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Research Article

A Comprehensive Review of Different Maximum Power Point Tracking Techniques

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Abstract –The greatest amount of electricity that is accessible must always be extracted in order to operate photovoltaic (PV) systems effectively. Determining the maximum available power is a time-varying challenge since environmental factors like irradiation, temperature, and shading can change fast. Maximum power point tracking (MPPT) strategies are suggested in order to extract the maximum possible power and track the ideal power point under these varied environmental conditions. The use of MPPT to extract the most power is essential for creating effective PV systems. Because it is clean and pollution-free, solar energy has gained a lot of interest. However, the solar array cannot operate uniformly at the maximum power point due to the partially shadowed state, resulting in a significant power loss. These MPPT approaches have a number of drawbacks and limitations, especially when there is partial shadowing brought on by uneven environmental circumstances. An overview of various maximum power point tracking (MPPT) methods for photovoltaic (PV) systems is given in this paper. This thorough analysis of MPPT techniques seeks to give electricity companies and researchers a resource and direction for choosing the optimum MPPT technique for typical operating and partially shaded PV systems based on efficiency and financial viability.

Keywords – Grey Wolf Optimizer, Maximum Power Point Tracking, Global Maximum Power Point, Incremental Conductance, Diode Current, Shunt Current

I. INTRODUCTION

As a way to lessen the negative environmental effects of fossil fuels, power generation from renewable sources like solar and wind is gaining greater attention lately [1]. The energy that the sun provides to the earth each day is enough to meet all of its energy needs for an entire year. The PV module, which is made up of solar cells, is the fundamental structural component of a solar system [2]. The fastest-growing renewable energy technology is photovoltaic (PV), which converts solar energy directly into electrical energy. The electricity produced by the PV source can also be used to change energy chemically, such as in hydrogen fuel cells [3]. Temperature and solar radiation levels affect how much power a PV system can produce. whenever you want [4]. The majority of the power generated is sent to the load by PV modules at MPP. MPP is the location on a PV panel's P-V characteristic where the load impedance and photovoltaic impedance are equal. Additionally, it is a location where there is less energy lost during the transfer of generated electricity to the load. MPPT procedures are used to find MPP along the P-V curve. The MPPT technique is a way to run a photovoltaic system so that the modules may deliver the majority of the power produced to the load [5]. greatest power point tracking (MPPT) technologies are incorporated [6] to produce the greatest power from the PV system under fluctuating irradiance and temperature.

When there is uniform irradiance, there is just one maximum power point that can be tracked by traditional MPPT techniques on the PV array characteristics curve. The PV array curve, however, has many maximum points because of the non-uniform irradiation that shadows and clouds cause for the PV arrays. Since most traditional MPPT approaches fall short in these situations, many contemporary MPPT solutions are offered to handle the numerous maximum points. One of the most important considerations for selecting an appropriate MPPT method generally revolves around three specifications. Performance, which includes tracking precision and speed, is the first factor. The control system's complexity, voltage and current sensors, parameter tuning or perturbation, and partial shading detections make up the second factor. The cost of the full MPPT system is the third consideration. Several optimized traditional approaches are used for MPPT in order to lower power losses and increase system effectiveness. The Grey Wolf Optimizer (GWO) method, the Whale Swarm method, the neural network algorithm, the particle swarm algorithm, the Optimize Adaptive Differential Conductance algorithm, and many other intelligent algorithms have been developed by researchers and inspired by numerous biological populations found in nature. [7] Mohanty et al. To maximize the amount of energy harvested from PV systems, several MPPT strategies have been put out in the literature. The various maximum power point tracking (MPPT) methods for photovoltaic (PV) systems are reviewed in-depth, logically, and currently in this work. To help power engineers and utilities choose the best MPPT approach, the benefits and drawbacks of each method are discussed.

A technique based on GWO, which applied a fixed-step P&O procedure close to the global peak, was put out. A hybrid technique that combines adaptive particle swarm optimization (PSO) and cuckoo search was proposed by Xu et al. [8] to solve the issue of premature convergence of traditional particle swarm. Premkumar et al. [9] put forth the innovative Salp Swarm Algorithm, which discovered the initial global peak operating point and was used by the P&O algorithm in the final step to achieve a faster convergence rate. An enhanced PSO method was put forth by Premkumar et al. [10] with the goal of capturing the global maximum power point (GMPP) faster, more precisely, and with less chattering of the power curve. Liu and Lu are [11]. A high-performance MPPT algorithm that combines a temporary running strategy and a sophisticated three-point weight comparison. [12] Liu et al. By increasing the MPPT time of traditional P&O technology, it was demonstrated that there was no divergence in an environment with varying irradiance levels. Under various environmental conditions, incremental conductance and a hybrid crow-pattern search strategy based on ANFIS (adaptive neuro-fuzzy inference system) were offered as a way to improve the MPPT controller in the PV-BES (photovoltaic-battery energy storage) system [13]. A new iteration of the P&O tracking algorithm with self-predicting and decision-making capabilities for PV maximum power extraction was described by Kumar et al. [14]. To address the aforementioned issues.

To help electricity engineers and utilities make the best MPPT decision, this article provides a thorough, organized, and current review of the various maximum power point tracking (MPPT) algorithms for photovoltaic (PV) systems.

II. METHODOLOGY

This Article provides review on different techniques of maximum power point tracking (MPPT) Algorithm.

A. *Optimized Adaptive Differential Conductance*

Incremental conductance (INC) method is a prime instance of MPP approach. Instantaneous conductance (panel) and INC (load) are used in the INC technique to calculate the MPP. According to Equation (1), the instantaneous conductance (I v) and INC (dI dv) define the resultant conductance. The resultant conductance (the slope of the P-V curve) for an ideal INC is zero as shown in (2). Equation (2) must be satisfied for a perfect condition to be attained in MPPT based on INC approach [15].

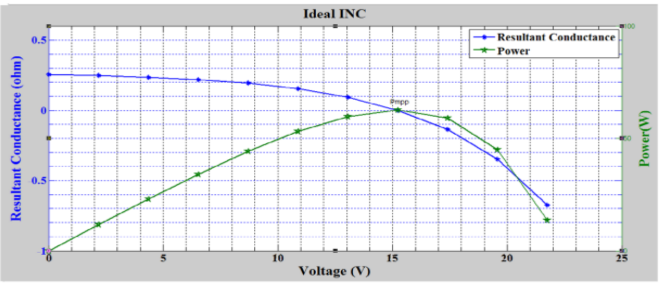


Fig. 1 Plot of resultant conductance and power against voltage for an ideal maximum power point tracking technique.

The plot of power and resulting conductance versus voltage at MPP is shown in Figure 1. According to Figure 1, power is at its highest level at Vmpp when the resulting conductance () is zero. Figure 1 also shows that power at MPP (Pmpp) occurs at Vmpp. An optimal maximum point tracking strategy is one that has resultant conductance equal to zero at Vmpp and maximum power at Vmpp. The ideal condition for maximum power is for the resulting conductance to be equal to zero.

$$\Upsilon = \frac{dI}{dV} = \frac{I}{V} \qquad (1)$$

$$I = I_{ph} - I_D - I_{sh} \qquad (2)$$

The goal of this study is to create an improved adaptive differential conductance tracking method for the MPP. This method was created to address issues with the traditional INC method, such as tracking accuracy.

A single diode model of the solar cells was used to produce the updated INC technique known as the optimised adaptive differential conductance technique. Figure 2 presents a model with a single diode. The series resistor (Rs) and shunt resistor (Rsh) make up the circuit. A large series resistor value causes a significant voltage drop across it, which causes the terminal voltage to decrease for a given current. The importance of series resistance losses increases with increasing illumination intensities. [15]. The performance of the cell is lowered by the addition of Rsh to the circuit, which also explains the dissipative phenomenon at internal cell losses. This suggests that extremely high Rsh values cause a large decrease in short circuit current. The recombination losses, which are mostly caused by junction non-ideality, surface effect, and thickness, are handled by the parallel resistance. The photovoltaic currents (Iph), diode current (ID), and shunt current (Ish) are further components of the circuit. The photogenerated Iph and the subsequent equivalent electrical circuit, shown in Figure 2, are affected by the values of Rs and Rsh in a single diode equivalent PV circuit.

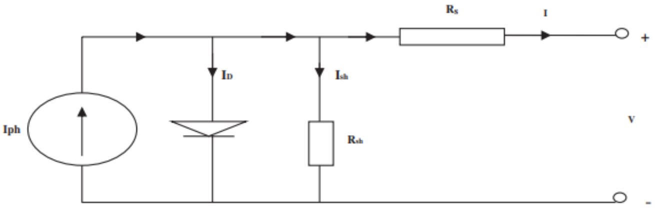


Fig 2. The equivalent circuit of PV cell with single diode.

According to Figure 3, the final conductance is positive and changes in an opposite manner with voltage for V Vmpp. On the other hand, for V Vmpp, the voltage also rises as the power does. The power began to vary inversely with the voltage once Vmpp was reached. Even if it is negative in this region, the resultant conductance is still inversely proportional to the voltage. The model is adaptable in monitoring MPP because of the variation in the resultant conductance's sign.

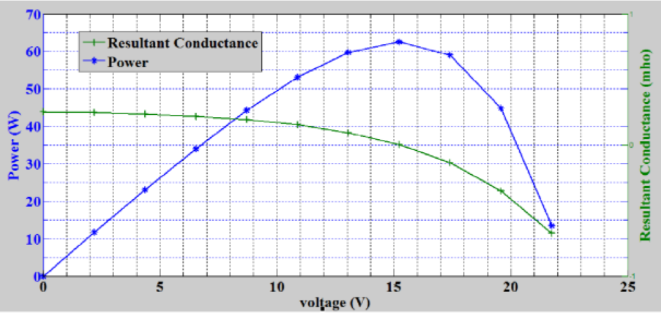


Fig. 3 Plot of resultant conductance and power against voltage for the proposed model.

At various irradiances, the resultant conductance and power vary with voltage. For all input voltage values, it was found that the resultant conductance was directly proportional to the received irradiance. The findings indicated that the value of resulting conductance increased with increasing irradiation.

This is due to the fact that while the load's impedance is constant, the panel's impedance decreases as irradiance rises. Figure 4 depiction of the link is quite apparent.

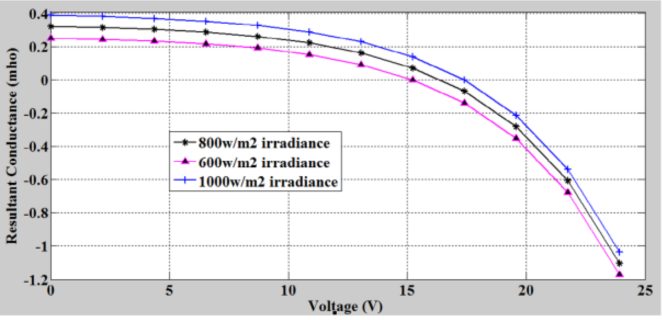


Fig. 4 Plot of resultant conductance against voltage at different irradiance for the proposed model.

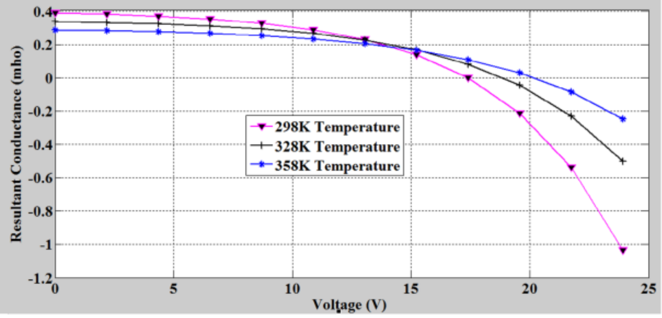


Fig. 5 Plot of resultant conductance against voltage at different temperature for the proposed model.

Table 1. Variation of Resultant Conductance with voltage at 600W/m^2 and 298K for the proposed model and conventional incremental conductance technique

Data point	Optimized adaptive differential conductance (OADC) at 600 W/m^2	Conventional incremental conductance at 600 W/m^2	Powers at 600 W/m^2	Voltage (V)
	Resultant conductance			
	ϒ (mho)	ϒ (mho)	P (W)	
1	0.2539	0.2090	0.0000	0.0000
2	0.2467	0.2018	11.6556	2.1758
3	0.2357	0.1909	23.0658	4.3516
4	0.2189	0.1741	34.0363	6.5274
5	0.1933	0.1485	44.2363	8.7032
6	0.1542	0.1093	53.1083	10.8790
7	0.0944	0.0495	59.7210	13.0548
8	0.0030	−0.0418	62.5302	15.2306
9	−0.1365	−0.1813	58.9910	17.4064
10	−0.3496	−0.3944	44.9322	19.5822
11	−0.6751	−0.7199	13.5483	21.7580

Table 1 demonstrated how the proposed and conventional INC techniques' resulting conductance fluctuates with voltage at 600 W/m2 and 298 K. At 600 W/m2 and 298 K, it was found that the optimised adaptive differential conductance produced a greater resultant conductance than the standard INC approach did. Additionally, it was noted that the suggested technique's resultant conductance at Vmpp is closer to the value for the ideal model (zero) than the INC technique's resultant conductance. Equation (3) was used to make the observation that the proposed model has an accuracy improvement over the traditional INC technique of 6.0558%. The MPP is tracked at the same rate for both models, though. This is due to the MPP taking place at point eight for the two models.

$$\text{IMTA} = \frac{\frac{1}{N}\left|\sum \Upsilon_{\text{old}}\right| - \frac{1}{N}\left|\sum \Upsilon_{\text{new}}\right|}{\frac{1}{N}\left|\sum \Upsilon_{\text{old}}\right|} \times 100 \qquad \text{................(3)}$$

Figure 6 displayed the results from Table 5 in an understandable manner. According to the figure, the suggested technique's resultant conductance against voltage intersected the power versus voltage plot at the Vmpp, whereas the INC technique intersected the power plot at a location outside of the Vmpp. This demonstrated the improved accuracy of the developed method.

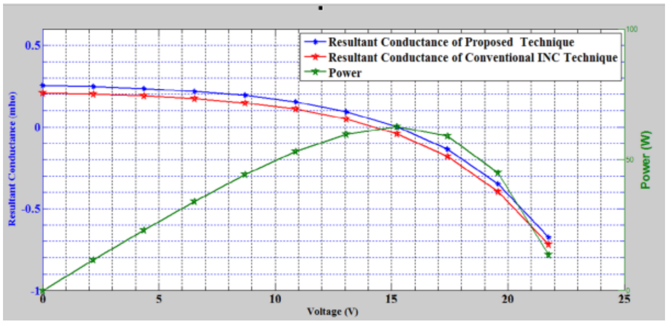


Fig. 6 Plot of resultant conductance and power against voltage.

The outcome showed that the new model was extremely accurate. At low temperatures, it more quickly and precisely tracks the MPP. While the MPP is tracked more quickly at low irradiance, it is tracked more accurately at higher irradiance. The optimised adaptive differential conductance technique was shown to be 6.0558% more accurate than the traditional INC technique. The fact that the research's results demonstrated how the strategies were expected to perform gives them significance. As it relates to some input and expected out parameters, the outcome will serve as a lookup table and chart for designers. The technology described in this research is significant because it will enable the use of a superior MPPT-based charge controller for photovoltaic applications. The amount of power transferred from the PV panel to the load with the least amount of loss will be maximised by the charge controller created using this technique [16]. Dynamic Group Cooperative Optimization Algorithm

B. *Dynamic Group Cooperative Optimization Algorithm*

To find the GMPP of SPV Panels, a stochastic-based Dynamic Group Cooperative Optimisation Algorithm (DGBCOA) is recommended in this work. By changing the DC boost converter's duty cycle, the control is achieved. To reduce the disadvantage of the currently used MPPT control techniques, the MPPT control is mathematically modelled. A comparison is performed with the most recent MPPT approaches, including PSO, CS, ABC, and DFO, as they are presented in the literature. Following are the primary contributions of the suggested work:

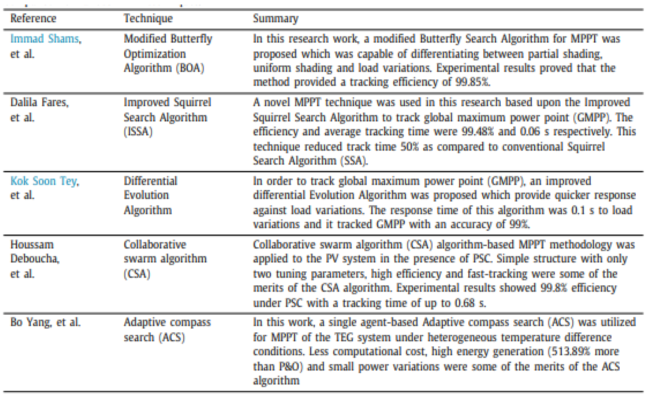
a. The proposed MPPT technique required few iterations to track global maxima due to the simultaneous working of explorative and exploitative groups.

b. The proposed technique has only 1 tuning parameter which makes it less difficult to balance the searching mechanism.

c. DGBCO based control technique for MPPT can also track GMPP under PSC and dynamic PS conditions with high efficiency.

d. Due to lower complexity of proposed algorithm, it can be implemented on a very low-cost microcontroller for experimental validation.

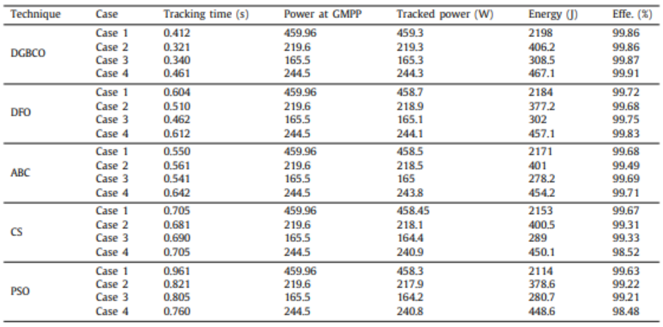
e. The results of four cases validate the dominance of the presented MPPT technique.



Reference	Technique	Summary
Immad Shams, et al.	Modified Butterfly Optimization Algorithm (BOA)	In this research work, a modified Butterfly Search Algorithm for MPPT was proposed which was capable of differentiating between partial shading, uniform shading and load variations. Experimental results proved that the method provided a tracking efficiency of 99.85%.
Dalila Fares, et al.	Improved Squirrel Search Algorithm (ISSA)	A novel MPPT technique was used in this research based upon the Improved Squirrel Search Algorithm to track global maximum power point (GMPP). The efficiency and average tracking time were 99.48% and 0.06 s respectively. This technique reduced track time 50% as compared to conventional Squirrel Search Algorithm (SSA).
Kok Soon Tey, et al.	Differential Evolution Algorithm	In order to track global maximum power point (GMPP), an improved differential Evolution Algorithm was proposed which provide quicker response against load variations. The response time of this algorithm was 0.1 s to load variations and it tracked GMPP with an accuracy of 99%.
Houssam Deboucha, et al.	Collaborative swarm algorithm (CSA)	Collaborative swarm algorithm (CSA) algorithm-based MPPT methodology was applied to the PV system in the presence of PSC. Simple structure with only two tuning parameters, high efficiency and fast-tracking were some of the merits of the CSA algorithm. Experimental results showed 99.8% efficiency under PSC with a tracking time of up to 0.68 s.
Bo Yang, et al.	Adaptive compass search (ACS)	In this work, a single agent-based Adaptive compass search (ACS) was utilized for MPPT of the TEG system under heterogeneous temperature difference conditions. Less computational cost, high energy generation (513.89% more than P&O) and small power variations were some of the merits of the ACS algorithm

Table: 2 Comparison of various MPPT Technique

DGBCO is a meta-heuristic population-based method that mimics the swarm's cooperative behaviour in order to find a comprehensive answer to the engineering optimisation problem. People naturally like to live in communities and groups, and they frequently share roles in order to gather food and battle the enemy together [17].



Technique	Case	Tracking time (s)	Power at GMPP	Tracked power (W)	Energy (J)	Effe. (%)
DGBCO	Case 1	0.412	459.96	459.3	2198	99.86
	Case 2	0.321	219.6	219.3	406.2	99.86
	Case 3	0.340	165.5	165.3	308.5	99.87
	Case 4	0.461	244.5	244.3	467.1	99.91
DFO	Case 1	0.604	459.96	458.7	2184	99.72
	Case 2	0.510	219.6	218.9	377.2	99.68
	Case 3	0.462	165.5	165.1	302	99.75
	Case 4	0.612	244.5	244.1	457.1	99.83
ABC	Case 1	0.550	459.96	458.5	2171	99.68
	Case 2	0.561	219.6	218.5	401	99.49
	Case 3	0.541	165.5	165	278.2	99.69
	Case 4	0.642	244.5	243.8	454.2	99.71
CS	Case 1	0.705	459.96	458.45	2153	99.67
	Case 2	0.681	219.6	218.1	400.5	99.31
	Case 3	0.690	165.5	164.4	289	99.33
	Case 4	0.705	244.5	240.9	450.1	98.52
PSO	Case 1	0.961	459.96	458.3	2114	99.63
	Case 2	0.821	219.6	217.9	378.6	99.22
	Case 3	0.805	165.5	164.2	280.7	99.21
	Case 4	0.760	244.5	240.8	448.6	98.48

Table 3 Quantitative Comparison summary of Results

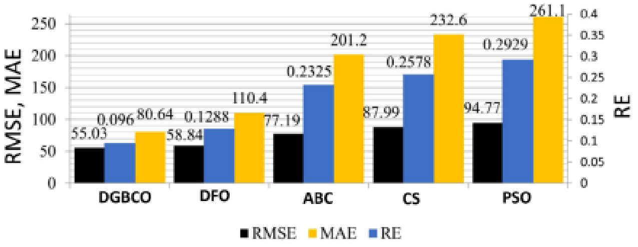


Fig. 7 Comparison of RMSE, MAE AND RE

DGBCO has been touted as a successful controller for PV systems in instances of partial shadowing. In comparison to intelligent control strategies, the suggested technique has the following advantages: higher power tracking efficiency; least fluctuation; and minimal oscillations at Global Maxima. In contrast to current SI-based MPPT controllers, a dynamic group-based approach is used. With this plan, the position update system is able to give up less precise solutions without experiencing significant voltage transient spikes. The DGBCO achieves better average power in less tracking time due to a reduced need for computing time and a quicker recovery of the optimal solution. In comparison to DFO, ABC, PSO, and CS, GM tracking is made possible by superior global maxima detection and tracking as well as a balance between exploration and exploitation. According to the results, the DGBCOA tracks the GM in an average period of 320–461 ms, 30%–60% faster than the previous method [18].

III. RESULTS AND DISCUSSION

In this article Actually We Review two different MPPT technique firstly Optimized Adaptive Differential Conductance, secondly, a stochastic based Dynamic Group Cooperative Optimization Algorithm (DGBCOA).

We go over the conductance variation with voltage, power, and resultant conductance against voltage at MPP in the first technique. It demonstrates that power is at its peak at Vmpp, when the resultant conductance () is zero. A modified INC technique is the optimised adaptive differential conductance technique. We also discuss the relationship between power and voltage in the preceding Figure 3. At various irradiances, the resultant conductance and power vary with voltage. For all input voltage values, it was found that the resultant conductance was directly proportional to the received irradiance. The findings indicated that the value of resulting conductance increased with increasing irradiation. How the suggested and traditional INC techniques compare in terms of the resultant conductance with voltage at 600 W/m2 and 298 K. At 600 W/m2 and 298 K, it was found that the optimised adaptive differential conductance produced a greater resultant conductance than the standard INC approach did. Additionally, it was noted that the suggested technique's resultant conductance at Vmpp is closer to the value for the ideal model (zero) than the INC technique's resultant conductance.

The Dynamic Group Cooperative Optimisation Algorithm (DGBCOA), which is supported as a method to ascertain the GMPP of SPV Panels, is discussed in the Second Technique. By changing the DC boost converter's duty cycle, the control is achieved. DGBCO is a meta-heuristic population-based method that mimics the swarm's cooperative behaviour in order to find a comprehensive answer to the engineering optimisation problem. According to the data, the DGBCOA follows the GM in an average time of 320–461 ms, 30%–60% faster than the industry standard.

IV. CONCLUSION

From the result, it was observed that the new model was very accurate. It tracks the MPP faster and more accurately at low temperature. On the other hand, the MPP is tracked faster at low irradiance but the tracking is more accurate at higher irradiance. In comparison with conventional INC technique, it was noticed that the optimized adaptive differential conductance technique developed was 6.0558% more accurate. The importance of the result obtained in this research is that it showed the expected performance of the techniques developed. The result will act as a lookup table and chart for designers as it concerns some input and expected out parameters. The significance of the method developed in this paper is that it will lead to the implementation of better MPPT-based charge controller for photovoltaic application. Charge controller developed using this method will maximize the transfer of power from the PV panel to the load with minimal loss.

DGBCO has been presented as an effective controller for PV systems under partial shading conditions. It has higher power tracking efficiency, least fluctuation, and low oscillations at Global Maxima as compared to intelligent control techniques. Unlike existing SI-based MPPT controllers a dynamic group-based strategy is employed. This scheme allows the position updating mechanism to abandon less accurate solutions without large surges in voltage transients. Due to lesser computation time requirement and faster recovery of the optimum solution, the DGBCO achieves higher average power in lesser tracking time. The outstanding global maxima identification and tracking and balance between exploration and exploitation enable GM tracking in the least iterative time as compared to DFO, ABC, PSO, and CS The results indicated on average the DGBCOA tracks the GM within 320– 461 ms achieving 30%–60% quicker GM tracking time

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