International Journal of Computing and Digital Systems
ISSN (2210-142X)
Int. J. Com. Dig. Sys. 8, No.4 (July-2019)

http://dx.doi.org/10.12785/ijcds/080409

Certain Study on MPPT Algorithms to track the Global MPP under Partial Shading on Solar PV Module/Array

M. Premkumar[1] and R. Sowmya[2]

[1]*Department of EEE, GMR Institute of Technology, Rajam, Andhra Pradesh, 532127, India*
[2]*Department of EEE, National Institute of Technology, Tiruchirapalli, Tamil Nadu, 620015, India*

Received 24 Jan 2019, Revised 7 May 2019, Accepted 28 May 2019, Published 1 July 2019

Abstract: The maximum power point tracking (MPPT) algorithms are used in PV power generation systems to handle the effect due to the partially shaded conditions. This paper confers the algorithms, modeling techniques, and control topologies of photovoltaic (PV) array systems are explored. The problems with conventional MPPT algorithms can be solved by applying various modern optimization algorithms that extract the maximum power from the solar panels. Various reliable techniques are discussed to identify the maximum power point globally. However, each method has advantages and limitations and, this paper presents reviews and findings from the existing optimized methods. The optimized algorithms presented in the various literatures are studied and analyzed. The hybrid MPPT algorithms are also discussed to present its effectiveness in tracking the maximum power point (MPP). The challenges in selecting a proper algorithm for partially shaded PV array are deliberated. Finally, the comparison between the stand-alone algorithms and the hybrid algorithms are presented for future research.

Keywords: Global MPP, hybrid MPPT, local MPP, MPPT, partial shading, solar PV array.

1. Introduction

Nowadays most of the power comes from thermal power plants; however, it is not sufficient to get enough coal later on. The dependency on renewable energy increases due to the depletion of fossil fuels in near future. The renewable energy sources will be the best alternative to solve problems regarding power blackout crisis. Effectiveness and efficiency are also the major factors for selecting the power generation system (PGS) [1]. The solar PV based power generation system is the pure and clean way of power generation using the natural energy source i.e. sunlight. It also leads to the formation of the way for the expansion of PGS in the world.

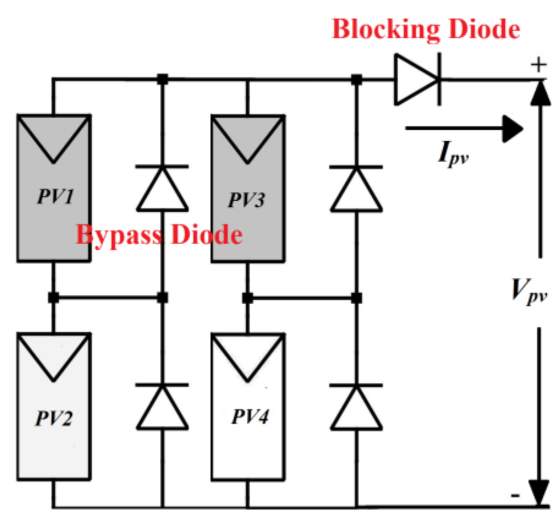
In power generation systems, it is quite essential that it must give maximum output with lossless properties from the available sources. In PGS, this is the area where the researchers generally face the problem of irradiance and partial shading conditions (PSCs) [1]-[2]. It is quite obvious that the amount of sunlight/energy will not be the same throughout the day. Due to the irregular energy, the PV array gets affected drastically, and thus decrease in efficiency of the power generation that leads to increase in complexity and cost [2]. It is necessary to track the global maximum power point (GMPP) during the generation. However, due to multiple MPPs, and non-uniformity of irradiance, the conventional MPPT techniques such as perturb & observe (P&O), incremental conductance (IC), fractional open circuit voltage / short circuit current etc. fails to operate, and it has advantages such as less cost, simple and smooth implementation with fewer parameters such as PV voltage and PV current [2]-[5]. However, these methods fail to track the MPP under partial shading conditions and its tracing/convergence speed is very low with more power oscillations. Many of the modernized techniques such as grey wolf optimization (GWO), particle swarm optimization (PSO), whale optimization (WO), artificial bee colony (ABC) algorithm, fuzzy logic (FL) based technique etc. and its hybrid algorithms are proposed by the researchers to optimize the problems [6]-[8]. This paper includes the discussion of various MPPT techniques to track the GMPP under partial shading condition (PSC). The paper is organized as follows. Section 2 discusses the PV system under partial shading on the solar panel. Section 3 presents the modern MPPT algorithm to address the issue in the tracking of GMPP. To overcome the issues in modern MPPT algorithms, the hybrid MPPT methods are discussed in section 4, and the comparison between the various techniques are discussed

E-mail: premkumar.m@gmrit.edu.in, sowmyanitt@gmail.com

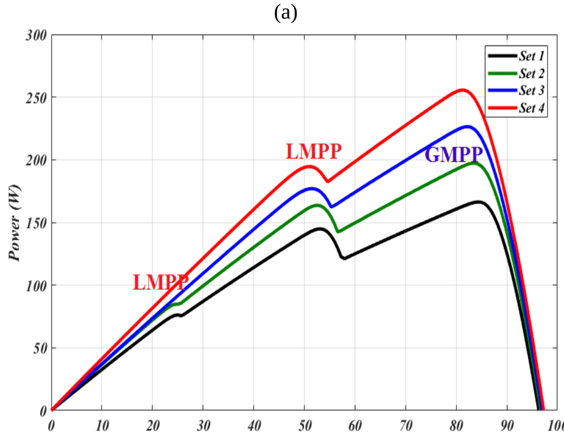
in section 4. Challenges in selecting the proper MPPT technique are discussed in section 5 followed by the conclusion.

2. PV Systems Under Partial Shading Conditions

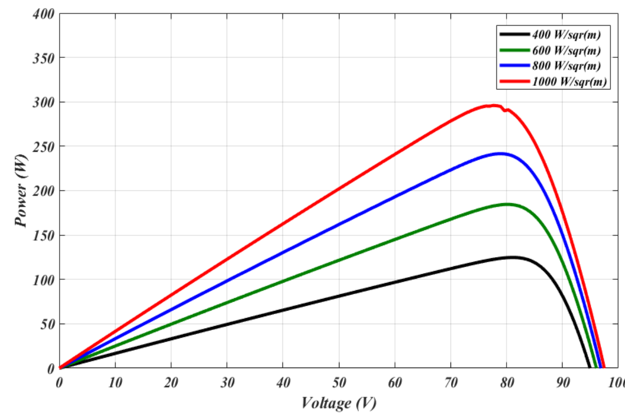
A PV array is a combination of PV modules connected in series/parallel. The total power of the PV array is a combination of power delivered by each PV module [1]-[5]. Fig. 1(a) shows the PV array, and it has two parallel connected PV strings. Each string has two series connected panels. If any of the modules is shaded, it becomes a load instead of acting as the power source. The shaded module gets damaged due to hotspot phenomenon. So, bypass diodes are added for the protection purpose due to self-heating during PSCs. The bypass diode across a PV module conducts under the shaded conditions. To protect the PV panel from the reverse current, the blocking diode is connected. Complicated shape characterized by multiple peaks can be observed in the PV curve which is shown in Fig. 1(b). As shown in Fig. 1(b), the P-V characteristic exhibits multiple local MPPs (LMPP) and one GMPP.



(a)



(b)



(c)

Figure 1. PV arrays under partial shading; (a) PV array with a shaded cell, (b) P-V characteristics (partial shading), (c) P-V characteristics (no shading)

It is essential to operate at global maximum power point (GMPP) to extract the maximum power from the PV system instead of tracking the LMPP. So, an efficient MPPT method is required to extract the optimal energy with high tracking accuracy [8].

3. New Optimized MPPT Techniques For Solar PV Systems

A. Grey wolf optimization (GWO) algorithm

The hunting mechanism and leadership hierarchy are discussed in GWO method. In GWO, simulating leadership hierarchy has four types namely delta, omega, alpha, and beta. The three steps of hunting like searching for prey, encircling for prey and attacking for the prey have been discussed in [9]-[10]. In alphas, there exists a male and female called as leaders. They are used for making decisions for hunting, sleeping time, time at which to wake up and so on. Alpha decisions are dedicated to the prey. They are also called as dominant wolves since they should provide orders to the prey to make them follow. Here, alpha is best in managing the prey and not a strong member.

Beta wolves are called as subordinate wolves. They help their superior wolves like alpha in decision making and other activities of the prey. It may be of either male or a female. These are the best prey to replace the alpha, in the case of alpha passes away or when they become old. Beta respects alpha and commands the below wolves. Its role is to act as the advisor to alpha. Omega is called as the low ranking wolf and also as babysitters. Their role is to act as the scapegoat and they are the last wolves that are allowed to eat. Delta wolves are also called as subordinates and they submit to alpha, beta and dominates omega [9]. Scouts for watching boundaries of territories, sentinels for protection and guarantee pack, elders for having experiencing wolves which are used to be alpha and beta, hunters for helping alpha and beta, caretakers for caring of weak wolves belong to this category. The flowchart of the GWO technique is shown in Fig. 2. The mathematical model of the GWO algorithm is as follows and the total mechanism of GWO algorithm is represented by the following Eqs. 1-2:

$$\vec{E} = |\vec{C}.\overrightarrow{X_P}(t) - \overrightarrow{X_P}(t)| \quad (1)$$

$$\vec{X}(t+1) = \overrightarrow{X_P}(t) - \vec{F}.\vec{E} \quad (2)$$

Where, t is the current iteration, E, F, and C are coefficient vectors; X_p is the position vector of hunting prey. X is the position vector of the grey wolf. Here, the vectors F and C are computed as follows:

$$\vec{F} = 2\vec{a}.\overrightarrow{r_1} - \vec{a} \quad (3)$$

$$\vec{c} = 2.\overrightarrow{r_2} \quad (4)$$

Where, α decrease linearly from 2 to 0 and r_1 & r_2 vector values is selected from [0, 1]. The duty cycle, d is considered as the grey wolf for the implementation of the GWO MPPT technique. Therefore, Eq.2 is modified as Eq.5 and fitness function of GWO is calculated using Eq.6, in which, P is the power, d is duty cycle, i is the number of current individual grey wolves, and t is the iteration count.

$$d_i(t+1) = d_i(t) - F.E \quad (5)$$

$$P(d_i^t) > P(d_i^{t-1}) \quad (6)$$

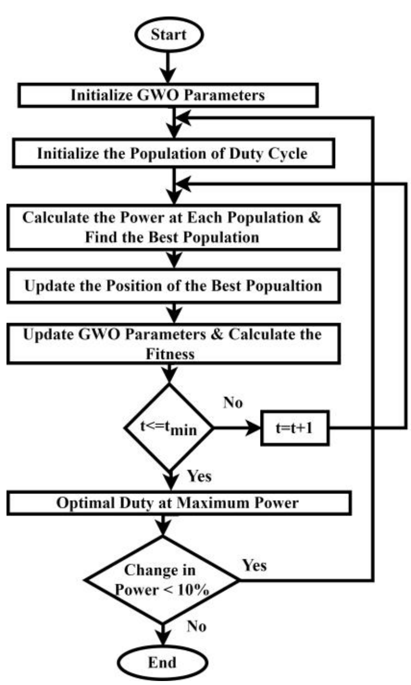


Figure 2. Flowchart representing GWO optimization technique [9]

B. Firefly algorithm (FA) with an updated beta coefficient

The authors of [11]-[14] proposed a simplified firefly algorithm with the updated beta coefficient which is best suitable to track MPP of the PV system under PSCs. In FA, the first position is randomized for using light absorption and random coefficients. The initial position is chosen between 0 & 1 and the above two variables are not required. The optimal location of FA is as follows:

$$X_i^{t+1} = X_i^t + \beta\left(X_j - X_i\right) \quad (7)$$

Where X_i and X_j represent the position of i and j, i and j are less bright and brighter firefly respectively. β is the firefly attractiveness factor. In this algorithm, the main objective of the FA is to obtain desired PV output power. The position of firefly represents the duty cycle D and β coefficient value. It is updated in all iteration for faster convergence and accuracy [11]. The flowchart is shown in Fig. 3.

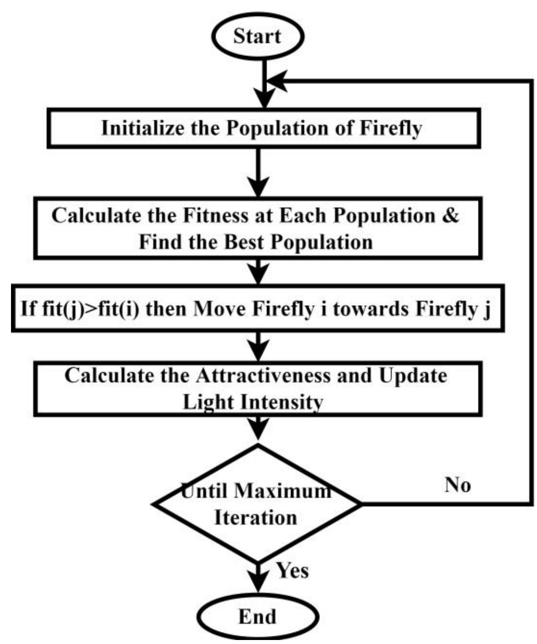


Figure 3. Flowchart for firefly algorithm [11]-[12]

C. Ant colony optimization (ACO) algorithm

The ACO algorithm is used to find approximate solutions for difficult optimization problems. It is chosen from the behavior of ants [15]. They exhibit a chemical called pheromone that drags response within members of same species. The ants follow the same path until they found the shortest path to travel and to find food for them. When the ants travel, they emit the pheromone which will be helpful for the other ants to travel back to the home on the same path. This method has only a few propositions related to use of ACO techniques [16]. It has a specific set of software agents called artificial ants to search food solutions to the given optimization problems. It is the modified form of particle swarm optimization method. This method reduces a large number of local MPPs of P-V characteristic of the PV systems. This method is utilized in both distributed and centralized type MPPT controllers. The flowchart of for Ant colony optimization is shown in Fig. 4.

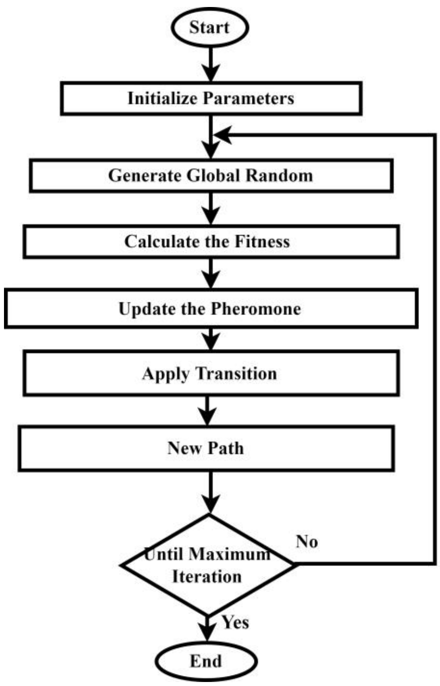


Figure 4. Flowchart for ACO technique [15]

D. Artificial bee colony (ABC) algorithm

The ABC algorithm has the ability to accomplish difficult tasks without any external guidance in dynamic and varied environments. It is a swarm-based algorithm used to solve problems of different dimensions and different models. The collective information obtained here cannot be obtained by an individual type alone. In this type, there exist three types of functional groups namely employed bees, onlooker bees, and scout bees [16]-[17]. Employed bees search for food and exploit food production source and onlooker bees are those which wait in the hive to make decisions to choose a food source and finally, scout bees are used to have a random search for the new food source. To have an optimal solution to the problems in lesser time these three groups are combined, communicated and coordinated.

The flowchart for ABC algorithm implementation is shown in Fig. 5. The duty cycle for the dc-dc converter for the implementation of the ABC algorithm in MPPT is as follows:

$$d_e = d_{min} + rand[0,1](d_{max} - d_{min}) \quad (8)$$

$$\text{new } d_e = d_e + \emptyset_e(d_e - d_k) \quad (9)$$

Where d_e indicates the duty cycle of the current position, d_{min} represents minimum value of the duty cycle, d_{max} represents the maximum value of the duty cycle, ϕ_e is constant at a range of [-1, 1], and d_k is the previous duty cycle.

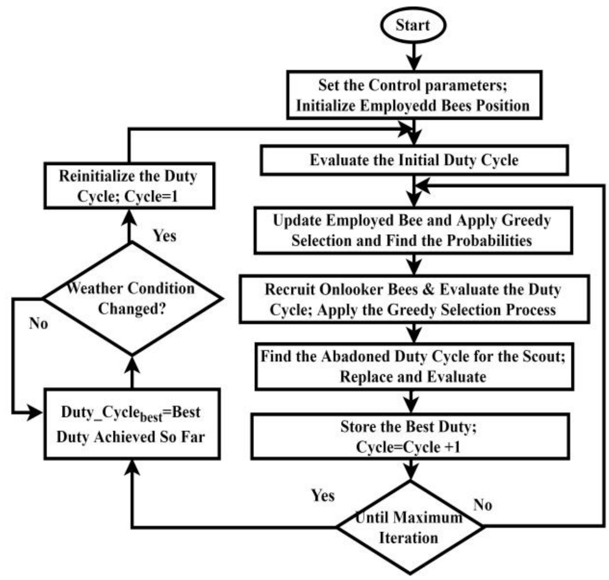


Figure 5. Flowchart for the ABC algorithm [16]

E. Deterministic particle swarm optimization (DPSO) algorithm

This method has an artificial intelligence technique which is used to find solutions for extremely difficult and impossible maximization and minimization problems. It has a simple algorithm and this method is easy to implement [18]. In this method, a group of particles (solutions) is initialized first and by updating generation, the optimal one among them is chosen. Particles move in solution space and each particle is updated by two best values for each of the iterations.

Among them, first one is by choosing the best solution using the fitness; it is achieved so far and called as p_{best}. The second one is by using particle swarm optimizer obtained by any particle in population as global value known as g_{best}. Each particle is modified from the current position by using distance between current position and p_{best} also by distance between the current position and g_{best}. The range of duty cycle for the global mode is as follows:

$$d_{min} = \frac{\sqrt{\eta_{bb} R_{L,min}}}{\sqrt{R_{PV,max}} + \sqrt{\eta_{bb} R_{L,min}}} \quad (10)$$

$$d_{max} = \frac{\sqrt{\eta_{bb} R_{L\,max}}}{\sqrt{R_{PV,min}} + \sqrt{\eta_{bb} R_{L,max}}} \quad (11)$$

Where d_{min} indicates the minimum duty cycle, d_{max} indicates the maximum value of the duty cycle, and η_{bb} is the efficiency of the converter. $R_{L,max}$ and $R_{L,min}$ are the maximum and minimum values of the load resistance connected to the output respectively. $R_{pv,max}$ and $R_{pv,min}$ are the maximum and minimum reflective impedances of the PV array. DPSO has more advantages than the conventional PSO [19]-[20] due to the reduction of a number of iterations and tuning effort.

F. Simulated annealing (SA) technique

The annealing means tempering of alloys like glass, metal or crystal by heating above the melting point, holding its temperature and cooling until a solid crystalline structure is obtained. Using annealing high-quality products are obtained [21]-[22]. Working of this process using simulation is called as simulated annealing. The global maximum peak is calculated by using SA which follows metal annealing process. In SA, consider different parameters like initial temperature, final temperature and cooling rate to track GMPP [22]. The flowchart of the SA technique is shown in Fig. 6. At every change in temperature using various perturbations at operating voltages energy is calculated. By comparing the obtained energy and current reference energy, if obtained energy is greater one then it will be considered as reference energy, whereas if it is less than current reference energy also there may be a chance to make it as reference energy depending on acceptance probability. If the reference operating point has more energy than the new operating point, then basing upon the acceptance probability, P_r it may be accepted as mentioned in Eq. 12.

$$P_r = \exp\left[\frac{P_k - P_i}{T_k}\right] \quad (12)$$

Where P_k is the power at the recent voltage, P_i is the power at the earlier operating point; T_k is the temperature of the current system. SA algorithm has the cooling schedule of either adaptive or static type geometric cooling schedule. The cooling schedule is represented in Eq. 13, in which T_k indicates k^{th} step temperature, T_{k-1} is the temperature at $(K-1)^{th}$ step and α is the cooling rate.

$$T_k = \alpha T_{k-1} \quad (13)$$

G. Optimal P&O control using least square support vector machines (LSSVM) method

As discussed earlier, the tracking of MPP is done using P&O algorithm, but the disadvantages caused due to P&O like power oscillations at MPP and low convergence rate etc. will be overcome using least square support vector techniques [23]. When there is a change in solar irradiation, the voltage will be perturbed. Using the LSSVM method, one of the advantages is, it does not consider nonlinearities.

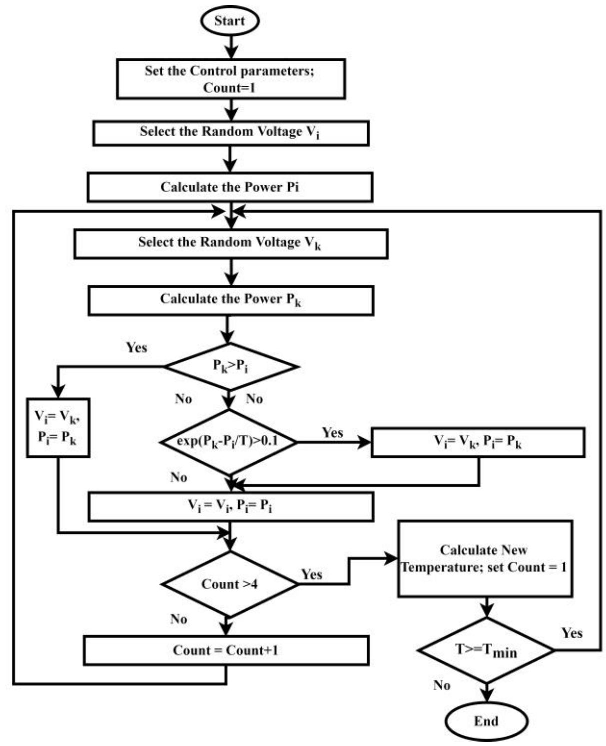


Figure 6. Flowchart for the simulated annealing (SA) algorithm [22]

The MPP changes so that there will be an increase in voltage gradually so that the change in voltage is very small which results in having an optimal convergence rate. The flowchart for the LSSVM method is shown in Fig. 7.

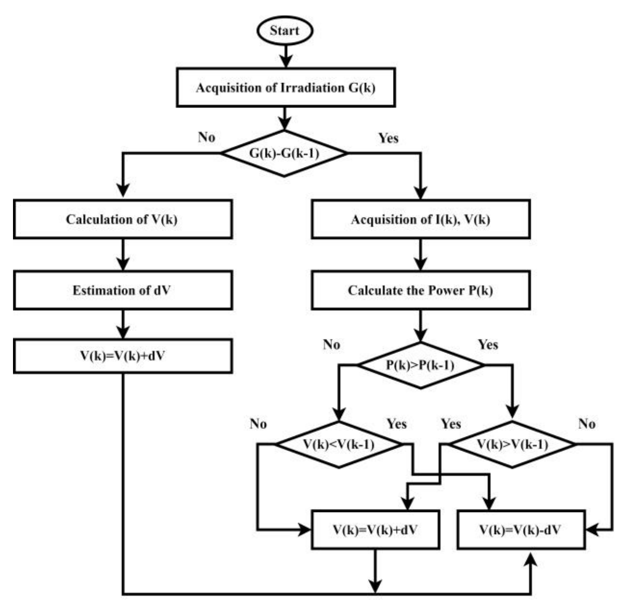


Figure 7. Flowchart of least square support vector machine method [23]

H. Cuckoo search

This is one of the methods to find GMPP and its flowchart is shown in Fig. 8. In this method, it can be expressed each egg as a solution, and cuckoo egg as a new solution [24]-[27]. The cuckoo birds lay their eggs in host nests and if they are not identified, it will grow and become mature cuckoos. The community having more number of cuckoos is the best-chosen one [25]. Also, the author's uses levy flight mechanism in the cuckoo search which is used for identifying the host nest similar to the search for food. It follows few rules like,

- Only one egg can be laid at a time and it is thrown into a host nest.
- Depending on the quality of the nest by seeing the cuckoo eggs, it will be moved to the next generation.
- The number of host nests is fixed and it discovers the cuckoo eggs limited to a probability of (0, 1).

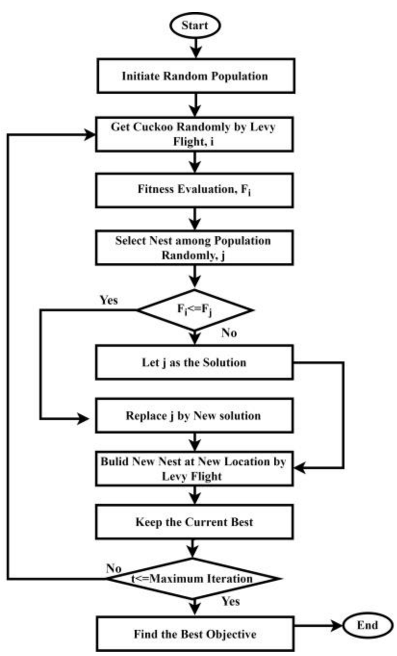


Figure 8. Flowchart of the cuckoo search algorithm [24]-[27]

I. Novel flower pollination algorithm (FPA)

It was proposed by [28]-[29] with the inspiration of natural flower pollination. Basically, pollination is of two types namely cross-pollination and self-pollination. Self-pollination is also called as the abiotic process and it is of pollens from the same plant [28]. Cross-pollination is also called the biotic process which is a procedure of taking pollen from one place to different places with the aid of honey bees, bats, etc. Basically, 90% of pollination is done by cross-pollination and the remaining 10% is of self-pollination. The implementation of the FPA algorithm is mentioned below:

Firstly, different parameters are initialized and then the fitness function of pollens is evaluated i.e., the quality of the pollens is evaluated using the fitness function and then the pollination process is started. Under this process, obtained higher fitness pollen is marked as g_{best} and checks whether each and every pollen is undergone either cross or self-pollination. Basing on the range between $0<r<1$, where r is the random number. Under cross-pollination condition, 4 particles assumed to undergo cross-pollination and the other goes through self-pollination. The resultant shows the pollination towards GMPP showing g_{best}. Under self-pollination condition, as the local pollination occurs between the pollens of same species i.e. pollens x_2 and x_5 attain the new position. After this, all pollen acquires their new position either by self or cross-pollination. This procedure is repeated till the maximum power is reached. During the irradiance conditions, the procedure is initiated from the first position and the parameters are monitored continuously.

4. Modern Hybrid MPPT Algorithms for the Solar PV System

The importance of the comparison between conventional MPPT algorithms with hybrid MPPT algorithms has been discussed in this section for the PV system under the partial shading conditions.

A. Hybrid P&O and GWO MPPT algorithm

The PV system efficiency can be improved by combining P&O and GWO algorithms. GWO handles the MPPT's initial state followed by the application of the P&O algorithm at the final stage to achieve fast convergence to the global peak. This method gives the high tracking capability, and high efficiency compares to the conventional methods [9], [30]. The P&O method tracks the MPP under normal operating condition once the GWO tracks the GMPP under non-uniform operating condition. Fig. 9 shows the flowchart for GWO and P&O hybrid algorithm.

B. Hybrid PSO-PI based MPPT algorithm

The PSO is a heuristic search method with a population that takes stochastic values. The PSO approach the GMPP, then GMPP traced and stops the algorithm and, is switched to PI mode to track the change the slope in that GMPP location [31]. This method is used to improve the performance of the PSO controller. To control the PSO, f is an objective function chosen to be output power equation.

$$f(x_i^k) > f(P_{ibest}) \quad (14)$$

An initial vector x^1 of four agents $[V_1, V_2, V_3, V_4]$ is:

$$x^1 = [V_1, V_2, V_3, V_4] \quad (15)$$

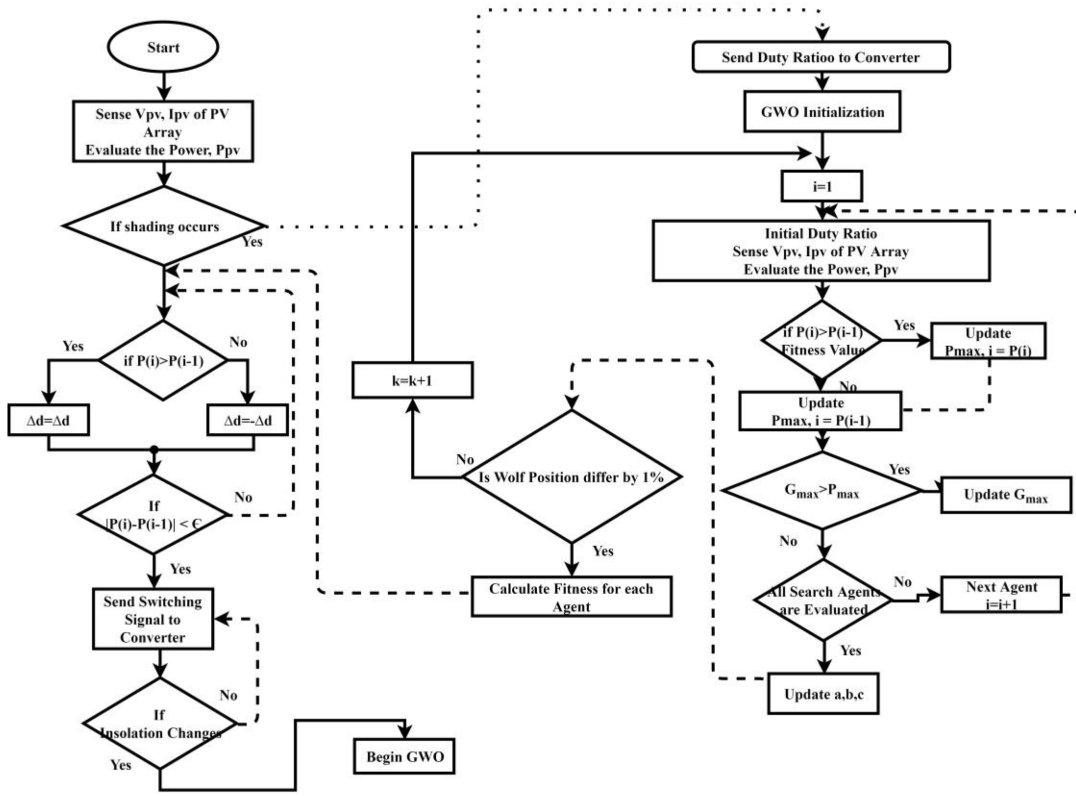


Figure 9. Flowchart for hybrid GWO and P&O algorithm [30]

These agents act as the reference voltage to the converter. At GMPP, the derivative of P(t) with respect to V(t) is zero. Hence, Control variable is represented as follows.

$$e(t) = \frac{dP(t)}{dV(t)} \quad (16)$$

PI controller nullifies the slope e(t) as it disappears at MPP.

$$V_{mp}(t) = K_p . e(t) + K_I . \int e(t)dt \quad (17)$$

$$\begin{cases} \frac{|P_{i+1} - P_i|}{P_i} \geq 10\% \\ |V_{i+1} - V_i| \leq 0.5V \end{cases} \quad (18)$$

Where i+1 is the actual value and i is the previous value. Hybrid PSO-PI increases the tracking speed and decreases the tracking error taking place. The flowchart is shown in Fig. 10.

C. P&O combined with PSO algorithm

At the initial stage of the algorithm, the global search is used by the PSO and at the final stage, P&O is used. The GMPP is tracked accurately by using this method. The GMPP can be traced within a shorten time using this algorithm compared to normal PSO method [32].

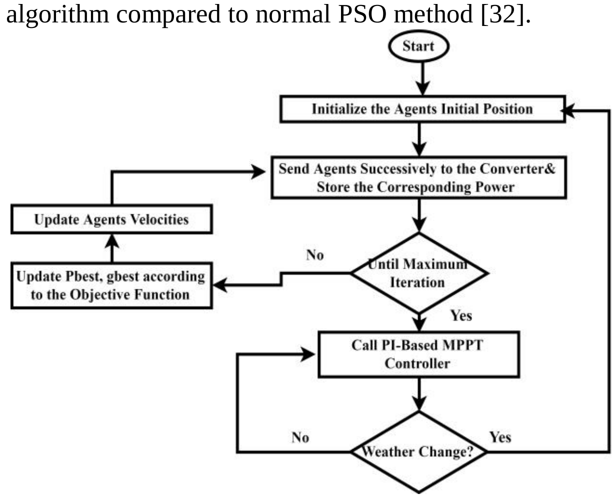


Figure 10. Flowchart of the PSO-PI hybrid algorithm [31]

Various shading methods are tested to find the efficiency of this method. By using the boost converter with interleaved topology, reliability increases, ripple current decreases, and efficiency increases. This method also has a better dynamic response compared to PSO method. The flowchart for the hybrid PSO-P&O MPPT technique is shown in Fig. 11.

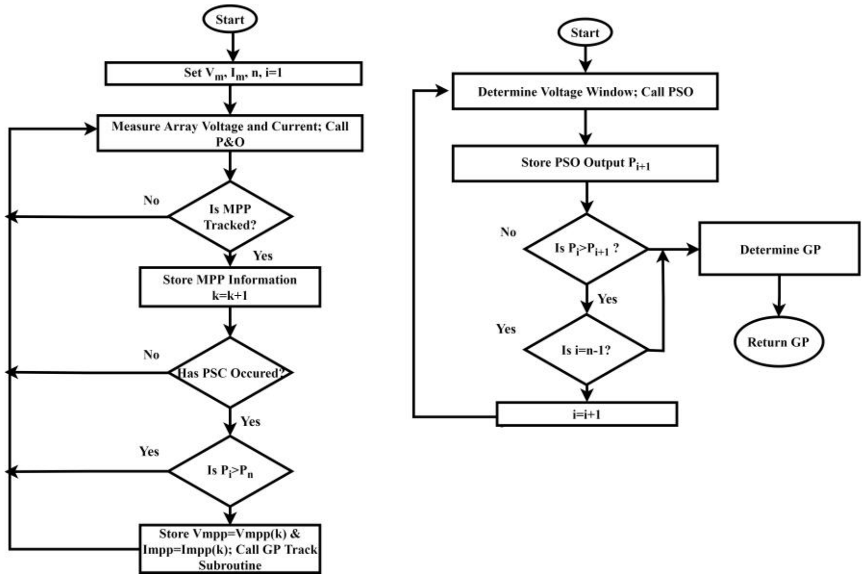


Figure 11. Flowchart for the PSO-P&O method [32]

D. Hybrid whale optimization (WO) and P&O MPPT Technique

The hybrid algorithm proposed by [33] is based on a WO which predicts the initial GMPP and is followed by P&O in the final stage to achieve a quicker convergence to a GMPP. Thus, this hybrid algorithm overcomes the computational burden encountered in a standalone WO, grey wolf optimization (GWO) and hybrid GWO. The conventional algorithm (P&O) searches for the maximum power point (MPP) in the predicted region by the WO. This combination is developed to achieve the maximum power with less power oscillation and a fast convergence rate to handle the rapid variations of solar irradiation and partial shading conditions. The flowchart for the hybrid WO-P&O MPPT technique is shown in Fig. 12.

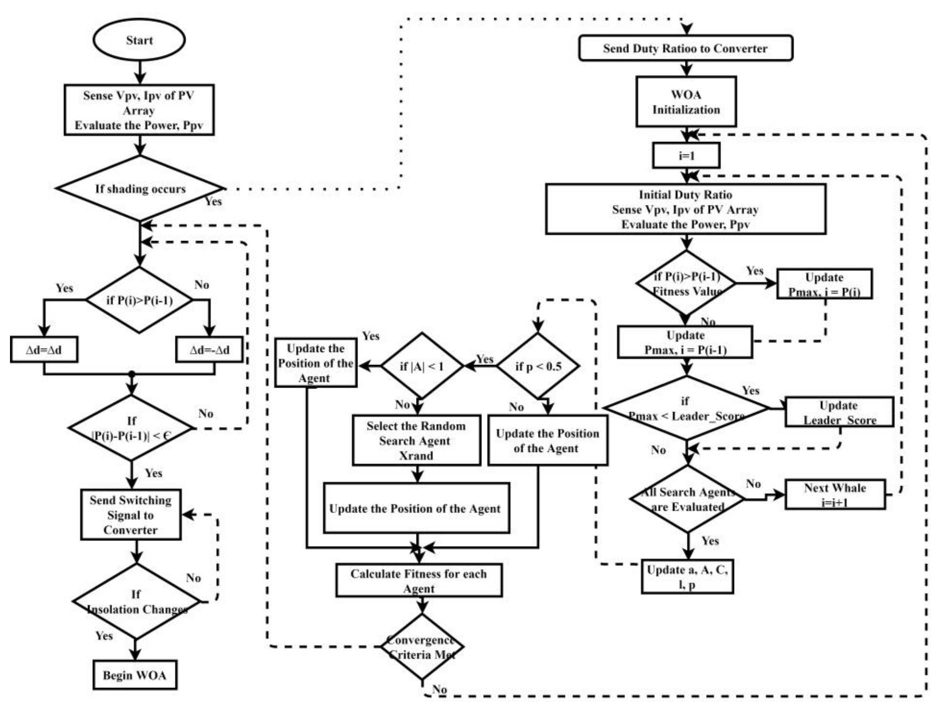


Figure 12. Flowchart of the hybrid WO-P&O MPPT algorithm [33]

The hybrid algorithms are not limited to above-mentioned techniques. A lot of research is carried out by the researchers such as hybrid FL-P&O [34], P&O combined with PSO [35]-[36], hybrid differential evolutionary (DE)-PSO method [37], a hybrid artificial neural network (ANN) [38] etc., however, these techniques are not analyzed in this paper. As discussed above, the merits and demerits of the different optimization MPPT techniques are presented in table 1 and the features of the different algorithms are presented in table 2.

TABLE I THE MERITS AND DEMERITS OF DIFFERENT MPPT METHODS

MPPT Algorithms	Merits	Demerits
Grey wolf optimization algorithm	Tracking efficiency is high, the absence of transient and steady-state oscillations, and the strong necessity of some parameters regarding the adjustments.	Complex structure, high cost, and requires more search space.
Firefly algorithm	Convergence is fast, LMPP is completely avoided, and higher tracking efficiency.	Compared to other swarm-based algorithms yields low results, for every iteration beta coefficient should be updated which is difficult.
Ant colony optimization	The initial position doesn't affect convergence, robust for various shading conditions, low cost, and control is simple.	Have complex calculations, and optimization is difficult since four parameters should be done at once.
Artificial bee colony optimization	Initial conditions do affect the convergence, simple, and fewer control parameters.	Complex, sometimes fall on LMPP due to fewer parameters.
Deterministic particle swarm-optimization	Improvement in convergence in terms of speed and accuracy, compared to conventional PSO it is simple.	Depends on initial conditions, and complex in the computation
Simulated annealing algorithm	Requires fewer parameters, and converges to GMPP accurately.	Oscillations at MPP, re-initialization is required.
Cuckoo search	High convergence speed, robust, fewer tuning parameters, and high efficiency.	Levy flight determines tracking time, and complex in calculations.
Hybrid GWO and P&O	Reduction of oscillations and search space, higher efficiency.	Costly, difficult in control structure and to implement.
Hybrid PSO and PI method	Tracking speed increases and error reduced.	Difficult control structure and costly.
Hybrid PSO and P&O method	Reduction of search space and oscillations in output power.	Complex control structure and the cost of hardware implementation is high.
Hybrid WO and P&O method	Reduction of search space and very less power oscillations.	Computation burden increases if search agents increased, and the high cost of hardware.

TABLE II COMPARISON OF VARIOUS OPTIMIZATION ALGORITHMS OF MPPT

MPPT Algorithms	Control strategy	Input parameters	Output parameters	Cost	Applications	Converter
Grey wolf optimization algorithm	Bio-inspired, Evolutionary algorithm.	V_{pv}, I_{pv}	Duty cycle	High	Stand-alone, Grid-tied	DC-DC
Firefly algorithm	Bio-inspired, Evolutionary algorithm	V_{pv}, I_{pv}	Duty cycle	Low	Stand-alone, Grid-tied	DC-DC
Ant colony optimization	Probabilistic algorithm	V_{pv}, I_{pv}	Duty cycle	Low	Stand-alone, Grid-tied	DC-DC
Artificial bee colony optimization	Bio-inspired, Evolutionary algorithm	V_{pv}	Duty cycle	High	Stand-alone, Grid-tied	DC-DC
Deterministic particle swarm optimization	Modified PSO	V_{pv}, I_{pv}	Duty cycle	Low	Stand-alone	DC-DC
Simulated annealing algorithm	Metal annealing technique	T^k	P_{max}	High	Stand-alone, Grid-tied	DC-DC
Cuckoo search	Bio-inspired	V_{pv}	Duty cycle	Low	Stand-alone	DC-DC
Hybrid GWO and P&O	Bio-inspired, Evolutionary algorithm	V_{pv}, I_{pv}	Duty cycle	High	Stand-alone, Grid-tied	DC-DC
Hybrid PSO and PI method	Adaptive Sampling time strategy	V_{pv}, I_{pv}	Duty cycle	High	Stand-alone, Grid-tied	DC-DC
Hybrid PSO and P&O	Evolutionary algorithm	V_{pv}, I_{pv}	Duty cycle	Low	Stand-alone	DC-DC
Hybrid WO and P&O technique	Bio-inspired	V_{pv}, I_{pv}	Duty cycle	Low	Stand-alone, Grid-tied	DC-DC

The MPPT algorithm performance parameters such as tracking time, and tracking efficiency of the various algorithms are listed in Table 3.

TABLE III COMPARISON OF THE PERFORMANCE PARAMETERS OF VARIOUS MPPT ALGORITHMS

MPPT Algorithm	Average Convergence Time (sec.)	Tracking Efficiency (%)
GWO	0.045	99
Firefly	1.91	99.4
ACO	3.45	98.5
ABC	2.78	99.1
DPSO	1.26	98.9
SA	2.9	94.2
Cuckoo Search	0.15-0.25	98.7
Hybrid GWO and P&O	0.022	99.6
Hybrid PSO and PI method	0.42	99.4
Hybrid PSO and P&O	0.049	99.1
Hybrid WO and P&O technique	0.0245	99.5

5. CHALLENGES AND FURTHER STUDIES

The most challenge in analyzing maximum power from the modern algorithms such gravitational search algorithm (GSA) [39], water cycle algorithm (WCA) [40], seeker optimization algorithm (SOA) [41], invasive weed optimization (IWO) [42], grenade explosion method (GEM) [43], biogeography-based optimization (BBO) [44], krill herd optimization (KHO) [45], harmony search algorithm (HS) [46] and evolution strategy is very helpful in better tracking and most recommended in future research. By choosing suitable parameters and narrowing down the search space, the MPPT technique can be improved. The above-mentioned MPPT techniques are easy to design as its control structure is simple and also less expensive. Conventional and the soft computing MPPT techniques are both helpful for the building up many hybrid techniques. The MPP tracking capability available with the various heuristic optimization techniques, which is used for tracking the MPP under different shading conditions, different PV rating, and the size. They can be classified by their tracking speed, algorithm complexity, cost, hardware improvement, oscillations under steady state and applications.

6. CONCLUSION

This review paper has provided a brief description regarding MPPT algorithms used in software and hardware platform. The main focus of this paper is MPPT optimization techniques for the PV system under partial shading conditions. Many hybrid techniques are implemented apart from the modern optimized MPPT algorithms. Also, merits and demerits are analyzed under the partial shading conditions to choose the best method for the PV systems. Here, the choice of MPPT depends on factors like availability hardware, reliability, cost, convergence time, and accuracy. To identify global peak under partial shading conditions for the PV system, the algorithms discussed in this paper will be helpful to select the best one. However, from various methods discussed, it is difficult to choose the better one. The review of MPPT algorithms is expected to provide a beneficial tool to the researchers working on the PV system and industries excelled in generating an efficient, clean and sustainable energy to mankind.

ACKNOWLEDGMENT

We extend our thankfulness to GMR Institute of Technology, Rajam, Andhra Pradesh, India, for allowing us to validate the study on PV system at power electronics laboratory.

REFERENCES

[1] B. Subudhi, and R. Pradhan, “A comparative study on maximum power point tracking techniques for photovoltaic power systems”, IEEE Transactions on Sustainable Energy (2013), Vol.4, No.1, pp.89-98.

[2] M. Premkumar, N. Dhanasekar, R. Dhivakar, and P. Arunkumar, “Comparison of MPPT algorithms for pv system based dc-dc converter,” Advances in Natural and Applied Sciences (2016), Vol.17, No.9, pp.212-221.

[3] L. Chun-Xia and L. Li-Uun, “An improved perturbation and observation mppt method of photovoltaic generate system”, in Proc. of 4th International Conference on Industrial Electronics and Applications, (2009), pp.2966-2970.

[4] J. Ahmed and Z. Salam, “A modified p&o maximum power point tracking method with reduced steady state oscillation and improved tracking efficiency”, IEEE Transactions on Sustainable Energy (2016), Vol.7, No.4, pp.1506-1515.

[5] J. Ahmed, and Z. Salam, “An accurate method for mppt to detect the partial shading occurrence in a pv system”, IEEE Transactions on Industrial Informatics (2017), Vol. 13, No. 5, pp.2151-2161.

[6] M. Premkumar, T.R. Sumithira, and R. Sowmya, “Modelling and implementation of cascaded multilevel inverter as solar pv based microinverter using FPGA,” International Journal of Intelligent Engineering and Systems (2018), Vol.11, No.2, pp.18-27.

[7] O. Khan, W. Xiao, and M.S. El-Moursi, “A new pv system configuration based on sub-module integrated converters”, IEEE Transactions on Power Electronics (2017), Vol. 32, No. 5, pp.3278-3284.

[8] A. Mohapatra, B. Nayak, P. Das, and K.B. Mohanty, “A review on mppt techniques of pv system under partial shading condition”, Renewable and Sustainable Energy Reviews (2017), Vol. 80, pp.854-867.

[9] S. Mohanty, B. Subudhi, and P.K. Rey, “A new mppt design using grey wolf optimization technique for photovoltaic system under partial shading conditions”, IEEE Transactions on Sustainable Energy (2016), Vol.7, No.1, pp.181-188.

[10] M. Premkumar, T.R. Sumithira, and R. Sowmya, “Implementation of solar pv based microconverter with optimal mppt control under partial shading condition,” Journal of Electrical Engineering (2018), Vol. 18, No. 2, pp.375-386.

[11] Y.M. Safarudin, and A. Priyadi, “Maximum power point tracking algorithm for photovoltaic system under partial shaded condition by means updating β firefly technique”, Proceedings of 6th

International Conference on Information Technology and Electrical Engineering, (2014), pp.1-5.

[12] K. Sundareswaran, S. Peddapati, and S. Palani, "MPPT of pv systems under partial shaded conditions through a colony of flashing fireflies", IEEE Transactions on Energy Conversion (2014), Vol. 29, No. 2, pp.463-563.

[13] X. Li, H.Wen, L.Jiang, E.G. Lim, Y. Du, and C. Zhao, "Photovoltaic modified β-parameter-based mppt method with fast tracking", Journal of Power Electronics (2016), Vol. 16, No. 1, pp.9-17.

[14] L. Jiang, and D.L. Maskell, "A uniform implementation scheme for evolutionary optimization algorithms and the experimental implementation of an aco based mppt for pv systems under partial shading", Proceedings of the IEEE Symposium on Computational Intelligence Applications in Smart Grid, (2014), pp.1-8.

[15] S. Titri, C. Larbes, K.Y. Toumi, K. Benatchba, "A new mppt controller based on the ant colony optimization algorithm for photovoltaic systems under partial shading conditions," Applied Soft Computing (2017), Vol. 58, pp.465-479.

[16] A.S. Benyoucef, A. Chouder, K. Kara, S. Silvestre, and O.A. Sahed, "Artificial bee colony-based algorithm for maximum power point tracking (MPPT) for PV systems operating under partial shaded conditions", Applied Soft Computing (2015), Vol. 32, pp.38-48.

[17] K. Sundareswaran, P. Sankar, P.S.R. Nayak, S.P. Simon, and S. Palani, "Enhanced energy output from a pv system under partial shaded conditions through artificial bee colony", IEEE Transaction on Sustainable Energy (2015), Vol. 6, No. 1, pp.198-209.

[18] K. Ishaque, and Z. Salam, "A deterministic particle swarm optimization maximum power point tracker for photovoltaic system under partial shading condition," IEEE Transactions on Industrial Electronics (2013), Vol. 60, No. 8, pp.3195-3206.

[19] Y.H. Liu, S.C. Huang, J.W. Huang, and W.C. Liang, "A particle swarm optimization based maximum power point tracking algorithm for pv systems operating under partially shaded conditions", IEEE Transactions on Energy Conversions (2012), Vol. 27, No. 4, pp.1027-1035.

[20] K. Ishaque, Z. Salam, H. Taheri, and A. Shamsudin, "Maximum power point tracking for pv system under partial shading condition via particle swarm optimization", Proceeding of the IEEE Conference on Power Electronics, (2011), pp.5-9.

[21] S. Lyden, and Md. Enamul-Haque, "A simulated annealing global maximum power point tracking approach for pv modules under partial shading conditions," IEEE Transactions on Power Electronics (2016), Vol. 31, No. 6, pp.4171-4181.

[22] E.N. Chaves, J.H. Reis, E.A.A. Coelho, L.C.G. Freitas, J.B.V. Junior, and L.C. Freitas, "Simulated annealing – mppt in partially shaded pv systems," IEEE Latin America Transactions (2016), Vol. 14, No. 1, pp.235-242.

[23] O. Dahhani, A.E. Jouni, B. Sefriti, and I. Boumhidi, "Optimal perturb and observe control for mppt based on least square support vector machines algorithm," in Proc. of the International Conference on Intelligent Systems and Computer Vision, (2015), pp.1-7.

[24] J. Ahmed, and Z. Salam, "A soft computing mppt for pv system based on cuckoo search algorithm," in Proc. of the 4th International Conference on Power Engineering, Energy and Electric Drives, (2013), pp.558-562.

[25] J. Ahmed, and Z. Salam, "A Maximum Power Point Tracking (MPPT) for PV system using Cuckoo Search with partial shading capability", Applied Energy (2014), Vol. 119, pp.119-129.

[26] J.Y. Shi, F. Xue, Z.J. Qin, W. Zhang, L.T. Ling, and T. Yang, "Improved global maximum power point tracking for photovoltaic system via cuckoo search under partial shaded conditions", Journal of Power Electronics (2016), Vol. 16, No. 1, pp.287-296.

[27] J. Ahmed and Z. Salam, "A soft computing mppt for pv system based on cuckoo search algorithm," in Proc. of the 4th International Conference on Power Engineering, Energy and Electrical Drives, (2013), pp.558-562.

[28] J. Prasanth-Ram, and N. Rajasekar, "A novel flower pollination based global maximum power point method for solar maximum power point tracking," IEEE Transactions on Power Electronics (2017), Vol. 32, No. 11, pp.8486-8499.

[29] J.P. Ram, T.S. Babu, and N. Rajasekar, "FPA based approach for solar maximum power point tracking," Proceedings of the IEEE Conference on Power Systems, (2016), pp.1-6.

[30] S. Mohanty, B. Subudhi, and P. Kumar, "a grey wolf assisted perturb & observe mppt algorithm for a pv system", IEEE Transactions on Energy Conversions (2017), Vol. 32, No. 1, pp.1-8.

[31] M. Kermadi, and E.M. Berkouk, "A hybrid pso-pi based maximum power point tracking algorithm using adaptive sampling time strategy", Proceedings of the 4th International Conference, (2015), pp.1-6

[32] K.L. Lain, J.H. Jhang, and I.S. Tian, "A maximum power point tracking method based on perturb-and-observe combined with particle swarm optimization", IEEE Journal of Photovoltaics (2014), Vol. 4, No. 2, pp.626-623.

[33] M. Premkumar, and T.R. Sumithira, "Humpback whale assisted hybrid maximum power point tracking algorithm for partially shaded solar photovoltaic systems," Journal of Power Electronics (2018), Vol. 18, No. 6, pp.1805-1818.

[34] D. Ajiatmo, and I. Robandi, "A hybrid fuzzy logic controller-firefly algorithm (flc-fa) based for mppt photovoltaic (pv) system in solar car," in Proc. of the IEEE International Conference on Power and Renewable Energy, (2016), pp.606-610.

[35] KL. Lian, JH. Jhang, and IS Tian, "maximum power point tracking method based on perturb-and-observe combined with particle swarm optimization," IEEE Journal of Photovoltaics (2014), pp.626-633.

[36] K. Sundareswaran, V. VigneshKumar, and S. Palani, "Application of a combined particle swarm optimization and perturb and observe method for mppt in pv systems under partial shading conditions," Renewable Energy (2015), Vol. 75, pp.308-317.

[37] M. Seyedmahmoudian, R. Rahmani, S. Mekhilef, and M. Than, A. Stojcevski, and TK. Soon "Simulation and hardware implementation of new maximum power point tracking technique for partially shaded pv system using hybrid DEPSO method," IEEE Transaction on Sustainable Energy (2015), Vol. 6, pp.850-862.

[38] H.M. El-Helw, A. Magdy, and M.I. Marei, "A hybrid maximum power point tracking technique for partially shaded photovoltaic arrays," IEEE Access (2017), Vol. 5, pp.11900-11908.

[39] E. Rashedi, H. Nezamabadi-pour, and S. Saryazdi, "GSA: a gravitational search algorithm," Information Sciences (2009), Vol. 179, No. 13, pp.2232-2248.

[40] H. Eskandar, A. Sadollah, A. Bahreininejad, and M. Hamdi, "Water cycle algorithm - a novel metaheuristic optimization method for solving constrained engineering optimization problems," Computers & Structures (2012), Vol. 110-111, pp.151-166.

[41] C. Dai, W. Chen, and Y. Zhu, "Seeker Optimization Algorithm," in Proc. of the International Conference on Computational Intelligence and Security, (2006), pp.225-229.

[42] S. Karimkashi and A.A. Kishk, "Invasive weed optimization and its features in electromagnetics," IEEE Transactions on Antennas and Propagation (2010), Vol. 58, No. 4, pp.1269-1278.

[43] A. Ahrari, and A.A. Atai, "Grenade Explosion Method - a novel tool for optimization of multimodal functions, Applied Soft Computing (2010), Vol. 10, No. 4, pp.1132-1140.

[44] D. Simon, "Biogeography-based optimization," IEEE Transactions on Evolutionary Computation (2008), Vol. 12, No. 6, pp.702-713.

[45] A.H. Gandomi, and A.H. Alavi, "Krill Herd: A new bio-inspired optimization algorithm," Communications in Nonlinear Science and Numerical Simulation (2012), Vol. 17, No. 12, pp.4831-4845.

[46] C.M. Wang, and Y.F. Huang, "Self-adaptive harmony search algorithm for optimization," Expert Systems with Applications (2010), Vol. 37, No. 4, pp.2826-2837.

Dr. M. Premkumar received his B.E. degree in Electrical and Electronics Engineering from Sri Ramakrishna Institute of Technology, Coimbatore, India, in 2004; and his M.E. degree in Applied Electronics from Anna University of Technology, Coimbatore, India, in 2010. He received his Ph.D. degree from Anna University, Chennai, India under ICE department in 2019. He is presently working as an Assistant Professor at GMR Institute of Technology, Rajam, India. He has more than 10 years of experience in teaching and he has published more than 40 papers in various peer-reviewed indexed journals. His current research interests include microinverters, non-isolated and isolated dc-dc converters, and solar PV MPPT techniques.

Ms. R. Sowmya received her B.E. degree in Electrical and Electronics Engineering from Saranathan College of Engineering, Tiruchirappalli, India in 2013 and M.Tech. Degree in Energy Engineering from National Institute of Technology, Tiruchirappalli, India, in 2015. Currently, she is pursuing Ph.D. in National Institute of Technology, Tiruchirappalli, India. She has published more than 20 papers in various peer-reviewed indexed journals. Her research interest includes control systems, Electric vehicle and Renewable Energy.