PV Output Power Enhancement using Meta-Heuristic Crow Search Algorithm under Uniformand Shading Condition

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Abstract- In uniform conditions, the power-voltage (P_V) curve has a unique global peak irradiance and no local peak irradiance. But in non-uniform or shading conditions P_V curve has many local peakswith a unique global peak. Therefore, tracking the global peak is the key factor to improve the photo voltaic (PV) performance under uniform and shading conditions. To track global peak radiation, maximum power point tracking (MPPT) controller is a mandatory requirement. Numerous softcomputing algorithms are developed and explained in past decades. But the ability to track the global maximum peak (GMP) is not assured under shading conditions due to trapping with local peaks instead of global peaks. In this research article, a new meta–heuristic crow search algorithm (CSA) is developed and extracted GMP under uniform and shading conditions of the PV module. The highlight of CSA is it works on dual mode search ability namely intensification and diversification. Because of this dual-mode operation, the local peak convergence problem is solved and it tracks GMP very fast. The experimental outcomes show that the CSA technique provides higher efficiency and faster tracking time.

Keywords Maximum Power Point Tracking (MPPT), Photovoltaic (PV), Global Maximum Power (GMP), Crow Search Algorithm (CSA).

1. Introduction

The promising scheme of 'Power for all' is introduced to meet electricity demand in India. According to data of India statistical information, the total amount of power generation capacity is 393389MW as of 31.12.2021. India is the third biggest electricity producer in the world with which coal contributes around 51.7% of 203190MW to power generation .Though the power generation in India is managed with high secure manner, the wastage of lignite and nuclear is one of the major reasons for environmental pollution and global warming issues. Increasing energy scarcity and environmental pollutions due to non-renewable energy resources pose a challenge to academic and industrial sectors [1]. In renewable energy resources, solar energy holds an important role because of its abundant availability with less maintenance [2]. However, two major drawbacks to solar energy are the higher installation charge and lower conversion efficiency of 9%–17%. The MPPT controller is a practical method for improving power from solar energy [3]. To enhance PV efficiency, MPPT techniques play an important role by operating a unique global point with the help DC-DC converter [4].

In recent years researchers have focused on meta–heuristic techniques for extracting GMP from PV modules. Three main classifications of meta–heuristic techniques (evolution, physics and swarm-based methods) are explained and shown in Fig.1.

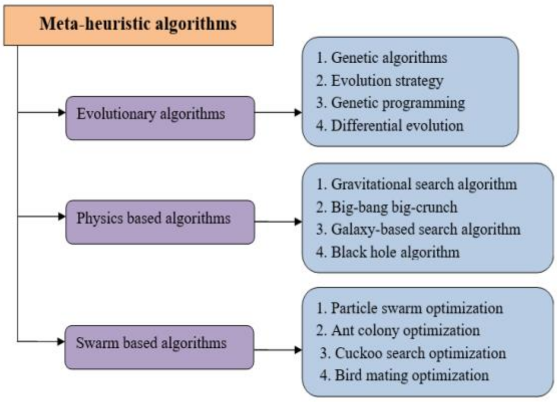


Fig.1. Classification of meta-heuristic algorithms

Genetic algorithm (GA) is a popular and simple evolution-inspired technique for non-linear problems [5]. The physics-based techniques are namely simulated annealing (SA) [6], black hole (BH) [7], gravitational search algorithm (GSA) [8] and charged system search optimization (CSS) [9]. These techniques are applied to non-linear critical problems. Particle swarm optimization (PSO) explained by [10] and the meta-heuristic methods are initiated to be very attractive for the continuous non-linear problem since PSO is verified to be highly competitive with physical and evolution-based algorithms. Some of the swarm-type algorithms are the cuckoo search algorithm (CSA) [11] and ant colony optimization (ACO) [12] which have notable merits over other evolution and physical-based algorithms. The search space mechanism of meta-heuristic algorithms is classified into two important conditions namely exploration and exploitation. The mechanism of exploration and exploitation is an important measurement to estimate the performance of search agent intelligence. In the exploration process, the search agents are ready to move globally in the specified region to find an optimal solution. During the exploitation process, the search agents move towards locally optimal solutions that are obtained from the exploration process. In both mechanisms, no proper guidelines are available for maintaining a better trade-off between exploration and exploitation. As a result, the majority of meta-heuristic algorithms take a random approach to exploration and exploitation, resulting in a long time to converge at an optimal solution [13].

The main drawback of swarm-based techniques is tracking local peaks instead of GMP under shading conditions. To overcome this problem, this research offers a novel meta-heuristic CSA for tracking GMP under uniform and different shading conditions. The results of the CSA technique are explained and tabulated in significant performances and compared with other conventional methods. This CSA can be expected to be an effective technique for dealing with non-linear solar MPPT problems.

Nomenclature

I_{ph}	Photo current (A)	G	Solar irradiance (W/m^2)
I_o	Reverse saturation current (A)	I	PV output current (A)
A	ideality factor	V_D	Diode voltage (V)
R_S	Series resistor (Ω)	V_{open}	Open circuit voltage (V)
R_{sh}	Parallel resistor (Ω)	I_{short}	Short circuit current (A)
I_D	Diode current (A)	V_{max}	voltage at maximum (V)
n_s	Number of cells connected in series	I_{max}	current at maximum (A)
K	Boltzman constant (1.381e10-23 J/K)	P_{max}	power at maximum (W)
Q	Electric charge (1.602e10-19C)	V	Output voltage (V)
STC	Standard test condition	T	Temperature (K)

2. Description of Solar PV Model

The single diode model is simple and accurate and is used to design an accurate PV module for analyzing the performance of PV panels under various environmental conditions. To design this model, five parameters are required and need to be estimated [14]. The single-diode model is depicted in Fig.2.

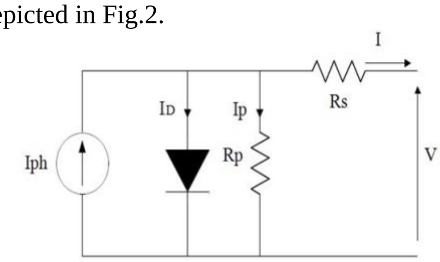


Fig.2 Single diode model

By applying Kirchhoff's law, the output current equation is derived as,

$$I = I_{ph} - I_D - \frac{V_D}{R_{sh}} \tag{1}$$

$$I = I_{ph} - I_0 \left[\exp\left(\frac{q(V + I_{ph} \cdot R_s)}{KTA}\right) - 1\right] - \frac{V + I_{ph} \cdot R_s}{R_{sh}} \tag{2}$$

The photocurrent (I_{ph}) mainly depends and environmental parameters such as sunlight(irradiation) and temperature. The expression of photocurrent is,

$$I_{ph} = [I_{ph.\ STC} + k\,(T - T_{STC})].\left(\frac{G}{G_{\ STC}}\right) \tag{3}$$

If number of series (N_{ss}) and parallel (N_{pp}) PV modules is connected then the output current equation of single diode PV model is expressed as,

$$I = N_{pp}\{I_{Ph} - I_0 \left[\exp\left(\frac{q(\frac{V}{N_{ss}} + I_{ph} \cdot \frac{R_s}{N_{pp}})}{KTA}\right) - 1\right] - \left(\frac{\frac{N_{pp}}{N_{ss}} + R_s.\ I_{ph}}{R_{sh}}\right) \tag{4}$$

3. Uniform and Shading Conditions on PV System

PV patterns are constructed by connecting PV panels in series/parallel for analyzing the appearance of different shading due to moving clouds, nearby tall buildings, bird droppings and dust. In uniform shading conditions, the schematic circuit diagram of four PV models is interlinked in series. All four PV modules receive the same level of irradiation. Tested PV patterns under uniform shading are shown in Fig.3. In non-uniform shading conditions, one or more PV modules received a different level of irradiation. Hence, there is a possibility of a hotspot issue on the PV module [15]. In a non-uniform scenario, multiple peaks are displayed as shown in Fig 4. The datasheet information of Trina solar- 500W is tabulated in table 1.

Table 1. Datasheet of Trina solar- 500W

Electrical characteristic of solar panel at STC	Trina solar- 500W
Open circuit voltage	51.5V
Short circuit current	12.13A
Maximum power voltage	43.4V
Maximum power current	11.53A
Maximum power	500W
Temperature co efficient of V_{open},	$-0.25\%/K$
Temperature co efficient of I_{short},	$0.04\%/K$
No. of cells connected in series (n_s)	150

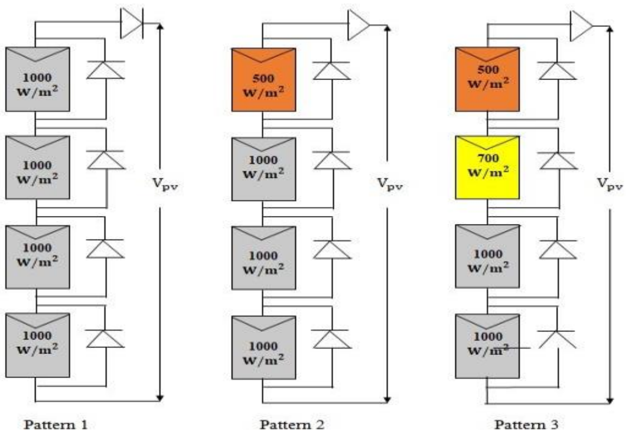


Fig. 3 Tested PV patterns

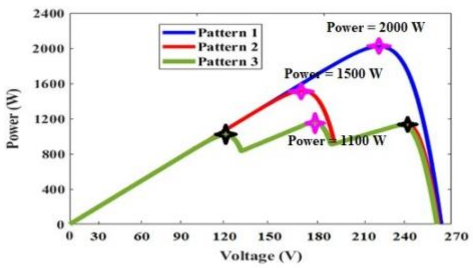
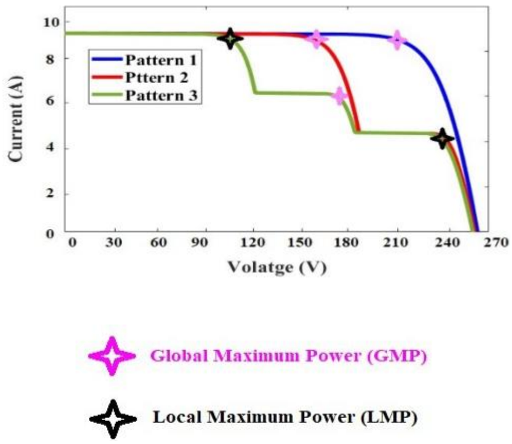


Fig.4 I-V and P-V curve for tested PV patterns



The evaluation of WOA provides better efficiency under shading. But the drawback of this technique is that the convergence time is increased due to improper exploration and exploitation processes [16]. The Block diagram of the MPPT circuit with a power electronics converter is depicted in Fig.5.

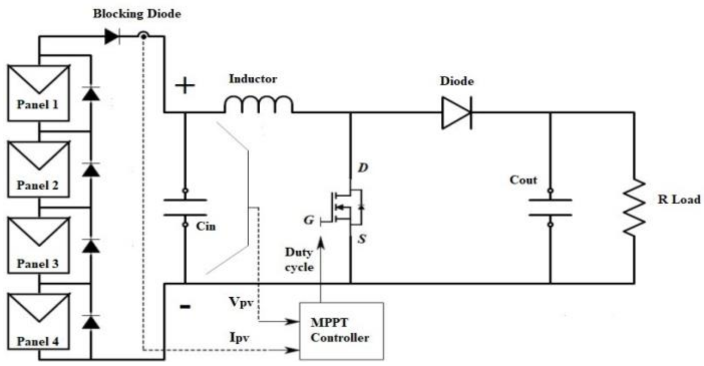


Fig.5 Block diagram of MPPT circuit with DC-DC Boost Converter

4. Crow Search Algorithm

Crow Search Algorithm (CSA) uses a recent meta–heuristic technique developed by Alireza Askarzadeh in the year 2016, which imitates the crow's behavior in keeping their food safely and bring back when required [17]. They have developed self-attentive in reflector tests with tool-making capability. Crows have the most powerful remembering ability and alertness. Crows can watch other birds and discover their hidden food.

5. CSA Implementation for MPPT

CSA provides a good agreement between intensification and diversification. In CSA, both aspects are mainly depending on the parameter of awareness probability (AP) [18]. If the AP values are decreased, then the result of the parameters of the CSA technique is ready to move for searching local peaks within the prescribed region called the intensification process. If the AP values are increased, then the parameters of CSA are exposed to search global peaks called the diversification process. The flowchart for the CSA technique with MPPT is shown in Fig.6.

The steps of CSA implementation on tracking maximum power from Solar PV systems are as follows:

Step 1: Initialization and definition of parameters

The defined parameters are the size of the flock (N), the number of max iterations ($iter_{max}$), the duration of the flight (fl) and awareness of the probability (AP).

Step 2: Read memory and position

Initially, all duty cycles are positioned with some dimensional search region as the memory of the flock.

Step 3: Evaluate the power

The decision variable is inserted to enable an analysis of the quality of duty cycle position at the initial condition into the objective function for each crow. Minimization in the error function is the parameter calculated through optimization to reduce the error level between the practical values and the calculated values.

Step 4: Update best position

In developing the crow's position, the crows (i) randomly select (j) and find the best position.

Step 5: Feasibility of checking updated positions

This step involves checking the feasibility of all new positions created by crows. If finding the new position is feasible, the crows update their position. If not, the crows stay in the same position with the inability to generate a new position.

Step 6: To compute the fitness function of crow's new position

In this step, the fitness function for all new positions of each crow is checked.

$$x^{i,k+1} = \begin{cases} x^{i,k} + (r_i * f^{i,k}) * (m^{i,k} - x^{i,k}) & r_j \geq AP^{i,k} \\ \text{A random position} & \text{Otherwise} \end{cases} \quad (3)$$

Step 7: Duty cycle updating
In this step, the new position of duty cycle updates their memory.
Step 8: check termination criterion
The steps from 4 to 7 are repeated until once maximum iteration is attained. The accurate position and memory of the duty cycle in the name of objective function is recommended as the solution of any non-linear optimization problems.

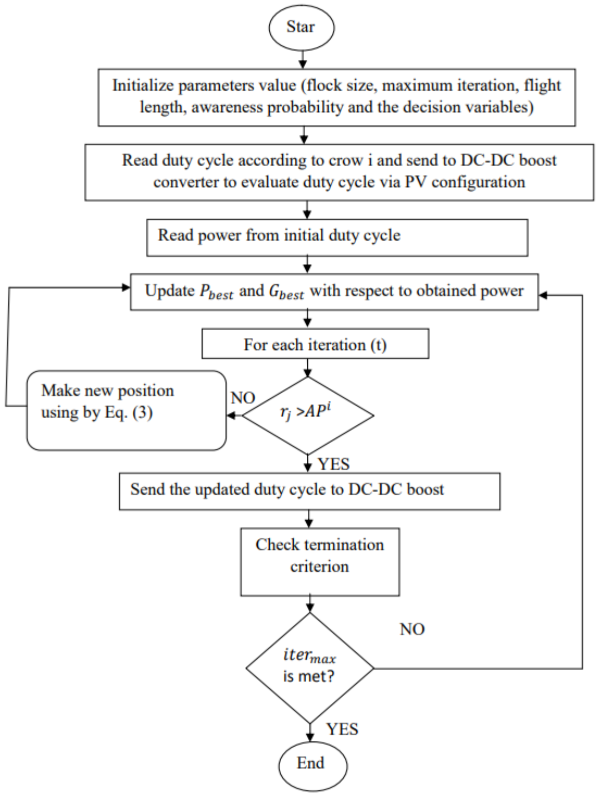


Fig.6 Flowchart for CSA implemented MPPT

6. Simulated Results and Discussion

The solar PV performance is simulated with the help of the MATLAB 2018a environment on an intel core i3 processor, 6 GB of RAM and windows 10 OS. In the pattern (1) scenario, four PV panels are interconnected in series with uniform irradiation. The P_V curve is shown in Fig.4 which denotes that the GMP is founded at 2000W. The proposed CSA takes 0.2 sec to reach GMP with an efficiency of 99.9%. The tracking period of PandO and WOA techniques is 0.293 sec and 0.299 sec respectively. The tracking efficiency of the P&O is 98.4% and the WOA is 99.6%. In comparison to the WOA, the PandO provides a fast convergence period under uniform shading conditions. The simulation performance of pattern (1) is depicted in Fig. 7.

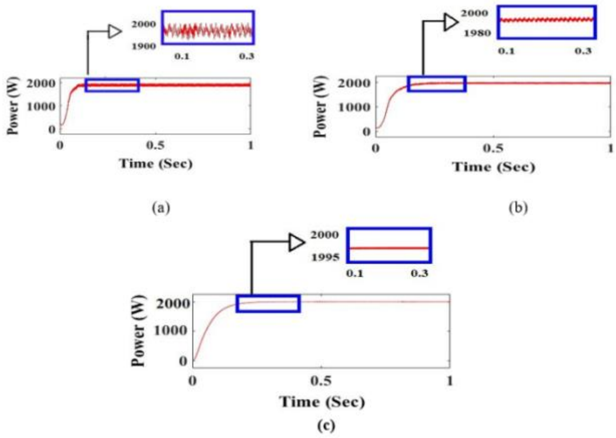


Fig.7 Simulated power curves of a) PandO b) WOA and c) CSA for the pattern (1)

In the pattern (2) scenario, two different irradiations are received by the PV module. Hence, the P-V curve consists of a unique GMP and one local peak. From Fig.4 it is known that theGMP is founded at 1500W. The proposed CSA takes 0.18 sec to reach GMP with an efficiency of 99.7%. The tracking period of PandO and WOA techniques is 0.25 sec and 0.24 sec respectively. The tracking efficiency of PandO is 94% and WOA is 99%. In comparison to P&O, the WOA provides fast convergence time under shading conditions. The simulation performance of pattern (2) is depicted in Fig.8.

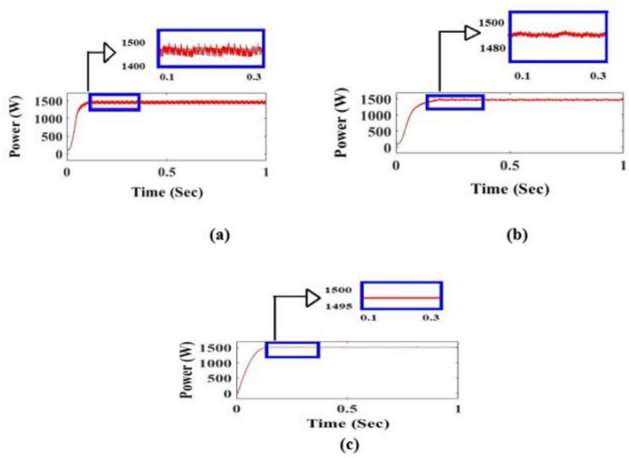


Fig. 8 Simulated power curves of a) PandO, b) WOA and c) CSA for the pattern (2)

In pattern (3), three different irradiations are received by the PV module. Hence, the P-V curve consists of a unique GMP and two local peaks. The GMP is founded at 1100W, with local peaks at 1075W and 1090W, respectively, as shown in Fig.4. The proposed CSA takes 0.13 sec to reach GMP with an efficiency of 99.8%. The tracking period of the PandO and WOA techniques is 0.22 sec and 0.16 sec respectively. The tracking efficiency of PandO is 90.6% and WOA is 98.8%. In comparison to P&O, the CSA provides a fast convergence time which is higher than 1.67 times. The simulation performance of pattern (3) is depicted inFig.9.

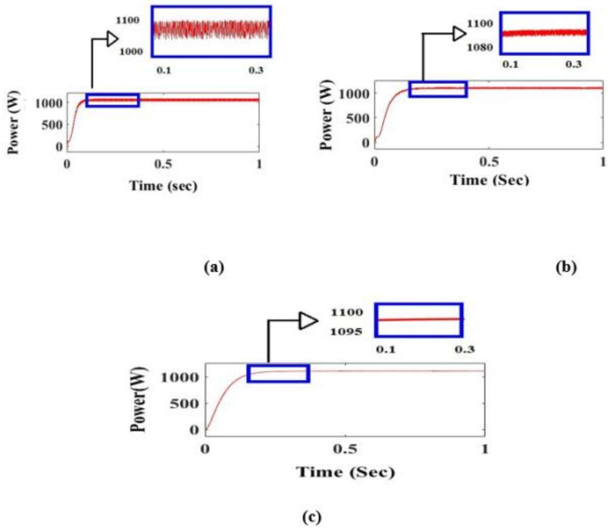


Fig.9 Simulated power curves of a) PandO, b) WOA and c) CSA for the pattern (3)

Table.2. Comparative simulation performance of different PV patterns

PV pattern	MPPT technique	Global peak power (W)	Tracked peak power (W)	Tracking efficiency %	Tracking period (sec)
	PandO		1950	97.5	0.293
Pattern (1)	WOA	2000	1987	99.3	0.299
	CSA		1997	99.8	0.20
	PandO		1410	94	0.25
Pattern (2)	WOA	1500	1485	99	0.24
	CSA		1496	99.7	0.18
	PandO		1020	92.7	0.22
Pattern (3)	WOA	1100	1087	98.8	0.16
	CSA		1096	99.8	0.13

The simulation results derived by different soft computing techniques for different PV patterns are tabulated in Table.2. With the information from the tabulation, it is clearly understood that the proposed CSA technique is providing better performance than other conventional techniques.

7. Hardware Implementation and Validation

Vikram solar- Eldora prime- 250W solar panel is utilized to predict the required I_V and P_Vcurves of the PV system. The PV power is supplied to the resistive load with the help of a DC-to-DC boost converter. Voltage (LV-25) and current (LA-55p) Hall Effect sensors are used tomeasure the voltage and current signal from the panel. These digital outputs are given to the processor of the Arduino Mega 2560 controller. This processor is used to carry out the MPPTtechniques and to generate pulses for the switch of the converter [19]. The controller is preferred for having two-time circuit configurations and can support up to 10 kHz frequency operation. In the MPPT controller, two analogy pins are required to measure the voltage and current from the PV panel [20]. The minimum gate-source voltage value of the IGBT switch is 20 V. But the controller can be provided anywhere from 3V to 5V. To boost the voltage level, TLP-250 driver circuit is constructed. The added advantage of TLP-250 is that it maintains the isolation between the controller and the DC-DC converter [21]. Further, the obtained signals such as voltage, current and power are captured from MSO (MSO7014B). The hardware setup is depicted in Fig.11. The solar panel and converter specifications are tabulated in table 3.

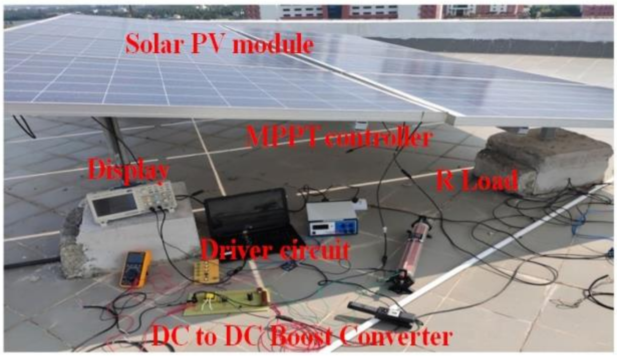
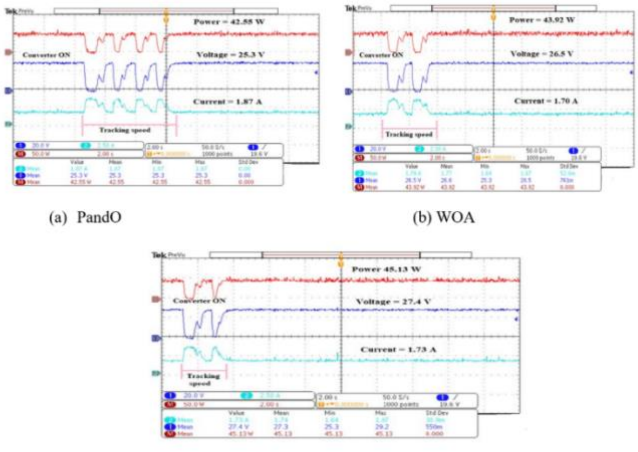


Fig.11 Hardware setup for the proposed MPPT scheme

Table.3. Converter and PV panel specifications

S. No	Parameters	Range
1	Switching frequency (F)	10 KHz
2	Inductor (L)	1.5 mH
3	Capacitor (C)	470µF
4	Load resistance (R)	10A, 100Ω
Solar panel specifications		
1	Voltage @ open [V]	37.44
2	Current @ short [A]	8.75
3	Voltage @ max [V]	30.49
4	Current @ max [A]	8.20
5	Power @ max [W]	250

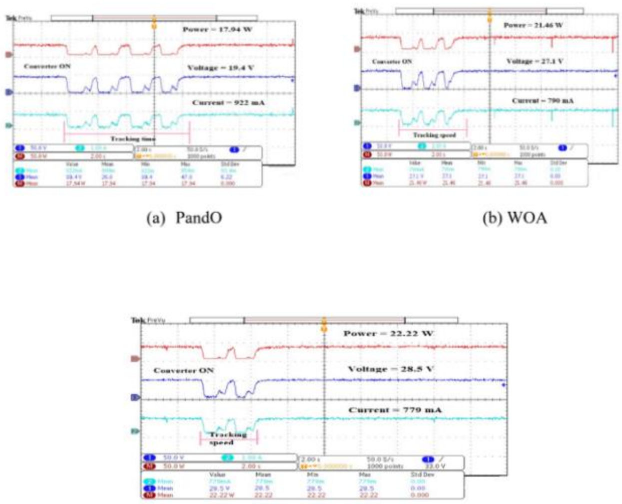
Considering the first aspects with the normal condition, the GMP is located at 46W. The measured duty cycle is 0.51. The proposed CSA is executed and tracked GMP is 45.13W with a tracking period of 2.1 sec with 98.1% efficiency. The conventional method P&O tracked GMP is 42.55W and the tracking period is 6.2 sec. Similarly, the WOA tracked GMP is 43.92W in 4 sec. The tracking efficiency of PandO is 92.5% and the WOA is 95.4%.Hardware results of a) PandO, b) WOA and c) CSA for the normal condition are depicted in Fig.12.



(a) PandO (b) WOA

(c)CSA

Fig.12 Hardware results for PandO, WOA and CSA under normal conditions



(a) PandO (b) WOA

(b) CSA

Fig.13 Hardware results for PandO, WOA and CSA under shading condition

Considering the second aspect of non-uniform conditions under partial shading, the GMPis located at 22.7W. The duty cycle is set at 0.45 to 0.55. The proposed CSA is executed and tracked with 97.8% efficiency at a GMP of 22.22W and a tracking speed of 2.4 sec.The conventional method of P&O tracking GMP is 17.94W and the tracking period is 9.5sec. Similarly, the WOA tracked GMP is 21.46W in 5.8 sec. The tracking efficiency of P& O is 79% and the WOA is 94.5%. Hardware results of a) PandO, b) WOA and c) CSA for shading conditions are depicted in Fig. 13. Hardware performance analysis istabulated in Table 4.

Table. 4. Hardware performance analysis

Conditions	MPPT technique	Tracked power (W)	Tracking efficiency %	Tracking period (sec)
Normal condition (Panel power = 46W)	PandO	42.55	92.5	6.2
	WOA	43.92	95.4	4
	CSA	45.13	98.1	2.1
Shading condition (Panel power = 22.7W)	PandO	17.94	79	9.5
	WOA	21.46	94.5	5.8
	CSA	22.22	97.8	2.4

8. Conclusion

In this work, a new meta–heuristic CSA technique is developed to track GMP from solar PV modules under uniform and shading conditions. This proposed technique provides all solutions away from the worst values during the process of intensification and taking globalization into account in the process of diversification. The highlights of the CSA are to enhance the decision-making ability and the capability of fast-tracking time. The intensive simulation analysis and the evaluation of different irradiations on PV patterns are performed and explained. Moreover, this technique removes the complexityproblem and reduces the number of iterations to reduce highly fluctuating oscillations around GMP. The performance of CSA is analyzed under steady state and dynamic conditions and also compared with the performance of other popular techniques namely PandO and WOA. CSA technique is successfully tested and performances are evaluated by MATLAB/Simulink and real-time hardware environment. The results obtained from the proposed CSA are proven for quick convergence and reduced steady-state oscillations around GMP. The proposed technique can track GMP very quickly and precisely in comparison to other conventional methods under different shading conditions. The simulation and hardware results indicate that the proposed CSA contributes higher efficiency and faster tracking time under normal and shading conditions.

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