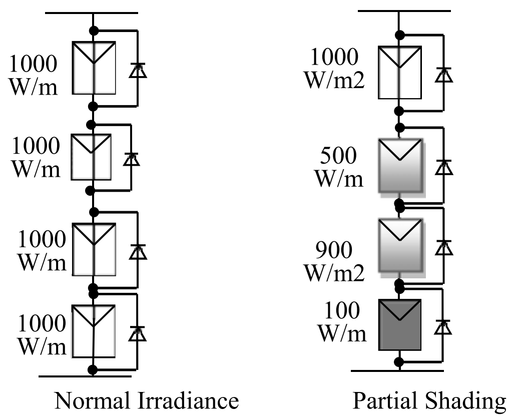


Figure 2. Normal Irradiance and PSC of PV panels

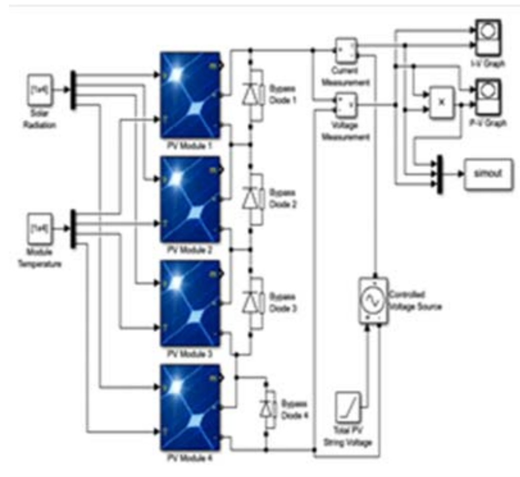


Figure 3. Interfacing mathematical PV module model to physical ports

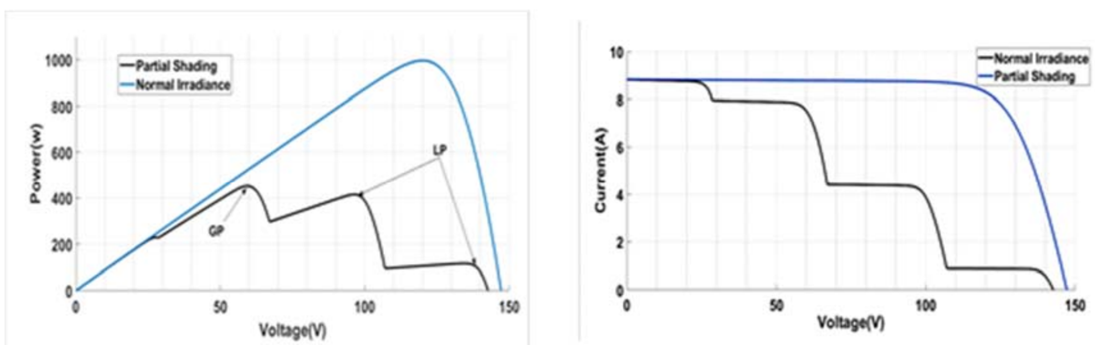


Figure 4. The P-V and V-I characteristics of PV panels under PSC

The current generated by PV under PSC is not constant. In case of normal irradiance of the PV panels, a constant current of approximately 8.3 A is generated at a functional operating voltage of 0 V to 120 V as shown in Figure 4. However, when the PV is under the PSC, the generating current cannot maintain a constant value. For example, in PSC, PV generates constant current 8.3 A from 0 V to 25 V, then decreases to 8 A, 4.1 A and 1.6 A at 55 V, 100 and 120 V, as shown in Figure 4. The PSC case demonstrate four peaks because it receives four different levels of irradiation.

4. CUCKOO SEARCH (CS)

Cuckoo Search (CS) was first developed by [Yang &Deb] [22]. These algorithms usually work based on a random search, which simulates the reproduction strategy of cuckoo birds. It is observed that several species of cuckoos perform brood parasitism, i.e. by laying their eggs in host birds' nests. Usually, three types of brood parasitism are seen (1) intraspecific, (2) cooperative and (3) nest takeover. Some host birds engage in direct conflict with the intruding cuckoos. If a host bird discovers the cuckoo eggs it will throw these alien eggs away or abandons its nest and builds a new nest elsewhere. Some cuckoo species have evolved in such a way that female parasitic cuckoos mimic the shape and color of the eggs of a few chosen host species. To increases its reproduction probability.

4.1. Lévy flight

Searching for a suitable host bird's nest is an important part of cuckoo's reproduction strategy. Normally, the search for the nest is similar to the search for food, which takes place in a random or in a quasi-random form. In general, while searching for food, animals choose directions or trajectories that can be modeled by certain mathematical functions. One of the most common models is the Lévy flight. A recent study by Reynolds and Frye shows that a Lévy flight can be thought of as a random walk where the step size has a Lévy probability distribution. In CS, nest searching is characterized by Lévy flight. Mathematically, a Lévy flight is a random walk where step sizes are extracted from Lévy distribution according to a power law as shown below [23]:

$$y = l^{-\lambda} \tag{3}$$

Where l is the flight length and λ is the variance. Since $1 < \lambda < 3$, y has an infinite variance. Figure 5 shows an example of Lévy flight in a two-dimensional plane.

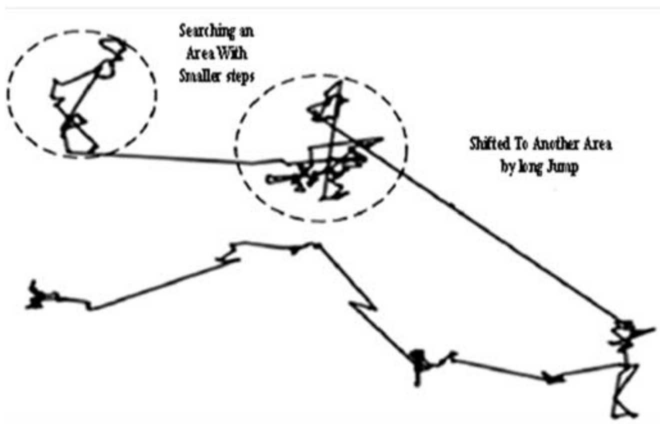


Figure 5. Example of Lévy flight in a two-dimensional plane

4.2. Cuckoo search algorithm

Three idealized rules for CS based on cuckoo's brood parasitic behavior: (1) Each cuckoo lays one egg at a time and places it in a randomly chosen nest (2) The best nest with the highest quality of eggs will be carried over to the next generation (3) The number of available nests is fixed and the number of cuckoo eggs discovered by the host bird maintains a probability Pa, where 0 < Pa < 1. When generating a new solution for a cuckoo, a Levy flight is performed as in the following expression [24] [25]:

$$x_i^{(t+1)} = x_i^{t} + \alpha \oplus Lévy(\lambda) \tag{4}$$

Where x_i^{t} are samples/eggs, i is the sample number, t is the number of iteration and α is the step size, which is related to the scales of the problem of interests. In most cases, we can use α=1. The product $\oplus$ means entry wise multiplications. The value of α is calculated by the following equation:

$$\alpha = \alpha_0 (x_j^{(t)} - x_i^{(t)}) \tag{5}$$

The value of Lévy (λ) is found from Lévy distribution given in Eq. 7

$$Lévy\ (\lambda) \approx u = l^{-\lambda} \tag{6}$$

5. MPPT USING CS

All the voltages are provided to the PV panels and the output power are calculated by the proposed model. The fitness function in CS is considered to be the output duty cycle that will fed to the Dc-DC boost converter at the GMPP of the PV panels, the d_{best} is the best one among the fitness. The duty cycle is changed in CS by the following equation:

$$d_i^{(t+1)} = d_{best}{}^{t} + \alpha \oplus Lévy(\lambda) \tag{7}$$

Where, $d_1 = d_1, d_2 \ldots n$

A simplified scheme of the Lévy distribution can be explained by:

$$s = \alpha_0 (d_{best} - d_i) \oplus Lévy(\lambda) \approx k \times \left(\frac{u}{(|v|^{\frac{1}{\beta}})}\right)(d_{best} - d_i) \tag{8}$$

Where, n=4, β=1.5 and k=0.8 is the Lévy multiplying coefficient (chosen by the designer), while u and v are determined from the normal distribution curves.

The flow chart of CS that illustrates how to use the algorithm to get the MPP of solar panel is shown in Figure 6.

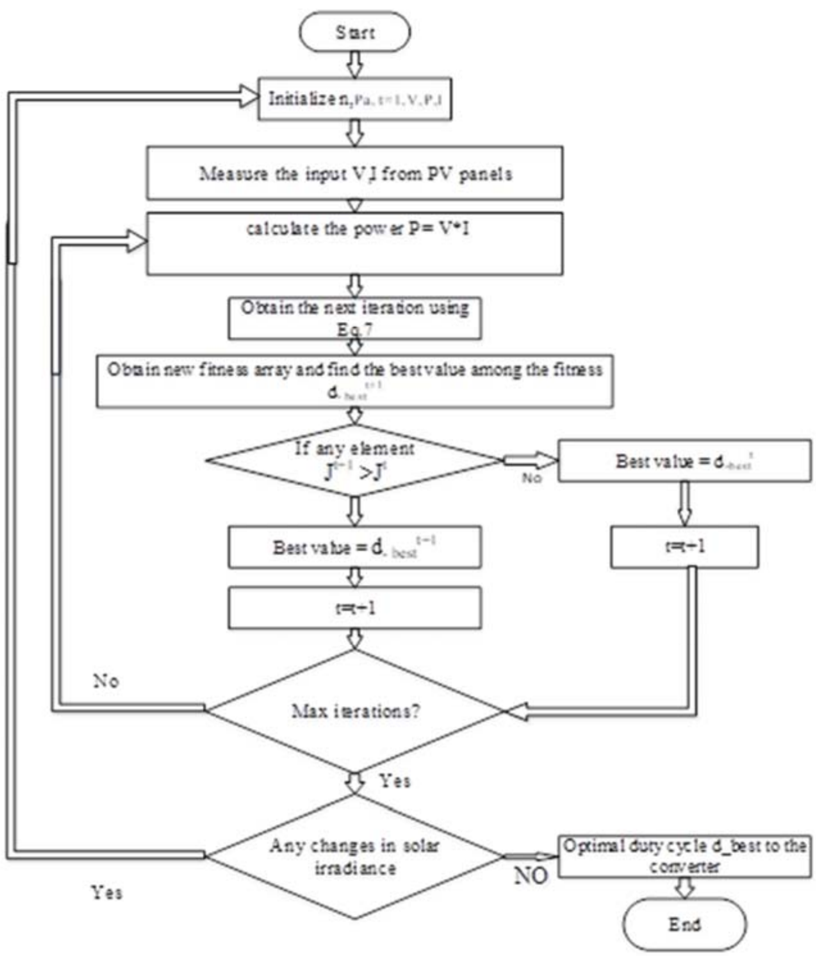


Figure 6. The flowchart of the CS algorithm

6. SIMULATIONS RESULTS

The proposed model is carried out in the Matlab/Simulink program software as shown in Figure 7. The DC-DC boost converter is selected in the proposed work to match the MPP controller with a resistive load. The selected parameters of the converter are;

L=1.1 mH; c_1=0.4*10^{-4} F, c_2=0.4mF and switching frequency f=25 kHz. The criteria for stopping the iterative process of calculations are the maximum number of iterations and the relative error in calculating the global extremum of the objective function:

$$\varepsilon = \frac{P_{best}^{i+1} - P_{best}^{i}}{P_{best}^{i}} \cdot 100 < 0.3 \tag{10}$$

Figure 8 and 9 show the performances of the CS and P&O for determination the GMPP of the PV under normal irradiance of the solar panels and in case of PSC that was shown in Figure 2. The following equation is used for evaluating the efficiency of the two algorithms in all cases

$$\eta = \frac{P_0}{P_{\max}} \cdot 100, \ \ \% \tag{11}$$

Where P_0 is the value of the output power of the PV panel, that tracked by the algorithm; $P_{\max}$ - the value of the maximum available power.

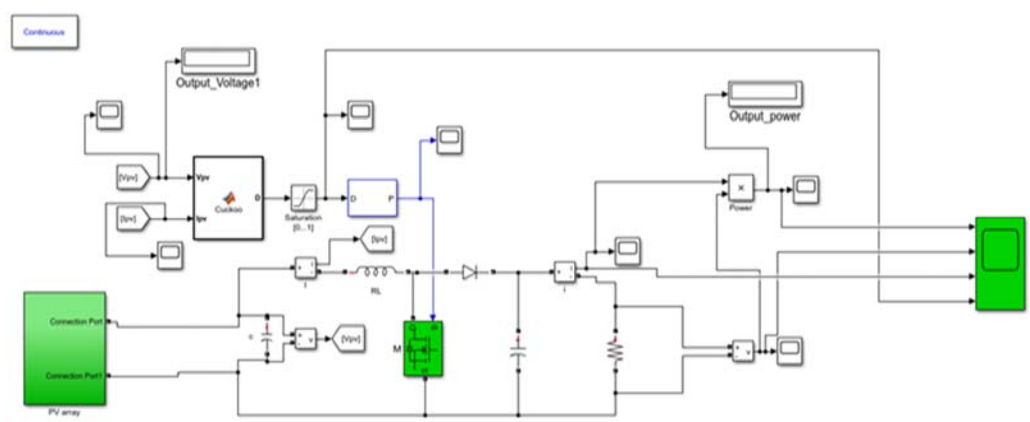


Figure 7. MATLAB/Simulink of the proposed model

As illustrated in Figure 8 the CS algorithm is able to track the GMPP of the solar panel after only four iterations the optimal duty cycle was (d_{best}=0.47) and the tracking time was 0.32 sec. Also in case of PSC the proposed algorithm tracked the global peak, while the P&O algorithm trapped in local peak which increase the system losses and reduce the reliability of the PV plant.

(a) (b)

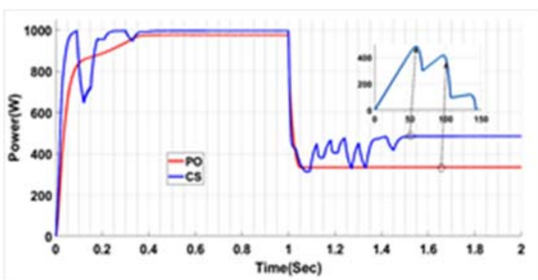
Figure 8. The performance of the two algorithms in the normal case (a) CS (b) P&O

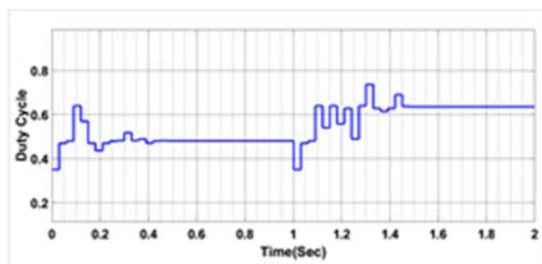
(a) (b)

Figure 9. The performance of the two algorithms in the PSC (a) CS (b) P&O

6.1. Fast variation of the solar irradiance under constant temperature

Case 3 are about the fast variation of the solar irradiance of the PV panel under PSC. In case 3, as illustrated in Figure 10. From time t=0 to t=1 sec all PV panels received the same amount of the solar irradiance G=1000w/m2, after t=1 sec the PSC occurs where, the solar irradiance of the PV panels were G1=1000 w/m2, G2=500 w/m2, G3=1000 w/m2 and G4=100 w/m. On the other hand, in case 3 as shown in Figure 10 after shifting from normal operations to PSC, the CS only can handle the GMPP in this case with highly tracking efficiency (η=99.7%), while the conventional P&O trapped at the local peak. Also, can be seen, the steady power performance of the CS are very well. Table 2 shows illustrates the detailed comparison between the CS and P&O for all test cases.





(a) (b)

Figure 10. (a) The performance of CS and P&O under fast variation of the PV under PSC. (b) duty cycle of the CS algorithm

Table 2. Results of the three cases of studies

case studies	CS			P&O		
	P_{max}, Watt	P_0, Watt	η,%	P_{max}, Watt	P_0, Watt	η,%
Normal Irradiance	996	995	99.8	996	976	97.9
PSC	452	451	99.7	452	331	73.9
Dynamic operation with PSC	484	483	99.7	484	334	69

7. CONCLUSIONS

In this study, the performance of CS algorism investigated to track the GMPP of the solar panel under PSC and compared with the conventional P&O algorithm. Three different test cases of studies of PV modules are used under PSC to evaluate the performance of the proposed CS algorithm. For all test cases, the tracking efficiency of the CS is higher than 99 % within 300-500ms. The developed CS algorithm can handle the PSC very efficiently under different shading conditions, while P&O algorithm incapable of handling the PSC of the solar panel. The results also indicate that the tracked power by the CS has a very low fluctuations of the steady power compared to P&O algorithm. The CS has proven accuracy, robustness, and effectiveness of efficient energy utilization for the standalone PV system.

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