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Comparative Evaluation of Optimization Algorithms for Maximum Power Point Tracking under Partial Shading Conditions

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***Abstract*:The global demand for electrical energy has witnessed a substantial increase, presenting a challenge for power systems worldwide. In addition to technical considerations, the escalating issue of global warming has become a paramount concern in the planning studies of various sectors. Notably, the imperative to reduce carbon emissions in electric power generation has gained prominence. The formulation and resolution of a single-objective non-linear optimization problem are carried out, considering different operational scenarios. Recent heuristic algorithms, including Particle Swarm Optimization (PSO), Cat Swarm Optimization (CSO), and the Chimp Optimization Algorithm (ChOA), are employed to address the complexities associated with maximizing power output under partial shading conditions in solar PV systems. The inherent challenges of achieving MPPT under such conditions make conventional analytic approaches computationally intensive. Hence, the study leverages heuristic algorithms to optimize solar PV system performance, providing efficient solutions to the associated optimization problems. This approach is particularly relevant in the broader context of mitigating the environmental impact of power generation while meeting the increasing demand for electrical energy.**

Keywords:Solar PV systems; MPPT; Optimization techniques; Cat Swarm Optimization (CSO); Chimp Optimization algorithm (ChOA).

I. INTRODUCTION

India is experiencing a surging demand for electricity due to a rapidly growing population, increasing smart city initiatives, and widespread use of electronic devices. This heightened demand raises concerns about elevated carbon emissions and atmospheric pollution. Globally, the demand for energy has seen a significant uptick, prompting a shift towards renewable sources over the past two decades, renewable energy generation has witnessed rapid growth, constituting 26.3% of global energy consumption. Notably, hydroelectricity contributes 15.8%, wind energy 5.3%, solar energy 2.7%, and the remaining 2.5% comes from other renewable sources like modern biomass, wave, tidal, and geothermal energy. Solar, Wind, and Biomass are some of the renewable energy sources abundantly available in nature.

Researchers have extensively investigated various techniques for Maximum Power Point Tracking (MPPT) in Photovoltaic (PV) systems. Femia et al. [1] emphasized the efficiency and cost-effectiveness of the Perturb and Observe (P&O) method. Tofoli et al. [2] conducted a comparative analysis, noting that P&O significantly increased extracted power and brought the operating point closer to the MPP. Selvamuthukumaran et al. [3] proposed a flexible step size MPP tracking system with efficient performance under uniform atmospheric conditions. Gil-Velasco and Aguilar-Castillo [4] observed that P&O finds the MPP with less convergence time. Dileep et al. [5] surveyed perturb and observe methods, categorizing them based on simplicity, implementation, cost, and convergence speed.Ram et al. [6] found that P&O with fuzzy outperformed Fuzzy and a new delta P&O method under constant insolation levels. Kumar et al. [7] proposed a superior minimal rule-based fuzzy logic control-based MPPT technique. Kofinaset al. [8] examined the MPPT controller by applying a novel neuron to tune ANN under stable weather conditions to harness maximum solar energy. Beriber and Talha [9] introduced a fuzzy logic based MPP tracking method under uniform irradiance conditions, highlighting faster and stable traced MPP. Liu et al. [10] investigated the PSO for MPPT in PV systems across diverse operational scenarios They highlighted the advantageous features of the PSO technique, including its straightforward implementation, system independence, and improved efficiency.

The study's findings indicate that both PSO and Cat swarm optimization (CSO) techniques exhibit promising convergence to global optima. Notably, CSO demonstrates a shorter tracking time for Maximum Power Point (MPP) across all considered shading patterns when compared to PSO. While standalone PSO and Grey Wolf Optimizer (GWO) approaches have shown some success in effective MPP tracking, literature surveys highlight their tendency to get stuck in local peaks, especially under shading conditions. The optimization of algorithm parameters and exploration

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capabilities emerges as critical factors influencing the effectiveness of these optimization approaches. When the complexity of the problem is enhanced, then the existing techniques in the literature are not meeting the research objectives. To address these challenges, the study introduces the Chimp Optimization Algorithm (ChOA) which is specifically designed for GMPP to harness solar energy under fluctuating weather conditions. This study focuses on analyzing the performance of Chimp Optimization Algorithm (ChOA) in maximizing energy from solar photovoltaic (PV) systems under partial shading conditions. Despite previous research suggesting techniques to improve solar PV system tracking rates, several unresolved issues remain, necessitating further investigation. The study aims to bridge this research gap by introducing and applying Chimp Optimization Algorithm for the Maximum Power Point Tracking (MPPT) problem. While heuristic algorithms are commonly used for extracting maximum power from PV systems in research, a notable gap exists in comparing these approaches in terms of simulation results, convergence characteristics, and computational time. This study addresses this gap by comparing heuristic algorithms such as Particle Swarm Optimization (PSO), Cat Swarm Optimization (CSO), and ChOA, along with their enhanced variants, across all these aspects. By emphasizing the importance of accurate assessments to validate the superiority of proposed algorithms, this research provides valuable insights into MPPT tracking in solar PV systems, particularly under challenging conditions.

II. Maximum Power Point Tracking (MPPT)

There are various MPPT techniques accessible to date and more research is ongoing to develop more robust MPPT techniques. Based on the structure of the algorithm the MPPT techniques are classified into (i) Conventional (ii) AI Techniques and (iii) Soft computing Techniques. Conventional methods are used mostly as they had a simple and efficient tracking system. Most conventional algorithms can work efficiently when weather conditions are constant and these are fails when working under variable environmental conditions

A)Use of PSO algorithm based MPPT controller for solar PV module

PSOis a highly effective speculative technique based on the bird's movement. Among many heuristic approaches, the PSO algorithm is highly adopted due to its simplicity as well as effectiveness. The basic motivation behind this invention is the social behaviour simulation of fish schooling or bird flocking. Particle Swarm Optimization (PSO) employs multiple particles to form a swarm that traverses the search space, collaboratively determining the optimal global solution. The PSO is applied to compute the optimization problem, thereby making the candidate solution precise and of better quality. The optimization of a problem with PSO is based on the population size of the candidate size. MPPT of PV strings under shading and the schematic implementation is shown in Fig.1.

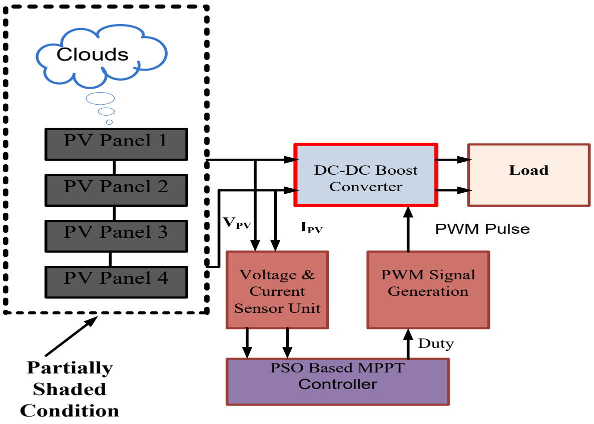

Fig.1 PV system with partial shading and MPPT controller using PSO

B) CSO algorithm based MPPT controller for PV module

In population-based search optimization methods, maintaining a significantly high diversity is crucial during the early stages of the search. This enables the exploration of the entire search space effectively. Conversely, as the optimization algorithm progresses towards convergence and approaches the optimal solution, fine-tuning becomes essential for efficient identification of the global optima. The Cat Swarm Optimization (CSO) algorithm, a naturally inspired meta-heuristic, has established itself as a benchmark in solving optimization problems across various engineering fields. The schematic representation of the CSO algorithm is presented in Figure 2.

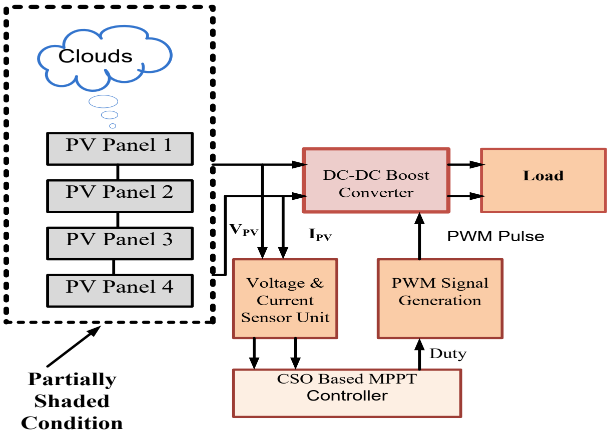

Fig.2 PV system with partial shading and MPPT controller using CSO

Seeking mode and Tracing mode are the two distinct modes, in which this algorithm interprets the cat behavior. Virtual cats are then maneuverer in the search space based on these behaviors. The participation of cats in each iteration of seeking and tracing modes is determined by a predefined ratio known as the mixture ratio (MR)In the algorithm, the tracing mode, where cats exhibit performance in pursuing a target, is particularly instrumental. Consequently, it can be inferred that an optimal mixture ratio is a subtle parameter that needs to be set judiciously, especially when the cat spends more time in seek mode.

$$m = \text{Chaotic vector} \quad (5)$$

The function **f** reduces nonlinearly from 2.5 to 0 during exploration and exploitation via iteration, using random vectors r_1 and r_2, and regulation vectors and C. D represents distance between elements, and the chaotic vector m aligns with chimp sexual motivation in the search process. Unlike traditional swarm intelligence, chimp optimization involves independent groups with diverse behaviors, mathematically modelled to revise **f.** Each group uses constant parameters, updating locally and globally. Mathematical model for dynamic coefficients vector (f) in various ChOA groups as shown in Fig.4.

III. ChOA APPROACH FOR MPPT CONTROLLER

Chimp Optimization Algorithm (ChOA) optimizes MPPT in fractional shading for solar PV systems. The network maximizes power extraction from the PV source, delivering it efficiently to the utility end. The application of ChOA in a partially shaded PV system is illustrated in Fig.3.

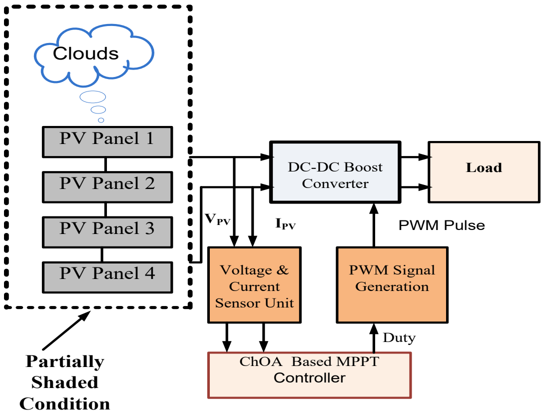

Fig.3 PV system with partial shading and MPPT controller using ChOA

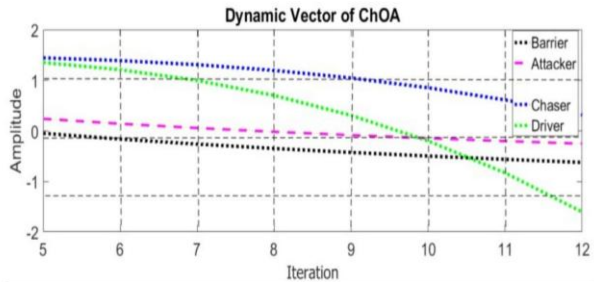

Fig.4 Mathematical model for dynamic coefficients vector (f) in various ChOA groups

Chimpanzee associations exhibit a fission-fusion dynamic, where individual roles remain constant over time. Each association, represented as an individual, performs specific functions that may evolve. The chimpanzee groups operate independently, with each member utilizing their unique skills for specialized tasks. The function of each chimp is classified as i) Drivers ii) Barriers iii) Chasers iv) Attackers. Drivers pursue prey without attempting to capture them, Barriers create obstacles in the escape route, Chasers swiftly pursue the prey, and Attackers focus on understanding the prey's escape strategy. Chimps may alter their roles during a hunt or maintain the same role throughout. Social incentives, such as support, sex, or grooming, drive chimps to participate in the hunt. Some chimps also seek "Social incentives" like humans, providing them with additional assets compared to other social predators. Sexual impulses may lead chimps to act chaotically in the final stages of the chase.

III.1 ChOA mathematical model

Hunting techniques involve two phases: exploration and exploitation. For modelling the process of chasing and the driving of prey, the below equations are applied.

$$D = \left| C \cdot X_{Prey}(t) - m \cdot X_{Chimp}(t) \right| \quad (1)$$

$$X_{Chimp}(t+1) = X_{Prey}(t) - a \cdot D \quad (2)$$

Equations from (3) to (5) are designed to provide the values of a,m and C.

$$a = 2.\ f.\ r_1 - f \quad (3)$$

$$C = 2.\ r_2 \quad (4)$$

A) Phase of exploration

During the attack phase, chimps employ various stages like chasing, blocking, driving to encircle the prey. Attackers typically manage the chase, while drivers, barriers, and chasers are intermittently involved. In the initial iteration, lacking knowledge of the prey's optimal position, the attacker's location becomes the assumed prey position. Another crucial ChOA parameter influencing the exploration process is C. This stochastic parameter enhances ChOA's exploration, reducing the risk of being trapped in local optima. Continuous random values generated by C contribute to the exploration phase across iterations. The attacking process is mathematically modelled with the linear decrease of **f** higher value of 2.5 to lower value of 0. The vector's scope decreases similarly to that of f, defined as a random vector within the range of [-2f, 2f]. Each extension's random value falls within [-1, 1], allowing a chimp's placement at any position relative to the available space and prey condition. While the projected chasing and blocking mechanism somewhat address exploration limits, there remains a risk of ChOA getting trapped in local minima. Impact of 'a' on updating chimp location is shown in Fig.5.

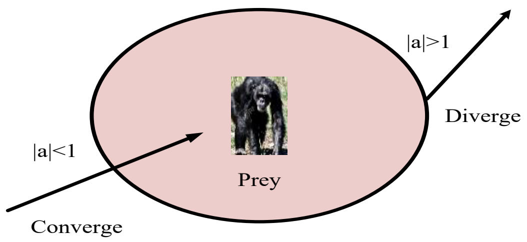

Fig.5 Impact of 'a' on updating chimp locations.

B)Chaotic maps

Chimps' chaotic behavior aids in overcoming local optima issues and slows convergence in solving high-dimensional engineering problems. Various chaotic maps have been employed in this study to enhance ChoA performance, introducing random behavior, as depicted in the Fig.6.

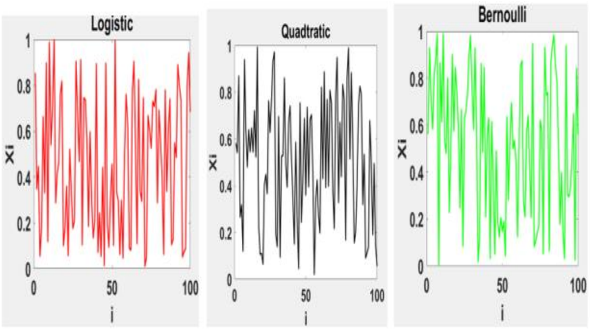

Fig.6 Chaotic random behavior of chimps

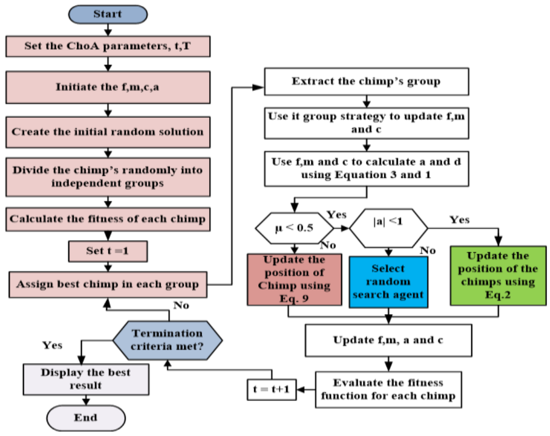

Fig.7 ChOA flowchart

The focused ChOA flow chart is presented in Fig.7. with a schematic flowchart guiding the optimization process. Initially, the algorithm randomly selects a population of chimps organized into individual chimp groups. The positions of these chimps are evaluated by the objective function, and the ensuing steps are iteratively performed until the specified stopping criterion is reached. This study specifically employs ChOA to address the non-convex optimization challenge associated with MPPT. The above figure provides a comprehensive overview of the procedural steps involved in utilizing ChOA for MPPT problem-solving.

III.2 Case Studies

Fig. 8 depicts the Simulink setup for comprehensive research on solar PV strings under various shading conditions using ChOA algorithm. Table 1 outlines the tuning parameters for ChOA.

Table 1 ChOA technique tuning parameters

Algorithm	Specifications	Value
ChOA	**f**	Coefficient vector
	r_1,r_2	Random values
	No. of search agents	01
	Iterations	08

m Chaotic

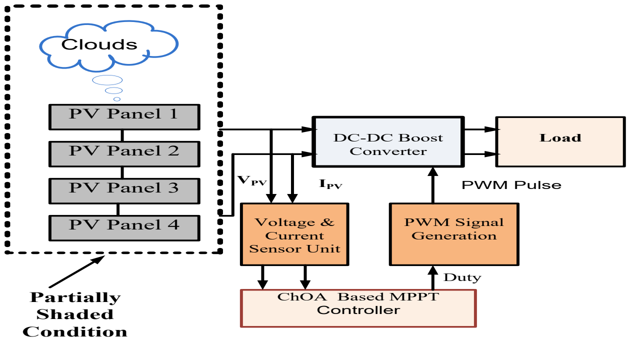

Fig.8Partially shaded PV system with ChOA Based MPPT controller

To study the P-V characteristics under partial shading conditions, three cases considering four different shading patterns as shown in Fig. 9 are proposed with different irradiance as mentioned in Table 2.

Table 2: Different Cases of irradiation patterns of PV system under shading conditions

Case No	Arrangement of PV modules	No. of PV Modules	Irradiance Level	Temperature
1	Pattern-1	4	1000W/m^2 1000W/m^2 800W/m^2 600W/m^2	25^{0}C
2	Pattern-2	4	1000W/m^2 1000W/m^2 500W/m^2 500W/m^2	25^{0}C
3	Pattern-3	4	1000W/m^2 800W/ m^2 900W/ m^2 550W/ m^2	25^{0}C

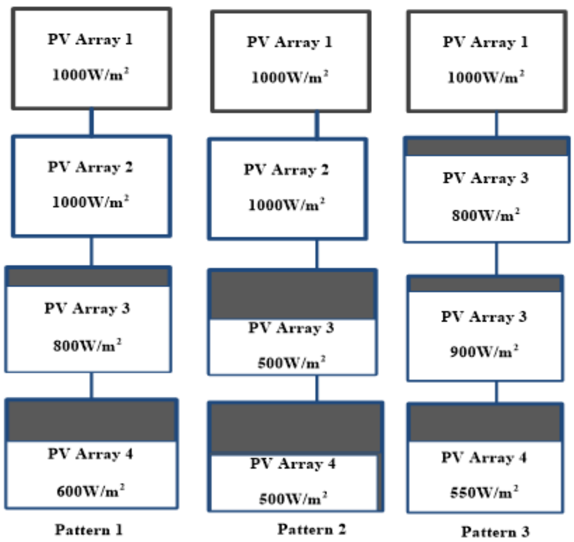

Fig.9 Different irradiation patterns of PV system under shading conditions

Case-1:

This case focuses on Pattern-1, detailing irradiance levels on modules and presenting P-V, P-I characteristics. For this shading condition, the GMPP voltage and current are 114V and 4.78A at 544W. The output voltage, current, and power obtained using ChOA optimization technique for pattern 1 are presented in Fig. 10.

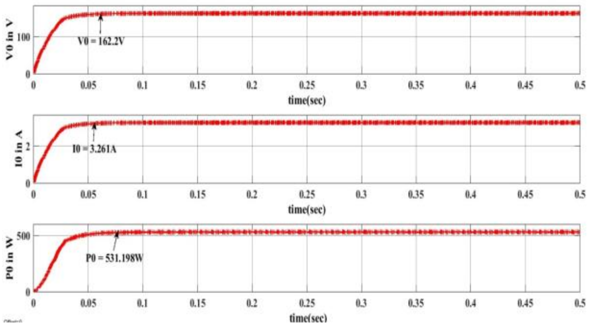

Fig.10 ChOA simulation results for Power, current, and voltage - Pattern 1.

Chimp Optimization demonstrates smoother MPP search with minimal oscillations in solar PV module power output under shading conditions. ChOA converges rapidly within seconds, contrasting with CSO's higher average convergence time. Both ChOA and GSO excel in pursuing GMPP under partial shading conditions. The simulation shows CSO yields 505 W, whereas ChOA achieves 531.198W from the PV array. Detailed qualitative analysis is summarized in Table 3.

Table 3 Pattern 1 performance of MPPT controller

Shading pattern	GWPP (W)	Type of algorithm	Output Voltage (V)	Output Current (A)	Output Power (W)	Efficiency %)
Case-1	544	PSO	162.2	3.261	531	95.5
		CSO	161	3.2318	521.4	95.7
		CHOA	161.5	3.2314	520.0	**97.8**

Case- 2:

Examining pattern-2 in this context, Fig. 11 indicates that the use of CSO for MPP tracking introduces significant disturbances and transients in output voltage and power curves during climatic changes. The proposed ChOA method proves to be a more efficient solution because of excellent damping of oscillations over diverse fluctuating conditions. The simulation results of pattern 2 with different optimization techniques are tabulated in Table 4.

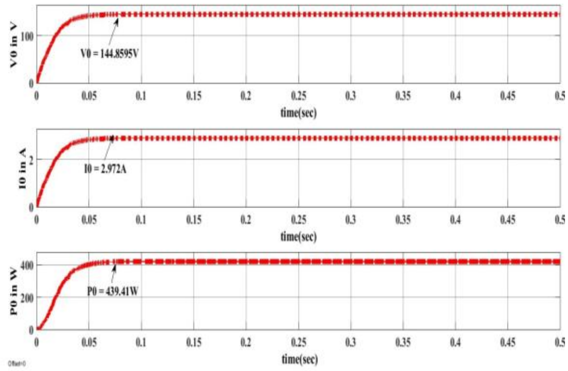

Fig.11 Simulation output of ChOA for pattern 2

Table 4 Comparison of performance of MPPT algorithms for pattern 2

Shading pattern	GWPP (W)	Type of algorithm	Output Voltage (V)	Output Current (A)	Output Power (W)	Efficiency %)
Case-2	440	PSO	145	2.91	426	96.72
		CSO	147	2.96	434	98.55
		CHOA	144	2.97	439	**99.82**

Case-3:

In this case study, pattern-3 is analysed, Pattern 3 ChOA simulation outputs are presented inFig.12. Notably, four peaks are observed, with LMPP at 500W and GMPP at 513.3W. The voltage is 81.63V and 6.21A of current at GMPP, showing a close alignment with the other peaks. Pattern 3 performance of MPPT controller is shown in Table 5.

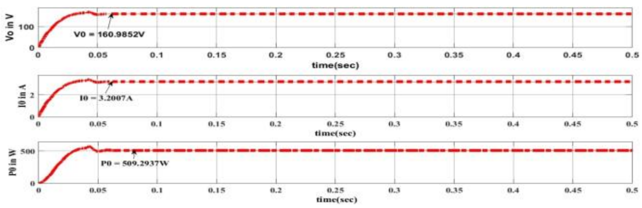

Fig.12 Pattern 3 ChOA simulation outputs

Table 5 Pattern 3 Performance of MPPT controller

Shading pattern	GWPP (W)	Type of algorithm	Output Voltage (V)	Output Current (A)	Output Power (W)	Efficiency %)
Case-3	513	PSO	158	3.12	499	97.56
		CSO	158	3.12	499	98.23
		CHOA	160	3.20	509	**99.99**

IV. COMPARATIVE STATISTICAL ANALYSIS

MATLAB/SIMULINK simulations for Chimp Optimization Algorithm (ChOA) and Cat Swarm optimization (CSO) were conducted under different partial shading patterns (G1 to G6). The results, summarized in Table 6, revealed that G1 shading pattern maximized power in the solar photovoltaic system. Fig.13illustrated that ChOA outperformed other optimization techniques in terms of speed and reliability under partial shading scenarios, particularly excelling in comparison toCSO across different shading conditions.

Table 6 Simulation results of PV module operated at various partial shading conditions

Different shading pattern	Parameter	PSO	CSO	CHOA
G_1= [1000,900,800,700]	Voltage(V)	115.4	117.3	**115.2**
	Current (A)	4.31	4.420	**4.54**
	Power (W)	497.92	518.35	**523.14**
	Max. Power(W)	525.12	525.11	**525.13**
	Conversion Efficiency (%)	94.82	98.72	**99.63**
G_2= [900,550,100,600]	Voltage(V)	82.11	82.45	**82.61**
	Current (A)	3.65	3.85	**3.95**
	Power (W)	299	317	**334**
	Max.Power(W)	330.11	336.62	**336.65**
	Conversion Efficiency (%)	90.76	94.28	**99.23**
G_3= [750,850,600,800]	Voltage(V)	81.26	82.45	**53.66**
	Current (A)	3.85	3.96	**6.24**
	Power (W)	313.67	325.61	**334.62**
	Max.Power(W)	340.05	340.06	**340.08**
	Conversion Efficiency (%)	92.30	95.81	**98.42**
G_4= [600,800,400,200]	Voltage(V)	54.21	54.33	**56.42**
	Current (A)	4.02	4.12	**4.33**
	Power (W)	217.93	224.11	**243.59**
	Max.Power(W)	258.31	258.29	**258.30**
	Conversion Efficiency (%)	84.45	86.74	**94.35**
G_5= [600,200,800,250]	Voltage(V)	64.15	66.31	**66.45**
	Current (A)	2.65	2.68	**2.83**
	Power (W)	169.31	176.82	**188.52**
	Max. Power(W)	191.22	191.19	**191.21**
	Conversion Efficiency (%)	88.63	92.45	**98.59**
G_6= [400,600,800,100]	Voltage(V)	84.25	85.46	**87.52**
	Current (A)	2.52	2.63	**2.62**
	Power (W)	212.09	223.85	**229.45**
	Max. Power(W)	233.12	232.51	**232.52**
	Conversion Efficiency (%)	91.22	96.29	**98.69**

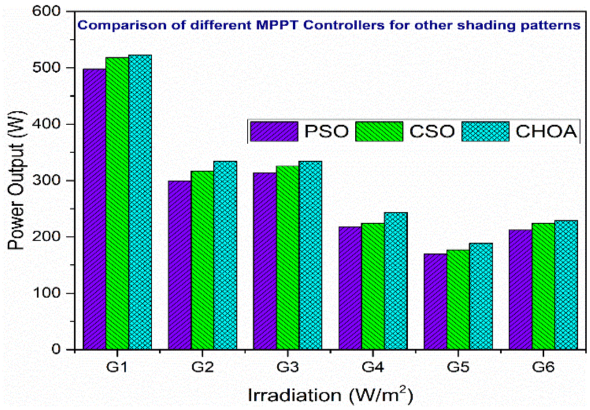

Fig:13. Power output variation with Irradiation for different algorithms

V. CONCLUSION

This research aims to improve PV system performance during partial shading using optimization techniques such as PSO, CSO, and ChOA. ChOA's performance is compared with basic PSO and CSO. From the results obtained, ChOA outperformed other algorithms by providing significant objective function values with less computational time.

- This research work is focused implicitly on analysing the convergence characteristics of proposed ChOA with their improved variants at all the stages reviewed in the second module.
- To reach global maximaby escaping local minima chances, the exploration and exploitation stages of both algorithms are tuned dynamically w.r.t. iteration in the optimization process. The results obtained at all the stages are shown that the ChOA outperformed over the CSO, and PSO.
- Comparative analyses with existing optimization techniques confirm ChOA's superior ability to search for GMPP.

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REFERENCES

[1] Femia, N., Petrone, G., Spangnuolo, G., and Vitelli, M., 2005. "Optimization of Perturb and Observe Maximum Power Point Tracking Method", IEEE Transactions of Power Electronics, 20 (4), pp. 963-973.

[2] Tofoli, F.L., Pereira, D.C., and Paula, W.J., 2015. "Comparative study of maximum power point tracking techniques for photovoltaic systems", International Journal of Photo energy, doi.org/10.1155/2015/812582.

[3] Selvamuthukumaran .R , Y.S.Kumar&Rajesh.G(2016), " Global Maximum power point tracking of multiple PV modules Under partially shaded condition using stepped comparison Search " Electric Power Components and systems. DOI:10.1080/15325008.2016.1157106.

[4] A. Gil-Velasco and C. Aguilar-Castillo, "A Modification of the Perturb and Observe Method to Improve the Energy Harvesting of PV Systems under Partial Shading Conditions," Energies, vol. 14, no. 9, Art. no. 9, Jan. 2021, doi: 10.3390/en14092521.

[5]G. Dileep and S. N. Singh, "Maximum power point tracking of solar photovoltaic system using modified perturbation and observation method," Renewable and Sustainable Energy Reviews, vol. 50, pp. 109–129, Oct. 2015, doi: 10.1016/j.rser.2015.04.072.

[6] Ram, J.P., Babu, T.S., and Rajasekar, N., 2017. A Comprehensive Review on Solar PV Maximum Power Point Tracking Techniques, Renewable and Sustainable Energy Reviews,67, PP. 826-847.

[7] Kumar., B., yogesh., K.,Chauhana and shrivastava, V., 2014. " A Comparative Study of Maximum Power Point Tracking Methods for a Photovoltaic – Based Water Pumping System, International Journal of Sustainable Energy., 33, pp 797-810.

[8] P. Kofinas, A. I. Dounis, G. Papadakis, and M. N. Assimakopoulos, "An Intelligent MPPT controller based on direct neural control for partially shaded PV system," Energy and Buildings, vol. 90, pp. 51–64, Mar. 2015, doi: 10.1016/j.enbuild.2014.12.055.

[9] DalilaBeriber and A.Talha , " MPPT Techniques for PV systems" , May 2013Conference: 4th International Conference on Power Engineering, Energy and Electrical Drives, POWERENG-2013 , At: Istanbul, Turkey.

[10]Liu, Y.H., Huang, S.C., and Liang, W.C., 2012. A particle swarm optimization –Based maximum power point tracking algorithm for PV systems operating under partially shaded conditions, IEEE Transactions on Energy Conversion, 27 (4), pp.1027-1035.