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Evolutionary and Metaphor-Metaheuristic MPPT Techniques for Enhancing The Operation of Solar PV Under Partial Shading Condition

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Abstract.: Photovoltaic (PV) systems are the most popular electric power generation systems for domestic as well as industrial applications because of its sustainability and excess availability in nature. Under Partial Shading Condition (PSC), the nonlinear characteristics of solar PV consist of multiple local Maximum Power Points (MPPs) and one global MPP. Hence, it is difficult to operate the operating point of the solar PV closer to true MPP. There are different tracking methods available for MPP Tracking in the literature. The classical Maximum Power Point Tracking (MPPT) methods are not suitable under partial shading conditions because the operating point of PV may settle down to any one of the local MPP. Also, these methods failed to mitigate the oscillations across the operating point of solar PV. The recently developed evolutionary based MPPT techniques are becoming more prominent in order to avoid the drawbacks of classical MPP techniques. In this article, different types of MPPT techniques such as evolutionary, metaphor-metaheuristic and hybrid MPPT techniques are discussed in detail along with their advantages and disadvantages. The comparative analysis is carried out by considering the parameters such as tracking speed, oscillation across MPP, settling time, implementation complexity and efficiency.

Key Words: Boost converter, duty cycle, MPPT, optimization techniques, PV array, PSC.

I. INTRODUCTION

From the last few decades, the installation of PV power generation systems has been increasing worldwide because of its long-lifetime benefits and large-scale government subsidies [1]. In India, solar PV is the fast-developing industry and its installation capacity keep on growing. As per the Indian government ministry, the installation of solar PV power as of 31 December 2018 is 25.21GW [2]. Solar energy can be converted into different forms such as solar thermal electricity, solar heat, and solar photovoltaic. The features of solar energy are highly reliable, environmentally friendly nature and easy to harvest when compare to all other renewable sources [3-4]. The solar energy is converted to electrical power either by utilizing indirect concentrated PV module or a direct PV module. The single solar cell generates 0.7 to 0.8V [3] which is negligible. The series and the parallel combination of modules form an array [5].

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In order to increase the voltage rating of the PV system, tens of PV cells are interconnected in series and parallel to form a module [6].

The PV array generates nonlinear I-V and P-V characteristics at different irradiation and temperature conditions and it is difficult to transfer the maximum power from the source to load. In order to extract and transfer the maximum power, the MPPT technique is used to track and operate the operating point of PV at MPP. Most of the researchers working on the development of different advanced and hybrid MPPT techniques for fast-tracking of MPP [7] and the number of publications (2009 to 2019-April) on MPPT are given in Table.1. From Table.1, it is observed that the number of MPPT publications is increasing every year. It resembles that the MPPT is grabbing more interest in the current research on PV technology.

The classical MPPT techniques are Perturb &Observe (P&O) [8], Incremental Conductance (IC) [9], Fractional Short Circuit Current (FSCC) [10], Incremental Resistance (IR) [11], Fractional Open Circuit Voltage (FOCV) [12] and Ripple Correlation Control (RCC) [13]. The FSCC MPPT method having a great advantage of the linear relationship between the operating current of PV at MPP with respect to the short circuit current [10]. In similar, FOCV MPPT technique, the operating voltage of PV at MPP is directly proportional to the open-circuit voltage of PV [12]. The implementation and understanding the operation of FSCC and FOCV MPPT methods are easy which are used in street lights where the necessity of accurate MPPT tracking is not required. The drawback of FSCC and FOCV MPPT methods is huge power loss because of periodic shunt down of the PV power generation systems when determining the open-circuit voltage and short circuit current of PV.

The P&O and Hill Climb (HC) MPPT method works on the same principle but the implementation is different. There are different perturbations sizes that are used in P&O to improve the MPP tracking performance of solar PV [8]. However, the conventional MPPT techniques are not suitable to track MPP under PSC.

In order to overcome the drawbacks of conventional MPPT techniques, soft computing and optimization techniques are utilized in articles [14] and [15] to extract the maximum power of solar PV. The advantages of soft computing techniques are highly robust, more flexible and easier to implement compare to conventional techniques. The soft computing MPPT techniques are Artificial Neural Network (ANN), Fuzzy Logic Controller (FLC), ANFIS, Bio-inspired, Chaos theory, and differential evolutional [16]. In addition, fuzzy logic MPPT controllers are most widely used for the extracting maximum power under partial shading condition of solar PV [17].

This technique does not require any mathematical calculations. Hence, the implementation-

Table.1. Number of MPPT articles publication from the year 2009 to 2019-April [8]

Type of journal		Years										
		2009	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019, April**
IEEE-Journals	Books	1	0	1	0	1	2	1	2	2	1	1
	Articles	293	360	501	569	699	852	864	1082	737	856	861
	other	1	1	0	2	0	2	1	2	0	5	3
	Total	295	361	502	571	700	856	866	1086	739	862	865
Elsevier-Journals	Books	86	97	83	124	216	198	215	224	243	312	313
	Articles	1092	1257	1798	1996	2772	3521	3926	4562	5865	6231	6243
	other	81	92	138	236	218	171	162	202	238	227	229
	Total	1259	1446	2019	2480	3206	3890	4303	4988	6346	6770	6785
Overall publications		1554	1807	2521	2480	3422	4746	5169	6074	7085	7632	7650

-complexity is less when compared to other conventional techniques. In addition, the fuzzy logic controller is used in HC, IC and P&O MPPT techniques to enhance their performance efficiency.

Fuzzy logic MPPT tracking involves three processes; fuzzification, inference, and defuzzification. In the article [18], the authors considered the PV voltage error (e) and change of error (Δe) as the input variables to track MPP of solar PV. The boost converter is interfaced in between PV system and load to step up the PV voltage. The drawback of the fuzzy controller is that it requires more training time for solving complex problems.

A high expertise person is required for the selection of membership function in a fuzzy technique [19]. In order to overcome the drawbacks of the fuzzy controller, an Adaptive Neuro-Fuzzy Interface System (ANFIS) is utilized in the article [20] to improve the dynamic response of solar PV at different irradiations and temperature conditions. The MPP tracking in ANFIS is done by calculating the open-circuit voltage of solar PV which is measured by periodically shut down of the PV system. Hence, the power loss exists in the photovoltaic power generation systems. The block diagram of PV fed dc-dc converter is given in Fig.1.

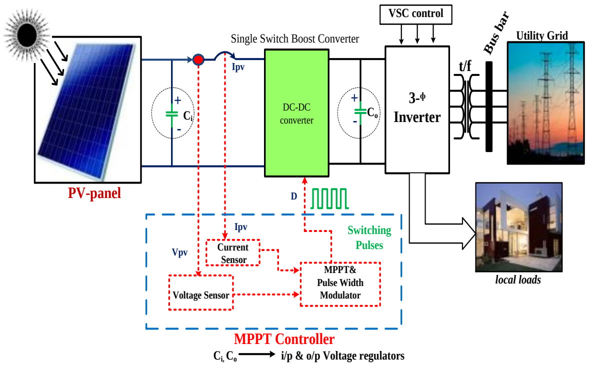


Fig.1. Schematic of PV grid-connected system [8]

In order to overcome the drawbacks of above MPPT techniques, a powerful bio-inspired evolutionary, swarm intelligence and hybrid optimization MPPT techniques are explained in this work in detail to solve the all complex and nonlinearity problems of solar PV without computing mathematical equations.

II. PARTIAL SHADING OF SOLAR PV

The numbers of PV cells can be connected in series and parallel to form an array of PV [21]. Whenever the shading effect occurs on the PV panels, the shaded panel consumes the power of the unshaded panel. As a result, a huge power loss occurs in the PV system.

Due to this power loss, the overall power generation capacity has been reduced. The hot spot effect damages the PV cell when the reverse operating voltage is increased beyond the breakdown voltage of PV. In order to overcome this issue, an antiparallel diode 'D' is connected across each solar panel to improve the efficiency of solar PV and the losses are reduced at higher extended level [22]. The partial shading solar PV strings and nonlinear power against voltage characteristics are given in Fig.2(a) and (b).

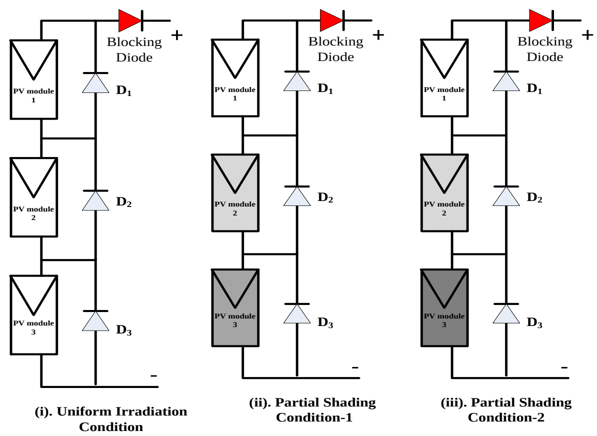


Fig.2 (a). Partial shading of the PV panel

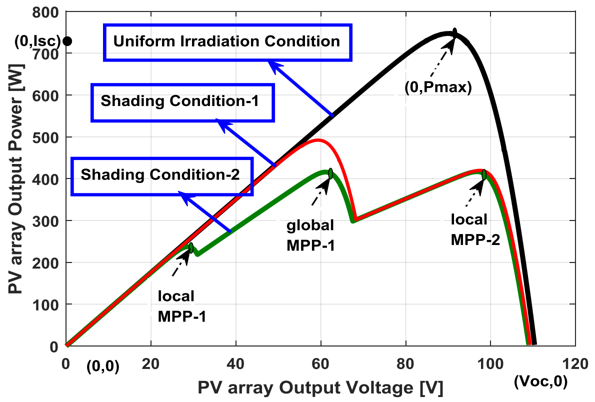


Fig2(b). Nonlinear P-V characteristics at different shading patterns conditions

From Fig. 2(a), the bypass diodes D_1, D_2, and D_3 which are useful to eliminate the reverse recovery losses of PV module at partial shading condition and it is observed that, at uniform irradiation condition (1000W/m^2), there is one MPP which is tracking by different conventional MPPT techniques. From Fig. 2(b), it is shown that under partial shading conditions (1000, 800, 500W/m^2 and 1000, 800, 200W/m^2), they are two local MPP's and one global MPP which is required to extract the maximum power of solar PV.

III. EVOLUTIONARY MPPT TECHNIQUES

In EV MPPT technique, there are three stages. In the first stage, different duty values are randomly initiated to all individual population and the second stage is involved to obtain the fitness value of each individual population. In the final stage, for the reproduction process, the best fitness function is evaluated among all individual fitness functions. From the article [23], the EV MPPT techniques are classified as, Differential Evolution [24], Evolution Program, and strategy [25], Genetic Programming [26], and Genetic Algorithms [27] are consisting of different operating features which are given in Table.2.

Table.2. Differentiation between the features of EVP, ES and GA's, [27]

	Evolutionary Programming	Evolutionary Strategy	Genetic Algorithms
Evolution type	Species mode	Distinct mode	Genetic mode
Illustration	Discrete	Continuous	Continuous
Regenerate	Sexual	Panmictic	Sexual
Distinction of operatives	Mutation	Mutation and recombination	Mutation and crossover
Adaption in the distinction of operatives	Adaptive	Self-adaption	Non-adaptable

A. Differential Evolution MPPT Tracking

The DE technique is easy to implement because it requires few operators to obtain an optimal solution. In general, there are few populations of particles and iterations required to solve the noise problems. In every iteration, the difference between the two particles is evaluated to mutate each other particles [24]. From the article [28], the two-dimensional vectors are used in DE for every iteration or generation with a population (p_a; a=1,2,3,4……Np).

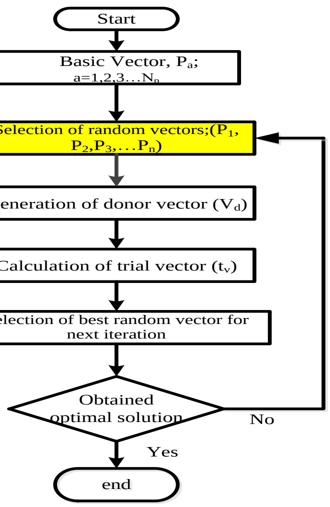
The number of particles (Np) needed in each and every iteration is the same which is described in Eq.1. In the first iteration, the first target vector is selected to search the entire search space. After obtaining the first iteration results, there are three random vectors selected and a mutation parameter 'm' is utilized to initialize the weight value to the two vectors and the weight difference between the two vectors is added to the third vector to obtain the donor vector which is illustrated in Eq.1.

$$V_d = P_{a1} + m * (P_{a2} - P_{a3}) \quad (1)$$

Where the range of mutation 'm' is in between '0' and '1'. So, based on the mutation value, the donor vector covers the entire population and it is added with the random vector to generate a new trial vector (t_v) and this process is called crossover. The condition of the trial vector is given in Eq.2. After completion of crossover, a selection is carried out between the trial and random vectors.

$$t_v = \begin{cases} V_d ; 0 < d < 1 \\ P_a < 0 \end{cases} \quad (2)$$

The Eq.2 is used to obtain the optimal solution which is used for the next iteration. This process continues until achieving the optimal solution. The basic operation of DE is given in Fig.3 (a) and its application on MPP tracking is given in Fig.3(b).



(a)

Fig.3 (a). Basic operation of the DE technique

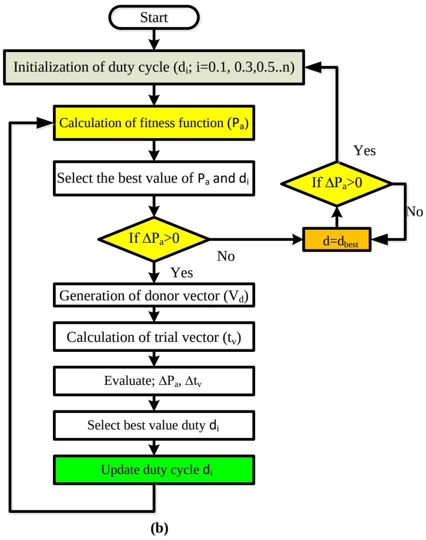


Fig.3(b). Operation of DE based MPPT controller

The partially shaded PV panel consists of more than one MPP. In order to track global MPP, a differential evolution MPPT technique is used in the article [29] because of its features such as global search, high convergence and tracking speed and easy to implement. The dc-dc converter is interfaced in between the PV system and load. The duty of boost converter is updated by using the DE MPPT technique to operate the MPP of PV closer to the global MPP. Here, the target vector is a duty cycle (d_i). At the initial stage, different duty values are randomly initiated to all particle's positions (P_i, i=1,2, 3…n) to search the entire search space of the P-V curve. After initialization, the highest power of particle position is considered as P_{best} and its corresponding duty cycle is considered as d_{best}. The analysis of DE MPPT technique for different application is illustrated in next section.

a. Literature survey of the DE based MPPT Technique

So far, the majority of software-based MPPT techniques scan the multidimensional I-V and P-V characteristics of PV in order to track MPP under partial shading condition. Based on a scanning approach, one of the most frequently used MPPT technique is DE. In DE evolution, multiple iterations are required for finding the MPP position on the P-V curve. As a result, the obtained MPP of PV will not be at the desired position [30].

Table.3. Analysis of DE based MPPT technique for different applications

S. No	Author	Article	MPPT method	Control Variable	Application	Results
1	Tajuddin	[28]	DE	Duty cycle/ Converter or Inverter	Standalone or grid-connected PV system	The authors compared the DE MPPT technique with HC technique in terms of accuracy and convergence speed. From the simulation results, the authors concluded that the DE MPPT technique convergence speed is less but the MPP tracking accuracy is high.
2	Hamed Taheri	[31]	Modified DE	Voltage or current of the boost converter	Standalone systems	The PV performance is based on the change of irradiation and temperature conditions. The authors used a modified DE MPPT technique to improve PV power extraction.
3	Muhammad Sheraz	[32]	DE with ANN	Duty cycle/dc-dc converter	Standalone systems	The authors used a hybrid intelligent (DE with ANN) MPPT technique to transfer the maximum power from the source to load at diverse atmospheric conditions.

Table.4. Analysis of GA based MPPT technique for different applications

S. No	Author	Article	MPPT method	Control Variable	Application	Results
1	Li, Guiqiang	[27]	GA	Voltage	Standalone PV systems	The authors considered PV power as a fitness function and duty values randomly initiated to all agents to track MPP with less computational complexity.
2	Stefan Daraban	[33]	Modified GA	Voltage or current of the boost converter	Standalone systems	The authors have developed a hybrid GA based MPPT controller by using the digital microprocessor and it is tested at diverse atmospheric temperature conditions.
3	C. Larbes and S.M. Cheikh	[34]	GA with Fuzzy	Duty cycle/boost converter	Standalone systems	The global MPP of PV is tracking by GA with the fuzzy controller at different irradiation and temperature conditions.

In order to overcome this issue, modified DE MPPT technique is used in the article [31] and it requires an optimum duty cycle information to adjust the duty of the boost converter. In addition, it gives high accuracy in MPP tracking because it does not require any random numbers for perturbing the PV voltage. As a result, the implementation complexity is reduced compared to the fundamental DE technique. The analysis of DE based MPPT technique for different applications is given in Table.3.

B. Evolutionary Program Based MPPT Tracking

The Evolutionary Program (EP) is a technique which is rarely used to extract the maximum power of solar PV. In the article [25], Rajasekar has proposed evolutionary programming to overcome the drawbacks of artificial intelligence MPPT techniques. The EP based MPPT tracking happens in three stages, at first stage different duty values are randomly initiated to all the candidates and in second stage mutation is used to perturb the population arbitrarily. In the final stage, each candidate competes with another candidate.

C. Genetic Algorithm Based MPPT Tracking

The GA implementation flowchart is given in Fig.4. In the article [27], the author 'Li and Guiqiang' proposed GA as an MPP tracking technique under shading condition of a PV system. The position of chromosomes is indicated as Y^K which is calculated by using Eq.3.

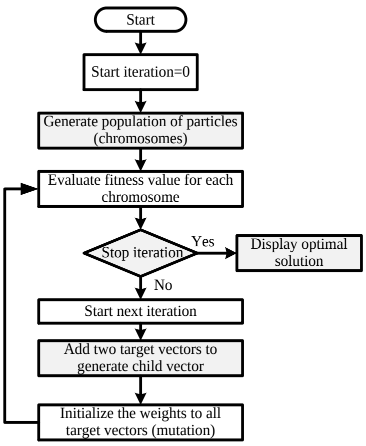
$$Y^k = V^k \tag{3}$$

Where V^k is the PV voltage at the k^{th} iteration. In the first iteration, the individual chromosomes best positions are selected by evaluating the performance of each chromosome. In the next step, two individual chromosomes are combined to form a child chromosome is called crossover. The PV-

power is considered as a fitness function to harvest the maximum power of PV.

$$d^k = 1 - \frac{(childchrome)^k}{V_{PV}} \tag{4}$$

Where d^k and V_{PV} are the duty cycle of the boost converter and PV voltage.



(a)

Fig.4. Flowchart of G A MPPT controller

a. Literature survey of GA based MPPT Technique

From the article [33], the authors have proposed a modified GA for the extraction of extreme PV power by absorbing the excessive sunlight energy. In this algorithm, the P&O technique is used to obtain the optimal value of the duty cycle by reducing the number of population and iterations. As a result, the MPP tracking time of GA is reduced. From the effective operation of P&O, the GA parameters such as the number of agents, search space and iterations are optimized. The macroblock is used in GA to reduce the boost converter components and simulation time. Most of the ANN-based MPPT techniques do not require any mathematical computation and it is having a property of high noise rejection capability. The analysis of GA for stand-alone and grid-connected PV systems is given in Table.4.

IV. METAPHOR-METAHEURISTIC MPPT TECHNIQUES

The metaphor-metaheuristic algorithms are applied for solving all complex optimization problems with help of different figures which is called metaphor. Due to the feature of global and random search, these techniques solve the high difficulty in optimization problems with less time. In the real world, most of the optimization problems are multidimensional, complex in constraints and nonlinear. Hence, in this article different metaheuristic MPPT techniques are discussed to obtain the MPP of solar PV. Those are Particle Swarm Optimization (PSO) [35], Ant Colony Optimization (ACO) [36] and Artificial Bee Colony (ABC) [37].

A. PSO based MPPT Technique

Among all of the optimization techniques, PSO is one of the most popular swarm intelligence optimization techniques which is proposed by Kennedy and Eberhart in 1995. After that, it is used in many problems optimizations like engineering designs, workers scheduling in industries and computational intelligence [35], [38]. The operating principle of PSO is inspired by the swarm behavior in nature such as fish schooling and birds flagging. In the PSO algorithm, the individual trajectories of agents (particles) search the entire search space of objective function in a particular direction by adjusting their positions. The movement of particles involves two major components: stochastic and deterministic. Each particle moves randomly from its own position to a global position in the search space of optimization function. The particle position 'Y' and velocity 'V' are updated by using Eq.5 and 6.

$$V_k^{t+1} = W V_k^t + \alpha c_1 \left(P_{best,k} - y_k^t\right) + \beta c_2 \left(g_{best,k} - y_k^t\right) \tag{5}$$

$$y_k^{t+1} = y_k^t + V_k^{t+1} \tag{6}$$

Where V_k^{t+1} and y_k^{t+1} are the updated k^{th} particle velocity and position at interval *t+1*. The variables c_1 and c_2 are the random vectors whereas α and β denotes the learning constraints. The variable $p_{best,k}$ is the best position of particle k and $g_{best,k}$ is the obtained particles best position [39].

The PSO technique is used in MPPT tracking under partial shading condition because of its attractive features are high tracking speed and less steady state oscillations across MPP. Moreover, this technique gives high accuracy in MPP tracking at different solar irradiation and atmospheric temperature conditions. In addition, this technique requires a one-dimensional vector for MPP tracking. In the article [40], the deterministic PSO MPPT technique is proposed to control the duty cycle of the dc-dc converter. Here, different duty values (positions) are randomly initiated to all particles and PV power is considered as a fitness function or objective function.

In the first iteration, all particle positions or duty values are adjusted by utilizing Eq. 7 and 8. The particle velocity is controlled by varying the distance between the two particles. The distance between the two particles varied by utilizing the learning constraints. The initialization and implementation flowcharts of PSO are given in Fig. 5.

$$\Delta d_k^{t+1} = W d_k^t + \alpha c_1 \left(d_{best,k} - d_k^t\right) + \beta c_2 \left(D_{best,k} - d_k^t\right) \tag{7}$$

$$d_k^{t+1} = d_k^t + \Delta d_k^{t+1} \tag{8}$$

Where 'W' is the inertia weight and Δd is the variation of the duty cycle. The best duty cycle of particle k is d_k and $D_{best,k}$ is the best duty value after computing all particles where the maximum PV power is extracted. The main advantage of the PSO technique is high convergence speed to obtain the value of duty cycle for achieving high converter output voltage but the convergence speed is based on the initial position of particles.

a. Literature survey of PSO based MPPT Technique

In the article [41], the PSO technique is applied to solve all complex nonlinear problems but it is having drawback is that it is difficult to initialize the operating and design parameters. In addition, this technique is not suitable to solve scattered problems. In order to overcome these issues, a hybrid PSO-PI controller is proposed in the article [42] for a standalone PV system. At first PSO is applied to track global MPP. Once the operating point sticks on MPP the oscillations across MPP occurs. In order to eliminate oscillations at MPP, a PI controller is included with PSO. An adaptive sampling time technique is used to move the operating point of PV towards the MPP. The objective function 'f' in this hybrid technique is the PV output power is derived as,

$$f\left(y_j^k\right) > f\left(P_{jbest}\right) \tag{9}$$

In vector y^1, there are three reference voltages which are applied to the dc-converter to step up the PV voltage and is given in Eq.10.

$$y^1 = \left[V^1 \quad V^2 \quad V^3\right] \tag{10}$$

At global MPP, the differentiation of power p(t) with respect to the voltage v(t) is zero and the error parameter e(t) is derived as,

$$e(t) = \frac{P(t)}{V(t)} \tag{11}$$

The error value is minimized and the slope of the PV curve is adjusted by using a PI controller. The voltage at MPP is derived as follows.

$$V_{mpp} = C_p e(t) + k_i * \int e(t) * dt \tag{12}$$

Where C_p is the error co-efficient and k_i is the integral constant. The optimization process repeated by utilizing Eq's 7 to 12. The analysis of PSO based MPPT technique for different applications is given in Table.5.

B. Ant Colony Optimization based MPPT Technique

From the literature survey [36], the swarm intelligence study is increasing continuously. ACO is the one of the most widely used swarm intelligence optimization technique which is used to solve the real-world

Table.5. Analysis of PSO based MPPT technique for different applications

S. No	Author	Article	MPPT method	Control Variable	Application	Results
1	Abdmouleh and Zeineb	[35]	PSO	Voltage or current	Standalone PV systems	The PSO technique is this article to track the global MPP with high convergence speed.
2	Alivarani Mohapatra	[42]	PSO with PI controller	Voltage/PV power	Standalone PV systems	In this article, PI controller is used in PSO to suppress the oscillations across MPP.
3	Rahul suryavansi	[41]	PSO with P&O	Duty cycle/boost converter	Standalone PV systems	The PSO-P&O MPPT technique is used to track MPP at various atmospheric conditions.
4	B.C. Kok, and H.H. goh	[43]	PSO with ANN	Duty cycle/boost converter	Standalone systems	In this article, the fuzzy logic controller is applied to measure the irradiation level of solar PV. Based on this irradiation level, the PSO is used to extract the optimum power of the PV panel.

Initialization of PSO

- Initialize all particle positions
d(k)=linespace (d_{max}, d_{min}, N_P)
- Initialize random vectors
P_{best}=0; k=1,2,3….N_P
$P_{pv\text{-}best}$=0; k=1,2,3….N_P
-Initialize the global search vectors
G_{best}=0, $g_{best\text{-}old}$=0.
- Initialize the PV power
P_{PV}=0

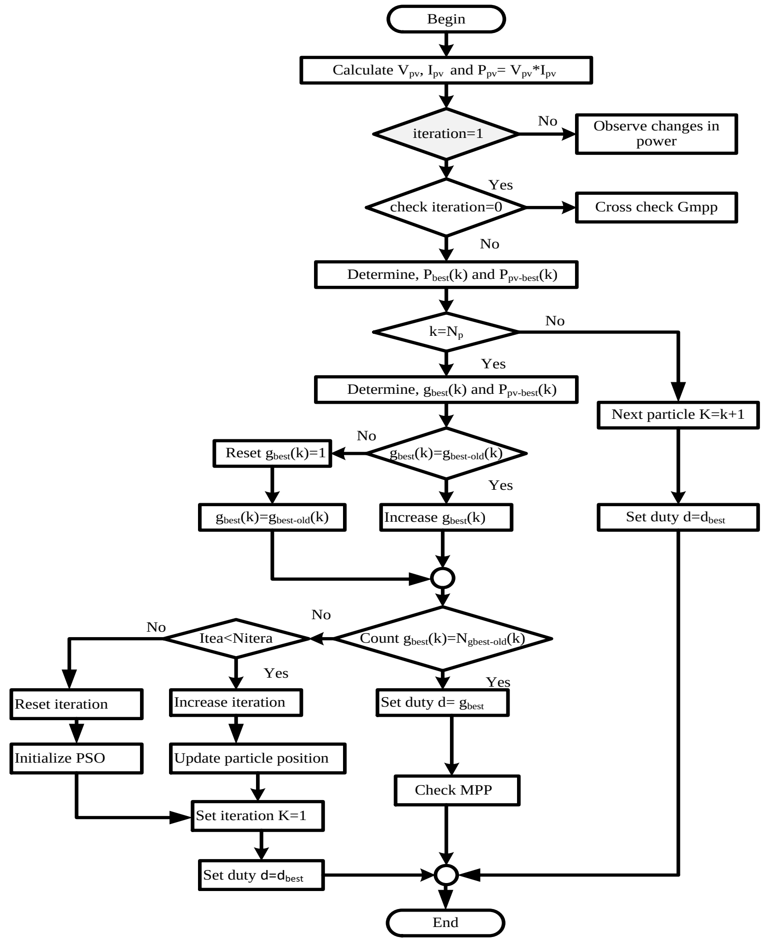
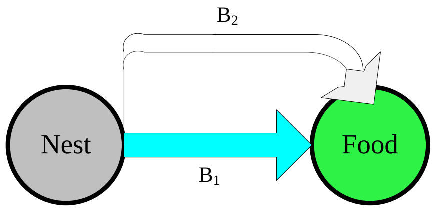


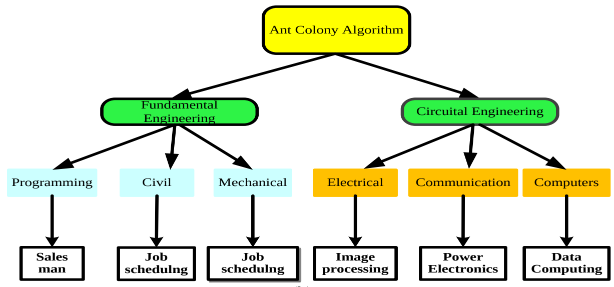
Fig.5. Initialization of swarm particles and its application in MPPT controller

nonlinear problems such as program scheduling of workers in the industry, image processing, material design, power electronic circuits implementation. The applications of ACO algorithm is illustrated in Fig.6(b). The ACO technique is implemented by Macro and Aran in the year1990 and its working principle is considered from the foraging behavior of ants. Ants follow the optimum path in the entire search space to find the best solution. When the ant searching for food, it will communicate with other ants by utilizing the chemical exchanger phenomenon. Each and every ant is able to follow the chemical substance produced (pheromone) path of other ants. If an ant finds a food source in searching space it marks the searching path with pheromone to follow the other ants until individual ants find the shortest path. At first, the ACO is used for combinational problem solving and nowadays many researchers utilizing this technique for different optimization problem applications.



(a)
Aron and Gose Double bridge experiment on ACO

Fig.6. (a). Explanation of ACO operating with double bridge experiment



(b)
Optimizing Applications

Fig6(b). ACO technique utilization in the engineering field

The author Chandra Mohan explained the ACO algorithm by considering the Deneubourg double bridge experiment. In this, there are two bridges, one is the shortest path bridge and another one is the longest path bridge which is shown in Fig.6(a). In probability condition, the ants select the shortest bridge to reach the nest, then the formation of pheromone is more in the shortest path when compared to high distance path. This is the probability of the remaining ants to choose the shortest path [44]. The selection probability of the shortest path of ants is evaluated by using Eq.13.

$$P = \frac{(n_1 + m)^h}{(n_1 + m)^h + (n_2 + m)^h} \tag{13}$$

Here, n_1 is the number of ants has selected the shortest path to move from nest to food and n_2 is the remaining ants used the longest path to reach the food. The constraints (m, k) are adjusted continuously until achieving the shortest bridge.

From the advantages ACO in engineering filed, in the article [45], the authors used the ACO MPPT technique to transfer the maximum power from the source to load by controlling the PV current. The duty of the dc-dc converter is adjusted corresponding to the PV peak current for step up the PV voltage. Under the partial shading condition, multiple MPP's can be identified. The PV voltage *Vpv* and current *Ipv* parameters are considered to evaluate *Vmpp*. At initial different positions (duty cycle) of ants are considered randomly and its movement observed until the ants return the nest to obtain the maximum peak voltage. Consider 'N' number of particles to achieve the optimal solution and its random solutions are *'K'* which are ranked based on their evaluation value ($f(s_1) < f(s_2) <\ldots f(s_n)$). For each dimension of random solutions, the probability function is considered as a gaussian function. The Gaussian sampling technique is used to generate the new solution for every dimensional particle [46]. The flowchart representation of ACO MPPT technique is given in Fig.7.

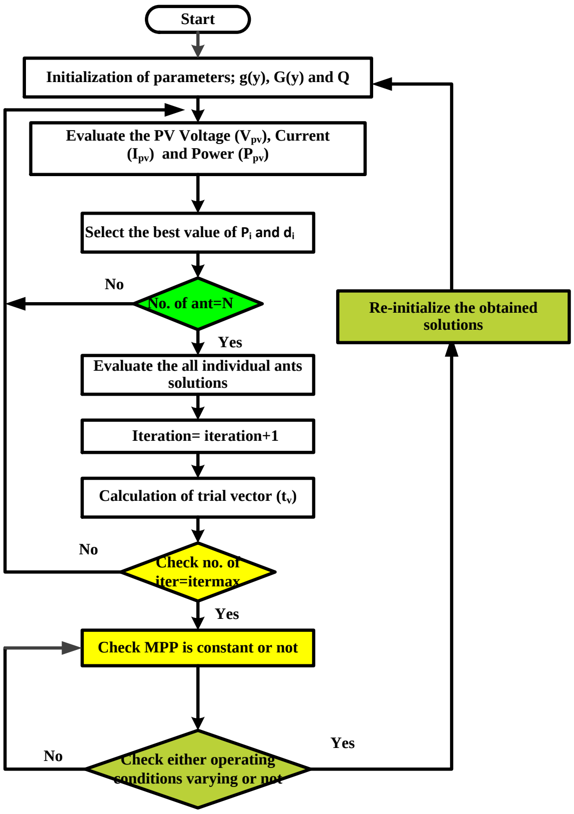


Fig.7. ACO based MPPT controller

a. Literature survey of ACO based MPPT Technique

From the article [36], ACO technique is attracting the researchers to apply on industrial optimization problems. In an article [46], an ACO MPPT is applied for MPP control and it is inspired by the social behavior of ants. The PI controller is used to tune the agents in the ACO algorithm and it is tested by using a standalone PV system. The ant colony PI controller based MPPT performance is improved by including a Fractional Open circuit Voltage MPPT method. In addition, it tracks the MPP effectively and efficiently. From the Matlab Simulink results, the authors concluded that the proposed hybrid (ACO-PI with FOV) MPPT technique giving superior performance at static and dynamic irradiation conditions over conventional MPPT techniques. The analysis of ant colony with some other techniques is given in Table.6.

Table.6. Analysis of ACO based MPPT technique for different applications

S. No	Author	Article	MPPT method	Control Variable	Application	Results
1	Jiang, Lian Lian	[36]	ACO	Voltage/boost converter	Standalone PV systems	The ACO MPPT used for PV voltage and current control application to transfer the optimal voltage from the PV system to resistive load.
2	Beshear and A. H. Adly	[46]	ACO-PI with FOV	Voltage/dc-dc converter	Standalone or Grid-connecte d systems	The fractional open circuit voltage method is used in ant colony method to reduce the oscillations across MPP and PI controller is used for stabilizing the MPP.
3	Kinattingal Sundareswaran,	[47]	ACO with P&O	Voltage or current	Standalone or Grid-connecte d systems	Here, initially, P&O technique used to reach MPP. After that, the ACO technique is used for fast convergence of MPP.
4	M. Adly	[48]	ACO with Fuzzy	Voltage/boost converter	Standalone systems	In this paper initially, a fuzzy logic based fractional open circuit voltage method is added with ant colony technique for accurate convergence of MPP.

C. Artificial Bee Colony Based MPPT Technique

ABC algorithm is inspired by the foraging behavior of honey bees. The honey bees live is in the form of a colony. The honey bee can communicate with one and another in the form of pheromone (chemical exchange) and waggle dance. If any bee find the food source and it brings back some food to the nest and it shares the food source location by waggle dance. The waggling dance varies from one group of species to another group of species and some bees used the directional dancing and strengths to share the direction and location of food source. In this way, the ABC optimization technique is utilized for the discrete and combinational problem-solving application [37]. The main components involved in honey bee forage selection is a food source, employed and unemployed foragers. The communication of bees is dependent on the quality of the food source. The probability employed foragers sharing of their information is directly proportional to the profitability of food source. In this way, the honey bees find the food source.

From the article [49], the authors used the ABC MPPT technique to track MPP under partial shading condition. At the initial stage, all the bees scanned the local MPP's and global MPP. After that, it moves forward to update the bee's positions. Here, the duty of boost converter is considered as the food source and the PV power is considered a fitness function. In this technique, the number of iterations required to select the optimal distance from food source to nest is less. As a result, the convergence speed of ABC is reduced. The bees are randomly initialized with different duty values (food source positions) in the search space by utilizing Eq.14.

$$P_i = duty_{\min} + \frac{(j-1)*(duty_{\max} - duty_{\min})}{N_p - 1} \quad (14)$$

Where P_i is the honey bees' position and j indicated as a number of bees *(j=1,2, 3…. Np).* Here, the maximum duty *($duty_{max}$)* and minimum duty *($duty_{min}$)* values are selected as 10% and 15% respectively. The evaluation of PV power for each duty cycle majorly depends on the simulation model and the quantity of nectar (food source). The bees are classified as employed bees and non-employed bees (onlookers). The employed bees and onlookers are separated into two phases to track global MPP. In the first phase, Eq.15 is used to update the employed honey bees' positions within its neighbor bee positions and in the second phase, the quantity of reactor is high then the onlooker is moved closer to the employed bees. The onlooker positions are updated by using Eq.16.

$$P_i(n+1) = P_i(n) + \phi\left(x_i(n) - x_j(n)\right) \quad (15)$$

$$P_i(n+1) = P_i(n) + \phi \frac{(duty_{\max} - duty_{\min})}{\frac{N_p}{2} - 1} \quad (16)$$

Where n is an iteration number and $\emptyset$ is the random number which is to be considered as a constraint to obtain the optimal solution of multidimensional problem. The operation ABC MPPT technique is given in Fig.8.

a. Literature survey of ABC based MPPT Technique

In the family of swarm intelligence techniques, ABC is a most useful metaheuristic swarm intelligence technique which is used to obtain the optimal solution of all complex problems [50]. Many research articles analyzed ABC algorithm optimizing behavior and it is compared with the other optimization techniques like GA, PSO, and GSA, etc. From the comparison results, they state that the ABC is a simple and less computation complexity algorithm which is used to track the MPP of solar PV. In an article [51], ABC based direct control MPPT technique is used to adjust the duty cycle of boost converter without using a PI controller. The Analysis ABC MPPT technique for different application is given in Table.7.

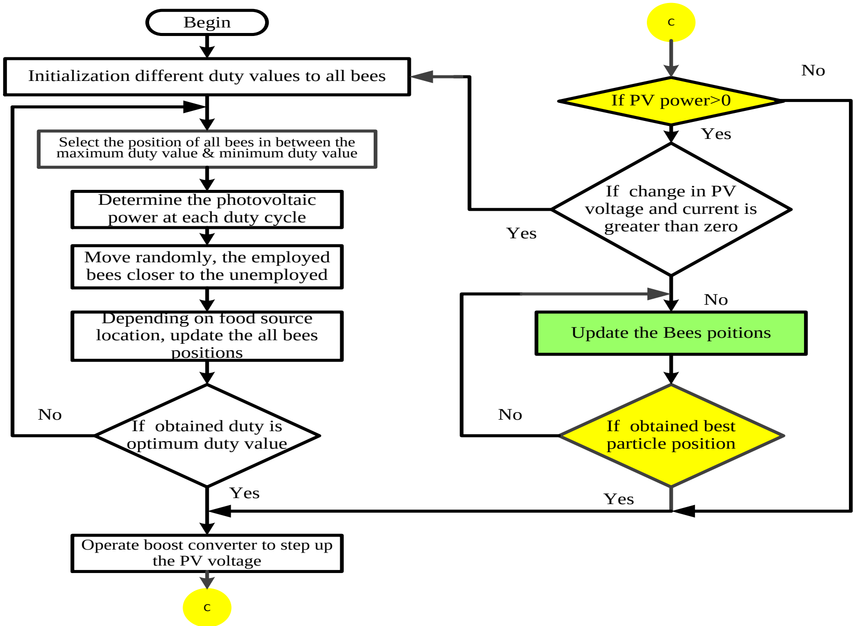


Fig.8. ABC optimization technique based MPPT tracking

Table.7. Analysis of ABC based MPPT technique for different applications

S. No	Author	Article	MPPT method	Control Variable	Application	Results
1	Pallavi Sawant	[37]	ABC	Voltage	Standalone PV systems	The authors proposed ABC MPPT technique for harvesting the maximum power of PV and it is compared with other conventional and swarm intelligence techniques.
2	A. S. Oshaba	[50]	ABC with two PI controllers	Current	Standalone systems	In the ABC method, there are two PI controllers used. One is tracking MPP by controlling PV output voltage and current. The sensed PV parameters are given to MPP block to regulate the duty of dc-dc converter and the second controller is used to control the speed of dc machine.
3	B. Babar and A. Crăciunescu	[51]	ABC with GA	Voltage	Standalone or Grid-connected systems	MPPT is a one of major technique in solar power generation systems to generate electricity from PV cells and it is compared with genetic algorithm in terms of efficiency and oscillations across MPP.

V.CONCLUSION

In this article a detailed analysis of evolutionary and metaphor- metaheuristic MPPT techniques have been carried out under uniform and non-uniform irradiation conditions. The hybrid MPPT techniques are compared successfully with evolutionary and metaphor- metaheuristic MPPT techniques in terms of oscillations across MPP, settling time, tracking speed and accuracy of MPPT tracking, etc. There are so many MPPT techniques that are used to control the duty of boost converter for standalone and grid-connected PV application. For MPP tracking, it is highly difficult to justify which one is the best MPP technique under partial shading condition. However, in this article based on the discussion of different MPPT techniques, the performance and suitability of each technique have been compared with other techniques. The selection of MPPT for a particular application majorly depends on the algorithm complexity, cost, accuracy, tracking time and convergence speed, etc. This review article is helpful for all researchers and students who are working on PV power generation systems under non-uniform sunlight intensity conditions.

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REFERENCES

1. Singh, Girish Kumar. "Solar power generation by PV (photovoltaic) technology: A review." Energy 53 (2013): 1-13.
2. https://en.wikipedia.org/wiki/Solar_power_in_India
3. Borenstein, Severin. "The market value and cost of solar photovoltaic electricity production." (2008).
4. Razykov, Takhir M., et al. "Solar photovoltaic electricity: Current status and future prospects." Solar Energy 85.8 (2011): 1580-1608.
5. Basha, Ch Hussaian, C. Rani, and S. Odofin. "Design and Switching Loss Calculation of Single Leg 3-Level 3-Phase VSI." 2018 International Conference on Computation of Power, Energy, Information and Communication (ICCPEIC). IEEE, 2018.
6. Ishaque, Kashif, Zainal Salam, and Hamed Taheri. "Modeling and simulation of photovoltaic (PV) system during partial shading based on a two-diode model." Simulation Modelling Practice and Theory 19.7 (2011): 1613-1626.
7. Podder, Amit Kumer, Naruttam Kumar Roy, and Hemanshu Roy Pota. "MPPT methods for solar PV systems: a critical review based on tracking nature." IET Renewable Power Generation (2019).
8. Salman, Salman, A. I. Xin, and W. U. Zhouyang. "Design of a P-&-O algorithm based MPPT charge controller for a stand-alone 200W PV system." Protection and Control of Modern Power Systems 3.1 (2018): 25.
9. Zakzouk, Nahla E., et al. "Improved performance low-cost incremental conductance PV MPPT technique." IET Renewable Power Generation 10.4 (2016): 561-574.
10. Sher, Hadeed Ahmed, et al. "An intelligent control strategy of fractional short circuit current maximum power point tracking technique for photovoltaic applications." journal of renewable and sustainable Energy 7.1 (2015): 013114.
11. Rezk, Hegazy, Ahmed Fathy, and Almoataz Y. Abdelaziz. "A comparison of different global MPPT techniques based on meta-heuristic algorithms for photovoltaic system subjected to partial shading conditions." Renewable and Sustainable Energy Reviews 74 (2017): 377-386.
12. Bharath, K. R., and Eenisha Suresh. "Design and implementation of improved fractional open circuit voltage based maximum power point tracking algorithm for photovoltaic applications." International Journal of Renewable Energy Research (IJRER) 7.3 (2017): 1108-1113.
13. Karami, Nabil, Nazih Moubayed, and Rachid Outbib. "General review and classification of different MPPT Techniques." Renewable and Sustainable Energy Reviews 68 (2017): 1-18.
14. Chandrasekaran, M., et al. "Application of soft computing techniques in machining performance prediction and optimization: a literature review." The International Journal of Advanced Manufacturing Technology 46.5-8 (2010): 445-464.
15. Rahnamayan, Shahryar, Hamid R. Tizhoosh, and Magdy MA Salama. "Opposition versus randomness in soft computing techniques." Applied Soft Computing 8.2 (2008): 906-918.
16. Singh, Rajesh, Ashutosh Kainthola, and T. N. Singh. "Estimation of elastic constant of rocks using an ANFIS approach." Applied Soft Computing 12.1 (2012): 40-45.
17. Shiau, Jaw-Kuen, Yu-Chen Wei, and Bo-Chih Chen. "A study on the fuzzy-logic-based solar power MPPT algorithms using different fuzzy input variables." Algorithms 8.2 (2015): 100-127.
18. Gounden, N. Ammasai, et al. "Fuzzy logic controller with MPPT using line-commutated inverter for three-phase grid-connected photovoltaic systems." Renewable Energy 34.3 (2009): 909-915.
19. Guenounou, Ouahib, Boutaib Dahhou, and Ferhat Chabour. "Adaptive fuzzy controller based MPPT for photovoltaic systems." Energy Conversion and Management 78 (2014): 843-850.
20. Padmanaban, Sanjeevikumar, et al. "A Hybrid ANFIS-ABC Based MPPT Controller for PV System With Anti-Islanding Grid Protection: Experimental Realization." Ieee Access 7 (2019): 103377-103389.
21. Salomé, Pedro, and Sascha Sadewasser. "Solar cell module." U.S. Patent Application No. 10/304,982.
22. Rani, C., and CH Hussain Basha. "A review on non-isolated inductor coupled dc-dc converter for photovoltaic grid-connected applications." International Journal of Renewable Energy Research (IJRER) 7.4 (2017): 1570-1585.

23. Dolara, Alberto, et al. "An evolutionary-based MPPT algorithm for photovoltaic systems under dynamic partial shading." Applied Sciences 8.4 (2018): 558.
24. Basha, Ch Hussaian, C. Rani, and S. Odofin. "Analysis and Comparison of SEPIC, Landsman and Zeta Converters for PV Fed Induction Motor Drive Applications." 2018 International Conference on Computation of Power, Energy, Information and Communication (ICCPEIC). IEEE, 2018.
25. Rajasekar, N., et al. "Application of modified particle swarm optimization for maximum power point tracking under partial shading condition." Energy Procedia 61 (2014): 2633-2639.
26. Escobar, Carlos A., et al. "Process-Monitoring-for-Quality—A Model Selection Criterion for Genetic Programming." International Conference on Evolutionary Multi-Criterion Optimization. Springer, Cham, 2019.
27. Pal, Sankar K., and Paul P. Wang. Genetic algorithms for pattern recognition. CRC press, 2017.
28. Pathy, Somashree, et al. "Nature-inspired MPPT algorithms for partially shaded PV systems: A comparative study." Energies 12.8 (2019): 1451.
29. Mohamed, Mohamed A., Ahmed A. Zaki Diab, and Hegazy Rezk. "Partial shading mitigation of PV systems via different meta-heuristic techniques." Renewable energy 130 (2019): 1159-1175.
30. Tajuddin, M. F. N., et al. "Single Phase Z-Source Inverter with Differential Evolution (DE) based Maximum Power Point Tracker." TELKOMNIKA Indones. J. Electr. Eng 14.1 (2015): 80-89.
31. Diab, Ahmed A. Zaki, and Hegazy Rezk. "Global MPPT based on flower pollination and differential evolution algorithms to mitigate partial shading in building integrated PV system." Solar Energy 157 (2017): 171-186.
32. Kumar, Nishant, et al. "Rapid MPPT for uniformly and partial shaded PV system by using JayaDE algorithm in highly fluctuating atmospheric conditions." IEEE Transactions on Industrial Informatics 13.5 (2017): 2406-2416.
33. Huang, Yu-Pei, Xiang Chen, and Cheng-En Ye. "A hybrid maximum power point tracking approach for photovoltaic systems under partial shading conditions using a modified genetic algorithm and the firefly algorithm." International Journal of Photoenergy 2018 (2018).
34. Hadjaissa, A., K. Ameur, and N. Essounbouli. "A GA-based optimization of a fuzzy-based MPPT controller for a photovoltaic pumping system, Case study for Laghouat, Algeria." IFAC-PapersOnLine 49.12 (2016): 692-697.
35. de Oliveira, Fernando M., et al. "Grid-tied photovoltaic system based on PSO MPPT technique with active power line conditioning." IET Power Electronics 9.6 (2016): 1180-1191.
36. Titri, Sabrina, et al. "A new MPPT controller based on the Ant colony optimization algorithm for Photovoltaic systems under partial shading conditions." Applied Soft Computing 58 (2017): 465-479.
37. soufyane Benyoucef, Abou, et al. "Artificial bee colony-based algorithm for maximum power point tracking (MPPT) for PV systems operating under partial shaded conditions." Applied Soft Computing 32 (2015): 38-48.
38. Liu, Bo, Ling Wang, and Yi-Hui Jin. "An effective PSO-based memetic algorithm for flow shop scheduling." IEEE Transactions on Systems, Man, and Cybernetics, Part B (Cybernetics) 37.1 (2007): 18-27.
39. Zhang, Lei, et al. "A task scheduling algorithm based on PSO for grid computing." International Journal of Computational Intelligence Research 4.1 (2008): 37-43.
40. Ishaque, Kashif, and Zainal Salam. "A deterministic particle swarm optimization maximum power point tracker for photovoltaic system under partial shading condition." IEEE transactions on industrial electronics 60.8 (2012): 3195-3206.
41. Hazra, Jagabondhu, and Avinash K. Sinha. "Congestion management using multiobjective particle swarm optimization." IEEE Transactions on Power Systems 22.4 (2007): 1726-1734.
42. Yau, Her-Terng, Chih-Jer Lin, and Qin-Cheng Liang. "PSO based PI controller design for a solar charger system." The Scientific World Journal 2013 (2013).
43. Kok, B. C., H. H. Goh, and H. G. Chua. "Optimal power tracker for stand-alone photovoltaic system using artificial neural network (ANN) and particle swarm optimisation (PSO)." Proc. ICREPQ (2012).
44. Adly, M., and A. H. Besheer. "An optimized fuzzy maximum power point tracker for stand alone photovoltaic systems: Ant colony approach." 2012 7th IEEE Conference on Industrial Electronics and Applications (ICIEA). IEEE, 2012.
45. Rezk, Hegazy, and Ahmed Fathy. "Simulation of global MPPT based on teaching–learning-based optimization technique for partially shaded PV system." Electrical Engineering 99.3 (2017): 847-859.
46. Besheer, A. H., and M. Adly. "Ant colony system based PI maximum power point tracking for stand alone photovoltaic system." 2012 IEEE International Conference on Industrial Technology. IEEE, 2012.
47. Xinchao, Zhao. "A perturbed particle swarm algorithm for numerical optimization." Applied Soft Computing 10.1 (2010): 119-124.
48. Garcia, MA Porta, et al. "Path planning for autonomous mobile robot navigation with ant colony optimization and fuzzy cost function evaluation." Applied Soft Computing 9.3 (2009): 1102-1110.
49. Goud, J. Saikrishna, et al. "Maximum power point tracking technique using artificial bee colony and hill climbing algorithms during mismatch insolation conditions on PV array." IET Renewable Power Generation 12.16 (2018): 1915-1922.
50. Oshaba, A. S., E. S. Ali, and S. M. Abd Elazim. "Artificial bee colony algorithm based maximum power point tracking in photovoltaic system." WSEAS Trans. Power Syst 10.123134 (2015): 22.
51. Ozturk, Nurcan, et al. "Modeling of Co (II) adsorption by artificial bee colony and genetic algorithm." Membrane Water Treatment 9.5 (2018): 363-371.

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