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A review on Bio-inspired MPPT techniques of PV system under partial shading condition

Hend S. Saad [1], Mohamed S. M. ElKsas[2], Sabry F. Saraya[2], Mohamed M. Abdelsalam[2]

1: Nile Higher Institute for Engineering and Technology, Mansoura, Egypt

2: Computers and Systems Department, Faculty of Engineering, Mansoura University, Egypt

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. Also the average convergence time and the tracking efficiency for each algorithm are presented. The challenges in selecting a proper algorithm for partially shaded PV array are deliberated. Finally, the comparison between the stand-alone algorithms is presented for future research.

Keywords*: *Maximum Power Point Tracking, Photovoltaic cells, Artificial bee colony, Firefly algorithm Ant colony optimization, and Grey wolf optimization

1. Introduction:

In the recent years the demand for power generation increases rapidly and on the other hand the availability of the conventional resources (like coal and petroleum) degrades drastically which makes a challenging future for the power production. Moreover the conventional resources based power generation has the effect of greenhouse emission. Due to these reasons renewable energy based power generation has increased manifold. Among all type of renewable energy technologies, PV based energy is a good choice as it is available universally, free of cost, atmospheric friendly, and has less operational and maintenance costs [1,2]. The necessity of photovoltaic (PV) generation systems is getting increased for both stand alone and grid connected system. Therefore, to make the PV generation efficient, a capable maximum power point tracking (MPPT) technique is required to predict and to track the MPP at all environmental circumstances and then force the PV system to run at that MPP point [3–6].

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) [7-8]. 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 [8]. 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 [9- 11]. 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. are proposed by the researchers to optimize the problems [12- 14]. 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 II discusses the mathematical modeling of solar panels. Section III presents the PV system under partial shading on the solar panel. Section IV discusses the modern MPPT algorithm to address the issue in the tracking of GMPP and the comparison between the various techniques are discussed in section IV. Section V presents the conclusion.

2. Mathematical modeling of solar panels:

The simple electrical model of a solar system subjected to solar radiation and connected to a load is in the form shown in Figure 1 [15]. This circuit combines a current source, a diode, a resistor in series and a resistor in parallel. A single diode equivalent circuit of the PV cell is applied to the model, considering its simple implementation, proper accuracy and low computational efforts needed [16]. Resistors in equivalent circuit represent the losses in cells. Losses in cell are due to factors such as sunlight reflection on the cell surface, absorption of photons without formation of electron and free hole, and recombination of electrons and free holes. According to Figure 1, characteristic equation of solar cell is expressed by Eq. (1).

$$i_{pv} = I_{pv} - i_D - i_{sh} \qquad (1)$$

where I_{pv} is photo-generated current, i_D is diode current, $i_{sh} = \frac{v_{pv}+i_{pv}R_{se}}{R_{sh}}$ is leakage current, v_{pv} and i_{pv} are PV output voltage and current, respectively, R_{se} and R_{sh} are series and parallel equivalent resistors of solar panel. Diode current is expressed based on I-V Characteristic of a Shockley diode by Eq. (2).

$$i_D = i_O(e^{\frac{v_D}{aV_t}} - 1) \qquad (2)$$

where I_0 is dark-saturation current, $v_D = v_{pv} + i_{pv}R_{se}$ is diode voltage, a is ideality factor of the diode, $V_t = N_s.k_b/e)T$ is thermal voltage of the diode, N_s is the number of series cells, k_b is Boltzmann's constant, e is the absolute value of electron's charge, and T is temperature of solar panel. By substituting Eq. (2) in (1), a characteristic equation of solar panel, can be obtained as Eq. (3).

$$i_{pv} = I_{ph} - I_o\left(e^{\frac{v_{pv}+i_{pv}R_{se}}{aV_t}} - 1\right) - \frac{v_{pv}+i_{pv}R_{se}}{R_{sh}} \qquad (3)$$

In Eq. (3), the value of photo-generated current I_{pv} , varies with the temperature and solar radiation based on Eq. (4) [17].

$$I_{pv} = [I_{pv,ref} + k_1(T - T_n)]\frac{G}{G_n} \qquad (4)$$

where $I_{pv;ref}$ is photo-generated current at standard conditions, K_I is Short-Circuit coefficient of temperature at standard conditions, and G is solar radiation. G_n =1000 W/m^2 and T_n = 25 ℃ are standard test conditions of solar panel. In Eq. (3), dark-saturation current value I_0 varies with the temperature based on Eq. (5).

$$I_O = I_{O,ref}\left(\frac{T}{T_n}\right)^3 exp\left[\frac{e.E_g}{k_b.a.V_t}\left(\frac{1}{T_n} - \frac{1}{T}\right)\right] \qquad (5)$$

where $I_{0;ref}$ is dark-saturation current at standard conditions, and E_g = 1.121[1 – 0.0002677(T – Tn) is the band gap energy of the silicon based on electron volts [18]. Validity and accuracy of model presented in Figure 1 depends heavily on the estimation of the parameters $I_{pv;ref}$, $I_{0;ref}$, R_{se}, R_{sh} and a. In this paper, these parameters were estimated using a GA optimization method.

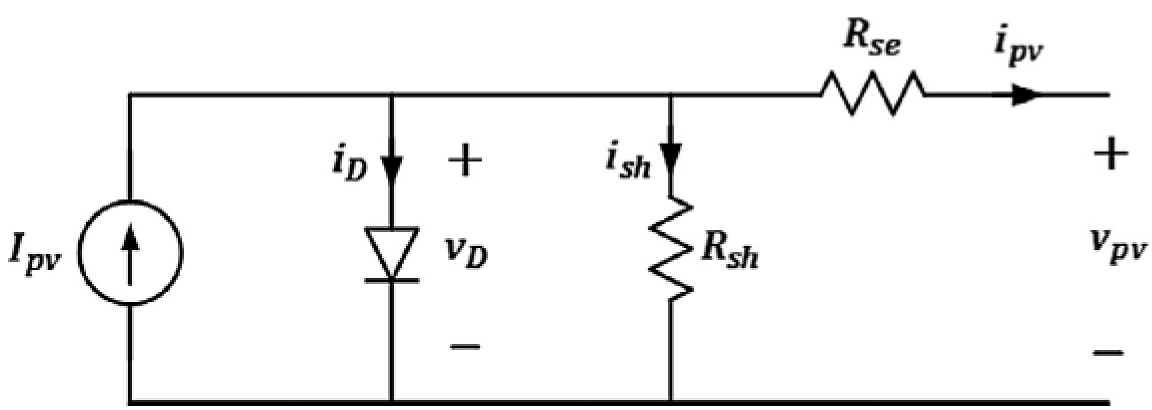
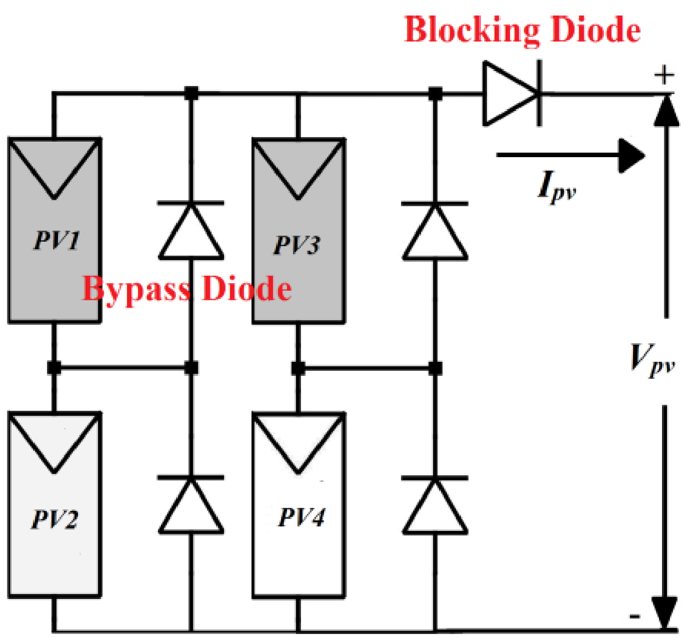


Figure 1. The equivalent circuit of a solar cell.

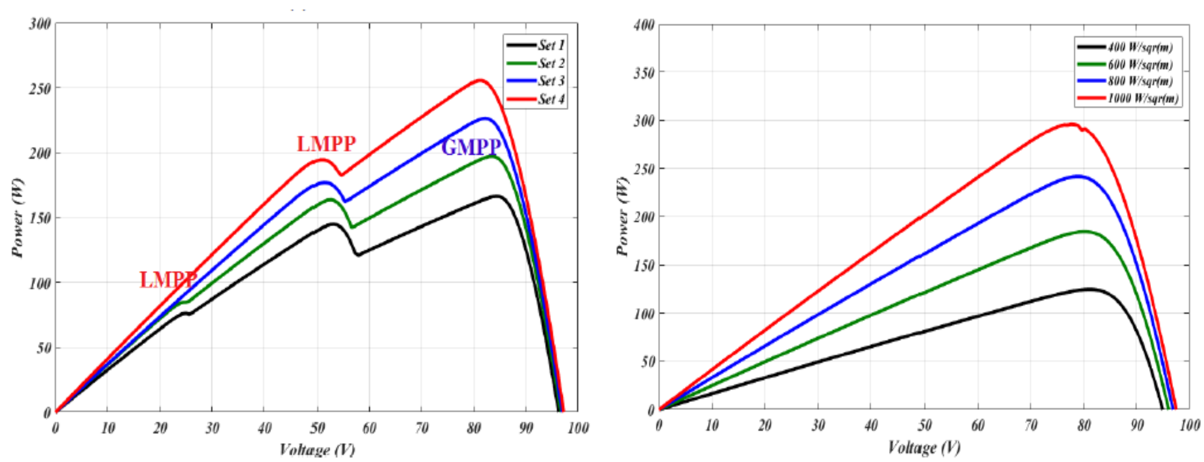
3. PV systems under partial shading conditions:

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 [19- 22]. Figure 2(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 Figure 2(b). As shown in Figure 2(b), the P-V characteristic exhibits multiple local MPPs (LMPP) and one GMPP but Figure 2(c) shows the P-V characteristic curve where there is 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 [23].



(a)



(b) (c)

Figure 2. PV arrays under partial shading; (a) PV array with a shaded cell, (b) P-V characteristics (partial shading), (c) P-V characteristics (no shading)

4. New optimized MPPT techniques for solar PV systems:

I. Artificial Bee Colony (ABC)

This technique consists of three types of bees groups namely employed bee, on lookers, and scout bee. The employed bees are used to identify the particular food source and share the information with the other bees. The on lookers or unemployed bees are used to gather information from employed bee, and spot the optimum food location. The scout bee is used to carry the random search for target the new food source. By these three groups, search in various dimensions with cooperation and communication with each other will help to achieve the optimal solution with less time consumption. The duty cycle is denoted as food position and optimal power is denoted as food source for Artificial Bee Colony algorithm [24, 25]. The algorithm tracks the target using

$$x_i = d_{min} + \frac{(i-1)[d_{max} - d_{min}]}{N_p - 1} \quad (6)$$

where N_p is number of bees, i is the number of iteration, d_{max} and d_{min} shows the maximum and minimum duty cycle values of dc–dc boost converter. The employed bee also acts as scout bee to check the new food location. By this, employed and on looker bee groups are operated and target the global maximum point for the PV system. Compared to PSO and enhanced PSO, the artificial bee colony algorithm operates with fast tracking response and convergence speed which suits well for partial shading condition in PV system. A boost dc–dc converter is connected between PV to load. The technique is implemented in PIC16F876A microcontroller and eZdsp TMS320F28112 DSP platform. Figure3 shows the flow chart of ABC.

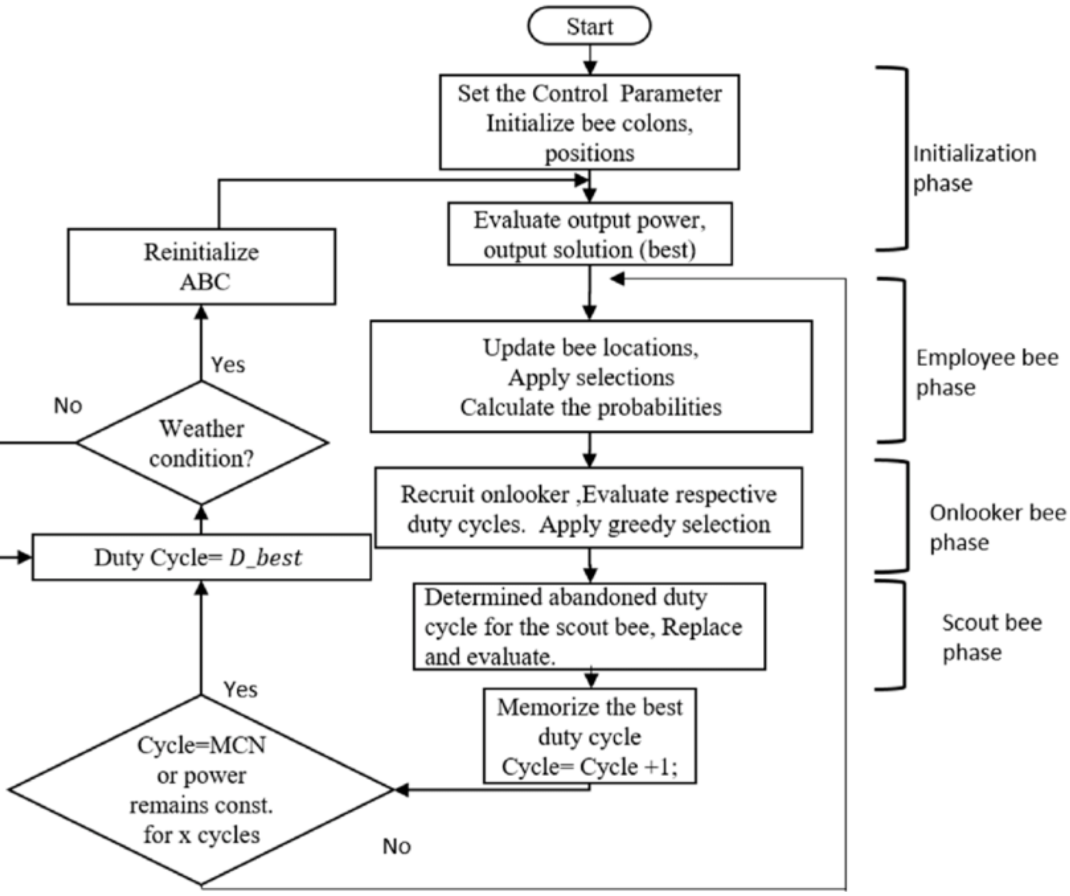


Figure 3. Flow chart of ABC

II. Firefly Algorithm (FA) based MPPT:

Firefly algorithm (FA) is based on the movement of fireflies. Detailed description of algorithm and its implementation to MPPT is presented in [26- 28]. The algorithm has three assumptions which forms the basis if the algorithm.

- All flies are considered unisex and gets attracted to each other irrespective of their sex.
- Each fly gets attracted towards a brighter fly.
- The brightness is determined by the landscape of objective function.

All the flies are initialized randomly in a defined space. The algorithm successively evaluates the relative brightness of each fly with respect to every other fly (except itself) considering the environmental variables. All the flies are spread over the given solution space moving towards the brightest fly neat to it and all the flies move toward the brightest. Once all the flies reach the brightest fly or the optimal condition is met, flies get initialized with random position.

For MPPT, the algorithm is initialized with parameter setting. The number of fireflies, termination criterion along with few constants are initialized. The fireflies are initialized at different duty cycle in the range of 2% to 98% randomly. The DC-DC converter is operated corresponding to the position of each fly, power is measured and maximum power returning position is determined. The fly returning maximum power remains at its position and others get updated based on this information. This repeats until termination criterion is met. Figure 4 shows the flow chart of FA algorithm.

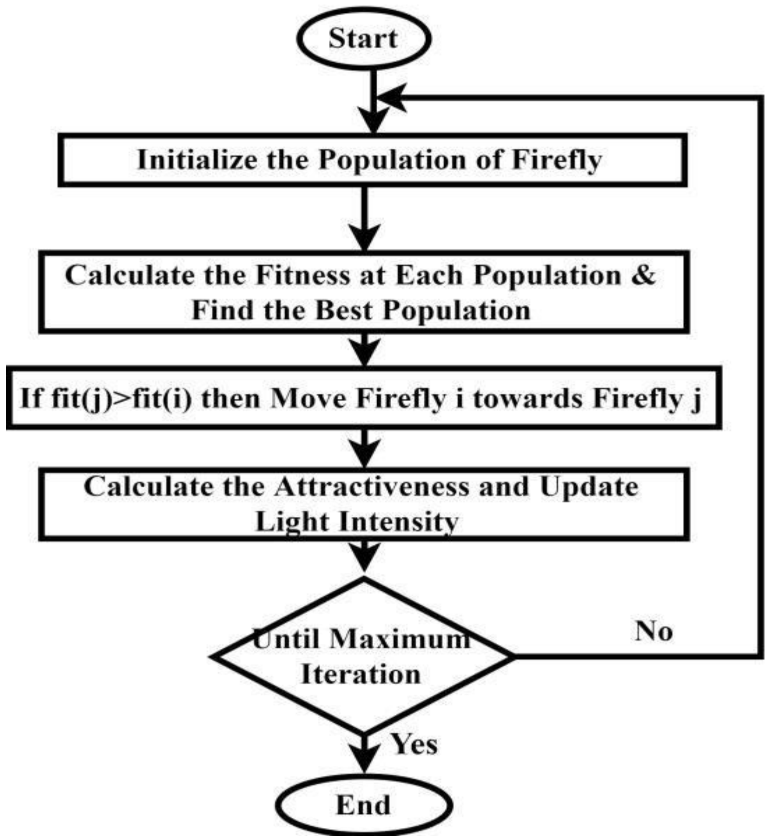


Figure 4. Flow chart of FA algorithm.

III. 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 [29]. 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 [30]. 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 Figure 5.

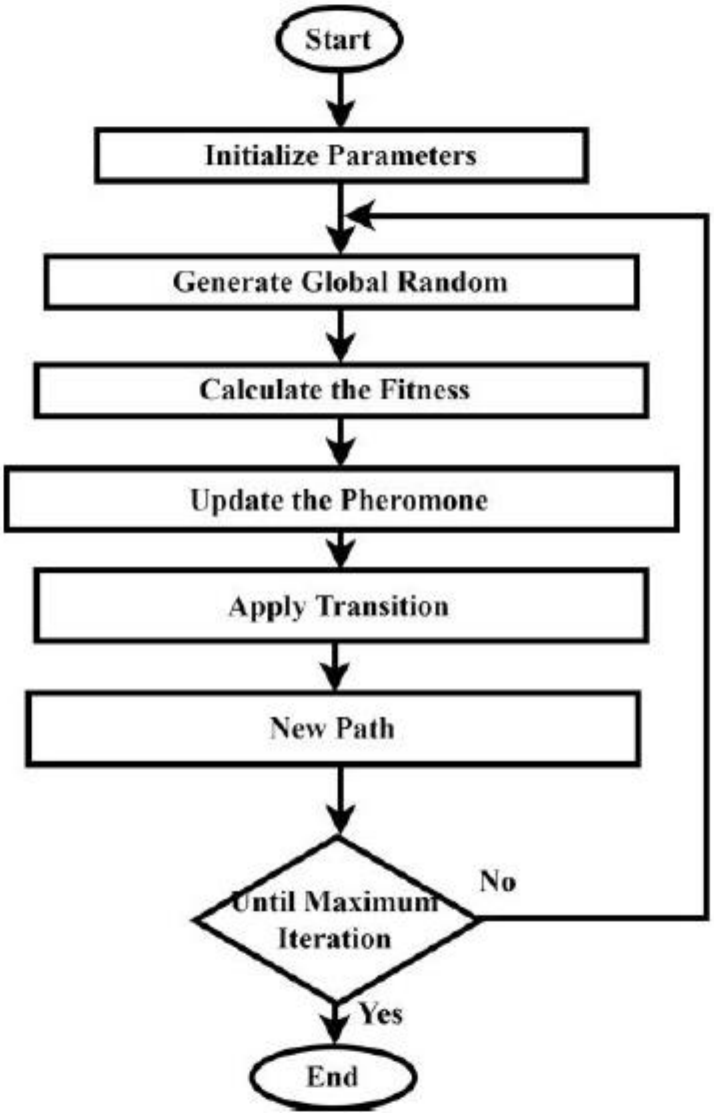


Figure 5. Flow chart of ACO algorithm

IV. Grey wolf optimization (GWO) algorithm:

The grey wolf optimization (GWO) is a meta-heuristic approach strongly inspired by optimizing the attacking technique used by the grey wolves while hunting. This technique is quite capable of imitating the leadership hierarchical order and also the hunting proficiency of grey wolves. There are mainly four types of grey wolves-alpha (α), beta (β), delta (δ) and omega (ω) which are being employed in order to simulate the leadership hierarchy properly. In the mathematical model of this bio-inspired technique, the fittest solution is assumed to be α. Then, β and δ are considered to be the second and third best solution, ω is denoted as the rest of the candidate solutions. There are mainly three steps for GWO, such as hunting, chasing and tracking of the prey by forming a group, then encircling the prey and then finally attacking the prey. This overall hunting mechanism is implemented while designing the GWO for executing optimization problems in MPPT for PV modules. The hunting technique of the grey wolves is guided by α clans which are termed as leaders and are followed by the β clans [31- 33]. The main duty of the δ and ω is to take care of all the wolves that are wounded in the entire pack. The flowchart of GWO algorithm is shown in Figure 6.

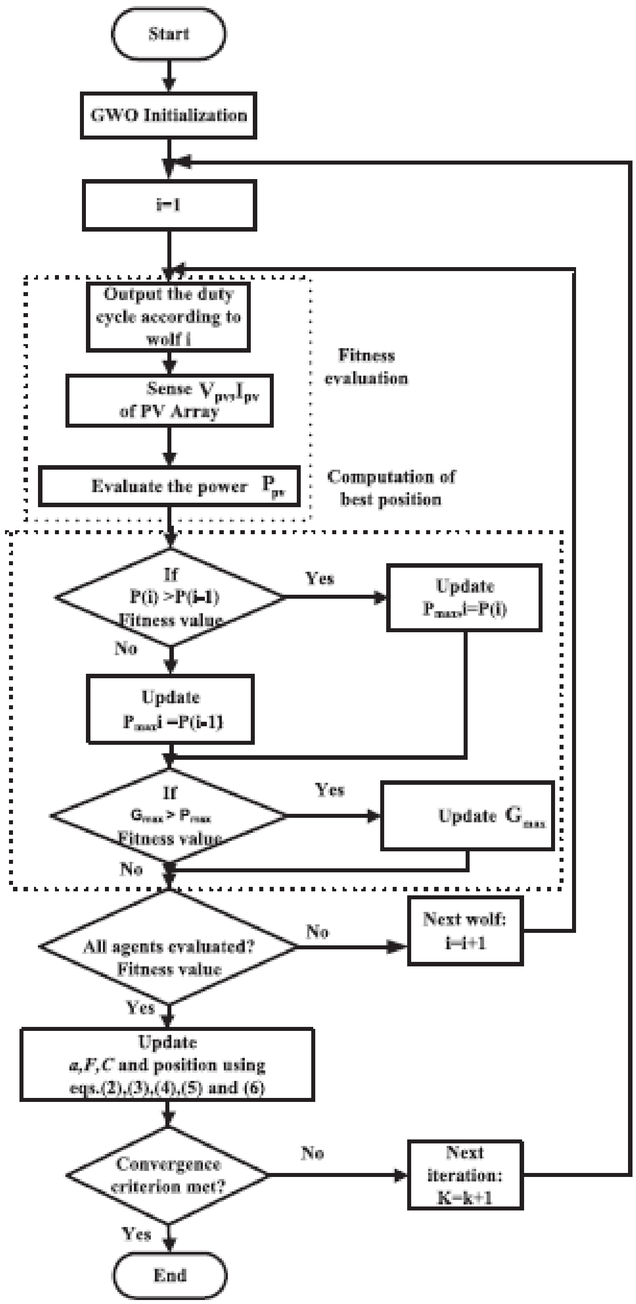


Figure 6. The flowchart of GWO algorithm

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 1 the merits and demerits of different MPPT methods

MPPT Algorithms	Merits	Demerits
Artificial bee colony optimization	Initial conditions do affect the convergence, simple, and fewer control parameters.	Complex, sometimes fall on LMPP due to fewer parameters.
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.
Grey wolf optimization	Higher tracking efficiency, no transient and steady state oscillations, robust, fewer parameters needed for adjustment	Computational complexity, Large search space, high cost

Table 2 comparison of various optimization algorithms of MPPT

MPPT algorithms	Control strategy	Input parameters	Output parameters	Cost	Applications	Converter
Artificial bee colony optimization	Bio-inspired, Evolutionary algorithm	V_{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
Grey wolf optimization	Bio-inspired, Evolutionary algorithm.	V_{pv}, I_{pv}	Duty cycle	High	Stand-alone, Grid-tied	DC-DC

5. 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 bio- inspired MPPT optimization techniques for the PV system under partial shading conditions. 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.

6. References

1- Ameli, Mohammad Taghi, Saeid Moslehpour, and Mehdi Shamlo. "Economical load distribution in power networks that include hybrid solar power plants." Electric Power Systems Research 78.7 (2008): 1147-1152.

2- Reisi, Ali Reza, Mohammad Hassan Moradi, and Shahriar Jamasb. "Classification and comparison of maximum power point tracking techniques for photovoltaic system: A review." Renewable and sustainable energy reviews 19 (2013): 433-443.

3- Enrique, J. M., J. M. Andújar, and M. A. Bohorquez. "A reliable, fast and low cost maximum power point tracker for photovoltaic applications." Solar Energy 84.1 (2010): 79-89.

4- Lim, Yan Hong, and D. C. Hamill. "Simple maximum power point tracker for photovoltaic arrays." Electronics letters 36.11 (2000): 997-999.

5- Salas, V., et al. "Review of the maximum power point tracking algorithms for stand-alone photovoltaic systems." Solar energy materials and solar cells 90.11 (2006): 1555-1578.

6- Hua, Chihchiang, and Chihming Shen. "Study of maximum power tracking techniques and control of DC/DC converters for photovoltaic power system." PESC 98 Record. 29th Annual IEEE Power Electronics Specialists Conference (Cat. No. 98CH36196). Vol. 1. IEEE, 1998.

7- Mohanty, Satyajit, Bidyadhar Subudhi, and Pravat Kumar Ray. "A new MPPT design using grey wolf optimization technique for photovoltaic system under partial shading conditions." IEEE Transactions on Sustainable Energy 7.1 (2015): 181-188.

8- Premkumar, M., et al. "Comparison of MPPT algorithms for PV system-based DC-DC converter." Advances in Natural and Applied Sciences 17.9 (2016): 212-221.

9- Chun-xia, Liu, and Liu Li-qun. "An improved perturbation and observation MPPT method of photovoltaic generate system." 2009 4th IEEE Conference on Industrial Electronics and Applications. IEEE, 2009.

10- Ahmed, Jubaer, and Zainal Salam. "A modified P&O maximum power point tracking method with reduced steady-state oscillation and improved tracking efficiency." IEEE Transactions on Sustainable Energy 7.4 (2016): 1506-1515.

11- Ahmed, Jubaer, and Zainal Salam. "An accurate method for MPPT to detect the partial shading occurrence in a PV system." IEEE transactions on industrial informatics 13.5 (2017): 2151-2161.

12- Manoharan, Premkumar, Sumithira Rameshkumar, and Sowmya Ravichandran. "Modelling and implementation of cascaded multilevel inverter as solar PV based microinverter using FPGA." Int J Knowl-Based Intell Eng Syst 11.2 (2018): 18-27.

13- Khan, Omair, Weidong Xiao, and Mohamed Shawky El Moursi. "A new PV system configuration based on submodule integrated converters." IEEE Transactions on Power Electronics 32.5 (2016): 3278-3284.

14- Mohapatra, Alivarani, et al. "A review on MPPT techniques of PV system under partial shading condition." Renewable and Sustainable Energy Reviews 80 (2017): 854-867.

15- Chin, Vun Jack, Zainal Salam, and Kashif Ishaque. "Cell modelling and model parameters estimation techniques for photovoltaic simulator application: A review." Applied Energy 154 (2015): 500-519.

16- Kheldoun, A. B. R. B., et al. "A new Golden Section method-based maximum power point tracking algorithm for photovoltaic systems." Energy Conversion and Management 111 (2016): 125-136.

17- Yatimi, Hanane, and Elhassan Aroudam. "Assessment and control of a photovoltaic energy storage system based on the robust sliding mode MPPT controller." Solar Energy 139 (2016): 557-568.

18- Tina, Giuseppe Marco, and Cristina Ventura. "Simulation tool for energy management of photovoltaic systems in electric vehicles." Energy conversion and management 78 (2014): 851-861.

19- Pandey, Shweta, and Prasanta Kumar Jena. "A Review on Maximum Power Point Tracking Techniques for Photovoltaic Systems." Int. Res. J. Eng. Technol 4 (2017): 1715-1720.

20- Premkumar, M., et al. "Comparison of MPPT algorithms for PV system-based DC-DC converter." Advances in Natural and Applied Sciences 17.9 (2016): 212-221.

21- Ahmed, Jubaer, and Zainal Salam. "A modified P&O maximum power point tracking method with reduced steady-state oscillation and improved tracking efficiency." IEEE Transactions on Sustainable Energy 7.4 (2016): 1506-1515.

22- Ahmed, Jubaer, and Zainal Salam. "An accurate method for MPPT to detect the partial shading occurrence in a PV system." IEEE transactions on industrial informatics 13.5 (2017): 2151-2161.

23- Mohapatra, Alivarani, et al. "A review on MPPT techniques of PV system under partial shading condition." Renewable and Sustainable Energy Reviews 80 (2017): 854-867.

24- Sundareswaran, Kinattingal, et al. "Enhanced energy output from a PV system under partial shaded conditions through artificial bee colony." IEEE transactions on sustainable energy 6.1 (2014): 198-209.

25- 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.

26- Windarko, Novie Ayub, et al. "Maximum power point tracking of photovoltaic system using adaptive modified firefly algorithm." 2015 International Electronics Symposium (IES). IEEE, 2015.

27- Dhivya, P., and K. Ranjith Kumar. "MPPT based control of sepic converter using firefly algorithm for solar PV system under partial shaded conditions." 2017 International Conference on Innovations in Green Energy and Healthcare Technologies (IGEHT). IEEE, 2017.

28- Nugraha, Syechu Dwitya, et al. "Maximum power point tracking of photovoltaic module for battery charging based on modified firefly algorithm." 2016 International Electronics Symposium (IES). IEEE, 2016.

29- 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.

30- 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.

31- Mohanty, Satyajit, Bidyadhar Subudhi, and Pravat Kumar Ray. "A new MPPT design using grey wolf optimization technique for photovoltaic system under partial shading conditions." IEEE Transactions on Sustainable Energy 7.1 (2015): 181-188.

32- Mohanty, Satyajit, Bidyadhar Subudhi, and Pravat Kumar Ray. "A grey wolf-assisted perturb & observe MPPT algorithm for a PV system." IEEE Transactions on Energy Conversion 32.1 (2016): 340-347.

33- Mohanty, Satyajit, Bidyadhar Subudhi, and Pravat Kumar Ray. "A grey wolf optimization based MPPT for PV system under changing insolation level." 2016 IEEE Students' Technology Symposium (TechSym). IEEE, 2016.