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Maximum Power Point Tracking Algorithm for Advanced Photovoltaic Systems

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Abstract

Photovoltaic (PV) systems are the major nonconventional sources for power generation for present power strategy. The power of PV system has rapid increase because of its unpolluted, less noise and limited maintenance. But whole PV system has two main disadvantages drawbacks, that is, the power generation of it is quite low and the output power is nonlinear, which is influenced by climatic conditions, namely environmental temperature and the solar irradiation. The natural limiting factor is that PV potential in respect of temperature and irradiation has nonlinear output behavior. An automated power tracking method, for example, maximum power point tracking (MPPT), is necessarily applied to improve the power generation of PV systems. The MPPT methods undergo serious challenges when the PV system is under partial shade condition because PV shows several peaks in power. Hence, the exploration method might easily be misguided and might trapped to the local maxima. Therefore, a reasonable exploratory method must be constructed, which has to determine the global maxima for PV of shaded partially. The traditional approaches namely constant voltage tracking (CVT), perturb and observe (P&O), hill climbing (HC), Incremental Conductance (INC), and fractional open circuit voltage (FOCV) methods, indeed some of their improved types, are quite incompetent in tracking the global MPP (GMPP). Traditional techniques and soft computing-based bio-inspired and nature-inspired algorithms applied to MPPT were reviewed to explore the possibility for research while optimizing the PV system with global maximum output power under partially shading conditions. This paper is aimed to review, compare, and analyze almost all the techniques that implemented so far. Further this paper provides adequate details about algorithms that focuses to derive improved MPPT under non-uniform irradiation. Each algorithm got merits and demerits of its own with respect to the converging speed, computing time, complexity of coding, hardware suitability, stability and so on.

Keywords: Keyword MPPT algorithms, PV system**,** Traditional techniques**,** Evolutionary Algorithms, Artificial Intelligent Techniques, Biologically Inspired Algorithms.

Introduction

The growing load requirement alongside the consumption of fossil energies compels the planet to seek replacement for energy reserves. Additionally, the problem concerning pollution because of global warming and other ecological problem related to traditional energy sources cause main attraction for adopting renewable energy resources (RES) [1]. Across different non-traditional energies, the solar energy is increasingly utilized due to the plentiful existences of solar irradiance [2]. The PV system changes the solar energy into electrical energy, however being the temperature and solar irradiation are varying inherently, consequently, it decreases the efficiency of PV. The major disadvantage of the PVs because of its uneven characteristics namely lesser converting efficiency, poor rating, huge realization expense, and maintenance problems. PV systems further get influenced because of partial shading due to tree branches, buildings, clouds, birds and so on. Such elements cause to use essentially the dc to dc converter with algorithm to track the MPP from PV cells in working environment. The MPPT [3] controlling method is used together with dc to dc converters, where the controlling algorithm adapts the duty cycle based on the changes in temperature and solar irradiance, boosts the low voltage performance of the PV cell [4,5]. A PV system has limited power value, and these PV cells are cascaded either serially or in parallel depends on the necessary voltage and current specification. The construction of the array with the interconnection of the combination of series and parallel form of PV modules [6]. This causes power electronics-based interfaces essential for guaranteeing every PV system with the voltage suitable for a grid or load [7]. PV system can be constructed with panels by rooftop arrangement, and it might work in autonomous and network-connected styles [8]. In PV system, the voltage at output is determined by the panel temperature and the current at output determined by the irradiation intensity. The PV produces the optimal output

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on the standard test condition with irradiation of 1000 W/m2, temperature of 25 °C and air density of 1.5 [3,9]. MPPT to provide possible peak power comprises of a controlling algorithm with a converter to guarantee that PV systems work at MPP. Any tracking method will become less effective if the PV systems under partial shades. In this research domain, there was an exemplar move in developing algorithms for MPPT since multitude of research papers are then published annually on global exploratory techniques [7, 8]. Several investigations were carried out in building a reliable and an efficient MPPT methods to obtain maximum power point of PV system [10]. Both traditional and computing intelligent algorithms are employed for MPPT [11, 12]. Certain traditional algorithms operate effectually on homogeneous solar irradiance and temperature however decline to follow the actual maximum operating condition while weather or shading changing circumstances [13,14]. The effective nature-inspired techniques based MPPT methods may be namely genetic algorithm (GA), ant colony optimization (ACO) algorithm, particle swarm optimization (PSO) algorithm, differential evolution (DE), artificial bee colony (ABC) algorithm etc. Such algorithms are applied to solve global exploration problems and can perform effectually on homogeneous solar irradiance and its based temperature, in addition to partial shade and swiftly varying weather factors. Hybridizing such algorithms has been performed for improving the operation and reliability of PV systems.

In [15], the authors suggested a swarm hunting MPPT algorithm to integrate the converters into module and the performance too contrasted with traditional P&O technique. In it, the swarm-hunting method was considered more advantageous. A study of comparison on firmly rooted global crest tracking techniques is recorded in a research conference [12, 16]. Certain researchers attempted to properly evaluate the traditional algorithms and investigated whether the algorithms perhaps uphold while shading partial. In [16], traditional MPPT methods were contributed, which explains the operation of algorithms with their advantages and disadvantages. The research toward generating firm technique has not decreased as one can notice the global analysis on MPPT [7, 8, 12]. In it, the study was carried out on applying five different evolutionary based algorithms which were dependable and more realistic for feasible implementation. It has been constructed thereby it contributed a precise idea about PV properties like partial shading and MPP exploratory methods.

Over recent years, the generation of electricity is substantially increased on traditional power sources. Because of growing requirements for electricity and intensified reliance on fossil oils, the expenditure for power becomes higher and further has negative impact on environment. So as to subdue these issues, non-traditional power sources are utilized which support in declining carbon release, depletion and price surge of fossil oils. The PV based power production has demonstrated a substantial capability in meeting the global power requirement. The benefits of PV systems comprise no expense towards fuel, lesser maintenance need and environmental benevolence. Because of these ecological and financial gains, PV systems are frequently used as power reserves for distribution of generation over micro grids. But, the realization and unification of PV systems yet continues a major problem because of huge capital expense. Moreover, there is uncertainty that the energy generated through PV system remains stable, since it relies totally on the solar irradiation and surrounding temperature. Secondly, the energy generation due to sunrays is limited because of lower efficiency over conversion by PV array. Thus, it is important to take advantage of commonly obtainable solar power. To maximise the amount of energy generated by a PV system, a maximum power point tracking algorithm (MPPT) must be developed. Under varying conditions of solar radiation and panel temperature, the primary goal is to maximise energy production from the PV modules. Parallel and series connections are used to form a framework that can provide the necessary voltage and current. Due to cloud cover or shadows cast by trees, buildings, and other nearby objects, certain portions of the module or the PGS may get less sunlight than others. There are a number of factors that influence how much electricity a photovoltaic (PV) system can produce while it is partially shaded. Under partial shading, PV systems connecting to a string undergo various insolation, causing Power-Voltage behavior quite intricate and shows several peaks [1].

Several approaches were suggested for MPPT namely the Hill Climbing (H&C), Perturb and Observation (P&O), the Ripple Correlation Control (RCC), the incremental conductance algorithm and so on, operates well at high solar irradiation however the efficiency due to tracking declines with decreasing solar irradiation. In past few years, additional research on MPPT was performed and the partial shading effect has been considered and discovered that traditional techniques exhibited extremely poor performance while on tracking. Several methods are impotent to track the actual MPP during partial shading conditions. Because of inefficiency of these techniques, many stochastically dependent algorithms and artificial intelligence methods have been constructed based on nature and biological behavior. These comprised such as Genetic Algorithm (GA), Artificial Neural Network (ANN), Fuzzy Logic Controller (FLC), Particle swarm Optimization (PSO), Ant Colony

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Optimization (ACO), Differential Evolution (DE), Firefly etc., can determine solution to obtain the maximum power on partial shading condition and swiftly changing environmental conditions. This paper discusses shortly about the behavior of PV array containing under partial shading condition accompanied by description of the MPPT phenomenon. MPPT processes are grouped into traditional methods, stochastic-based and artificial intelligence approaches. Ultimately, the comparison is performed between the techniques and conclusions are made.

Model of PV Module

The block diagram comprising the PV system shown in **Figure 1**. From the diagram, a solar panel interconnected with a dc-dc converter and the MPPT algorithm supplies the duty cycle to the converter for controlling purpose. The MPPT algorithm will observe the desired variables from PV system, and consequently, it changes the duty cycle applied to the converter. Therefore, under various situations, the maximum power output is acquired from the PV system. Later the output of the converter is directly linked to the dc electrical load or can be connected to ac loads via an inverter.

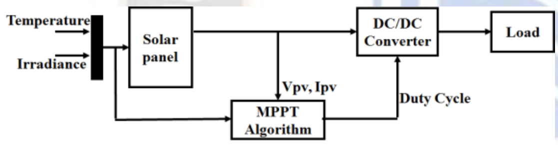

Figure 1 Block Diagram of PV system

A PV array contains several solar cells which are usually built using silicon. The electrons begin to transit which constitute the flow of currents when the sunrays incidents on solar cells. On the basis of electronics principle of semiconductor P-N junctional diode, it can be represented as a constant current source. There exist several kinds of models available to represent PV module, in particular, the single diode model is clearly set design [17, 18]. **Figure 2** depicts the fundamental equivalent circuit model of a PV unit [19]. A basic single diode model is depicted in **Figure 2**. In this model, a diode is connected parallel to a constant current source and shunt resistor, and additionally series connection of a resistor. The current produced by light energy is Ipv. This generated current flows in diode which represented by I_D and flows in shunt resistor R_{sh} which is represented by I_{sh}, and finally flows out as output current which represented by I. For the mathematical modeling of the PV system, the basic equations are given below.

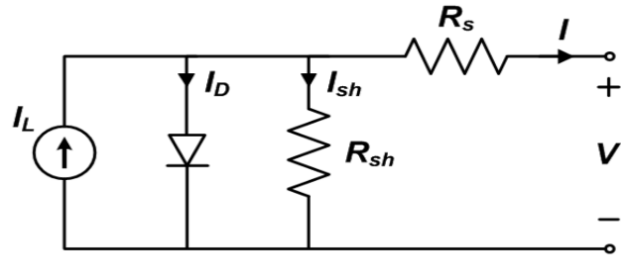

Figure 2 Fundamental equivalent circuit model of PV unit

I_L is the current that generated by PV cell on the basis of the solar irradiation and panel temperature. The I_L will be generated more on stronger irradiation. The output current can be stated as follows

$$I = I_L - I_0\left[exp\left(\frac{V+IR_{sh}}{V_T}\right) - 1\right] - \left[\frac{V+IR_{sh}}{R_P}\right] \quad (1)$$

In which, I_L is the insolation current, *I* is a PV module output current, *I*o is a diode reverse saturation current, *V* is a cell output voltage, *Rsh* is a series resistance and *Rs* is a parallel resistance. V_T is a voltage equivalence of temperature and it is represented as $\left(\frac{kT}{q}\right)$.*k* represents as Boltzmann constant; *T* is the temperature in Kelvin and *q* is an electron charge.

The mathematical model that employed to describe a PV array is depicted by following equation

$$I = n_p I_L - n_p I_o\left[exp\left(\frac{q}{kTA}\frac{V}{n_s}\right) - 1\right]$$

In where I is a PV module's output current, V is its output voltage, n_s is the number of cells linked in series, n_p is the number of cells connected in parallel, A is the P-N junction's ideality factor, and Io is the diode reverse saturation current.

'*A*' variable ascertains the aberration from ideal characteristics of P-N junction, and it takes the value ranging from 1 to 5. The reverse saturation current *I*o of cell changes with panel temperature on the basis of equation as follows.

$$I_0 = I_{rr}\left[\frac{T}{T_r}\right]^3 exp\left[\frac{qE_G}{kA}\left[\frac{1}{T_r} - \frac{1}{T}\right]\right] \quad (3)$$

In which, T_r is a reference temperature of the cell, I_{rr} is a reverse saturation temperature of a cell at a temperature of T_r, E_G is a band gap energy of a silicon semiconductor employed in construction of the cell.

The band gap energy of the semiconductor in terms of temperature is described by

$$E_G = E_G(0) - \frac{\propto T^2}{T+\beta} \quad (4)$$

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The photo cell current I_L which chiefly influenced by the solar irradiation and panel temperature can be stated

$$I_L = [I_{scr} + K_i(T - T_r)]\left(\frac{S}{100}\right) \quad (5)$$

In which, I_{scr} represented as short circuit current of the PV system module at standard irradiation and temperature, Ki is a temperature coefficient of short circuit current, S is a solar irradiance expressed in mW/cm^2

The power of PV module can be computed by the equation that stated below

$$P = VI = n_p I_L V\left[\left[\frac{q}{kTA}\frac{V}{n_s}\right] - 1\right] \quad (6)$$

Characteristics of PV Array

In general, the V-I characteristics of a PV module show nonlinearity, and so the maximum power point is difficult to track. The V-I characteristics of PV cell is depicted in **Figure 3**. P-V characteristics under constant irradiation and temperature is depicted in **Figure 4**.

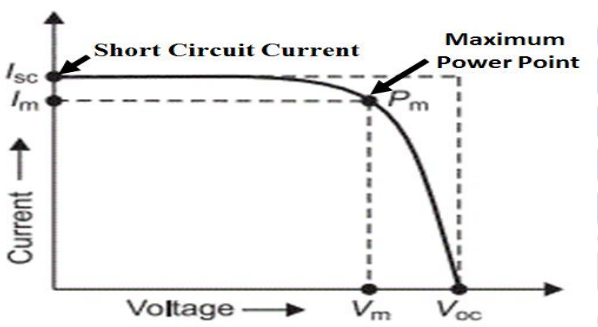

Figure 3 V-I Characteristics of PV cell

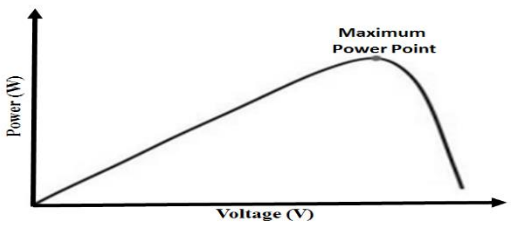

Figure 4 P-V characteristics under constant irradiation and temperature

Characteristics of PV array under partially shading condition

For larger PV systems, partial shading conditions happen whereby the PV cells sense various solar insolation because of buildings shadow, tree shadows, moving clouds, and other shadowing things. Inhomogeneous irradiance causes the hotspot issues, for instance, the variation of potentials among different PV modules. The hotspot issue may happen in a PV module, in which a particular PV cell constituted in an array that are connected in series is exposed to low illumination, and drain certain amount of power that produced by remaining cells. To safeguard the PV cells out of this issue, bypass diodes will be connected in parallel for every PV cell as depicted in **Figure 5**. The output power of PV substantially reduced because of partial shading, and the quantity of power loss relies upon PV array structure, shading conditions, and the bypass diodes included in each PV cell [1]. The direct impact of partial shading pattern is that the PV characteristics consequently happen to be complex with several peaks as shown in **Figure 6**.

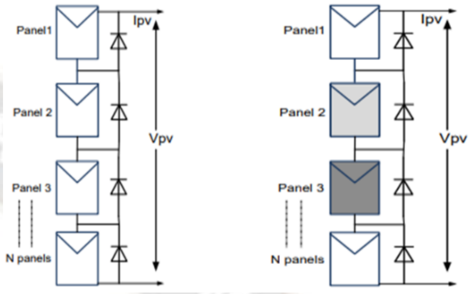

Figure 5 Connection of bypass diodes for each PV cell

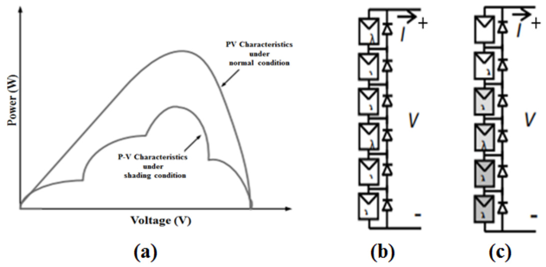

Figure 6 PV Characteristics under shading and normal conditions (a), normal and shaded condition of the PV cell (b) & (c)

From the P-V characteristics that depicted in **Figure 6a**, the connection of diodes makes the unshaded cells to deliver maximum power for a given irradiance and panel temperature. Whereas the absence of bypass diodes makes the shaded PV cells to deliver limited output current on comparing with unshaded cells. Diode arrangement may prevent destruction of the PV modules due to temperature, further it also reduces the power output from PV array. The bypass diodes will block the flow of reverse current. The presence of reverse current may result excess thermal production as a result thermal breakdown may occur.

MPPT Techniques

Traditional Techniques

The methods of Perturb & Observe (P&O) and Incremental Conductance (INC) are on the concept of "hill-climbing", which comprises the shifting of the operating point of PV strings in the course where the power increases. The method of hill climbing is the quite familiar MPPT techniques because of their easy realization and top performance for constant irradiance [3]. The benefits of these approaches are that they are simple and less computing

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ability. The weakness is too more familiar, those are the perturbations near MPP and they easily miss tracking and track the MPP in the false course under swiftly varying climatic pattern. The algorithms of P&O and the INC are the generalized approaches that are in practice. Such approaches have the benefit of an uncomplicated application however they too bear some disadvantages. Other methods which founded on distinct concepts, they are artificial neural network, fuzzy control, fractional short circuit current or open circuit voltage, current sweep and so on. Many of the techniques produce a regional maximum and certain techniques namely the fractional short circuit current or open circuit voltage attains MPP approximately instead of precise one. Under usual conditions, the P-V characteristics just has one maximum, hence there is no issue. Whereas, when the PV array is under partial shading, there exists several maximal MPP. To overcome this issue, improved methods have been realized. Such methods vary in several features namely the needed sensors, the complexity, the cost, convergence speed, effective range, proper tracking on changing irradiance and temperature, hardware required for the realization.

Perturb and observe (P&O)

The MPPT technique of P&O algorithm is on the basis of the estimation of output power and the variation of power due to sampling of voltage and current of PV array [4]. The MPPT tracker works at regular period by increasing or decreasing the voltage of PV array. For a given disturbances, the system causes an increase in the power output. Any following disturbances will make the voltage to increase in the similar direction [5]. The DC converter duty cycle is changed and the process is reiterated until the MPP is attained. In fact, the system fluctuates near MPP. Decreasing the step size of perturbation can reduce the fluctuation. But the lesser step size decelerates the MPP tracking. For varied quantities of irradiance and panel temperatures, the system may show several characteristics. Each characteristic has its maximum power, and the respective voltage is given to the dc-dc converter.

Incremental Conductance (InC)

The use of the Incremental Conductance approach provides excellent operation under swiftly varying climatic conditions. The fundamental equations of it are described as follows [6]

$$\frac{dI}{dV} = -\frac{I}{V} \quad \text{At MPP} \qquad (7)$$

$$\frac{dI}{dV} > -\frac{I}{V} \quad \text{to the left of MPP} \qquad (8)$$

$$\frac{dI}{dV} < -\frac{I}{V} \quad \text{to the right of MPP} \qquad (9)$$

In which, V and I are output voltage and current correspondingly, the left side and the right side of equations constitute incremental and the instantaneous conductance of PV module. Obviously if the change in output conductance is negative, the PV array will work at MPP. On comparison of conductance at every sample instance, the MPPT will follow the MPP of the PV array. In both P&O and INC methods, the attaining speed of MPP influences on increment size of the recommended voltage. The disadvantages of such methods are majorly two types. The important first one is that PV system can readily miss the track of the MPP when the irradiance varies swiftly [7]. In the event of step variations PV system track the MPP really good, since the variation is immediate and the characteristic may not go on varying. But, if the variation of irradiance in accordance with a slope, the characteristic where the schemes will continuously vary with irradiance. Thus, the variations in the voltage and current are because of the voltage disturbance. Consequently, it is impossible to find the variation on power is because of its own incremental voltage or because of the irradiance variation. Secondly, the stability of fluctuations of the voltage and current near MPP. This being discrete control, the voltage and current are not fixed at MPP in fact they fluctuate near to it. The fluctuating amount relies upon the amount of the changing rate of the reference voltage. If such rate is high, the fluctuating amount will be greater.

Fractional Open Circuit Voltage

This approach employs the linearity between the open-circuit and the MPP voltages, which changes over irradiation and temperature [3, 4].

$$V_{MPP} = k_1 V_{oc} \qquad (10)$$

In which,k_1 is a constant based on the PV array characteristics and this has to be evaluated in beforehand by computing the$V_{MPP}$and V_{oc} at various quantities of irradiance and various temperatures. k_1 takes the value ranges from 0.71 to 0.78. Once the proportionality constant,k_1, is computed, the MPP voltage, V_{MPP} ,can be found regularly by quantifying V_{oc}. In order to quantify V_{oc} the converter has to be switched off temporarily. Thus, the power loss happens for every measurement. One more issue in this technique is that it is unable to track the MPP for irradiance slopes, since theV_{MPP} estimation is discrete. Another demerit is that the MPP achieved is not an actual one since it has approximated relationship.

Fractional ShortCircuit Voltage

In a method of fractional short circuit voltage [3, 4], the relation between the short circuit current I_{sc} and the MPP current I_{MPP} under changing weather conditions is depicted by the equation

$$I_{MPP} = k_2 I_{sc} \quad (11)$$

The proportionality coefficient k_2 must be evaluated based on every PV module, similar to early technique that occurred for k_1. The k_2 commonly takes the value from 0.78 to 0.92. Determining the short circuit current during system operation is a major issue. It normally needs connecting an extra switch to a dc-dc converter for frequently shorting the PV module and determine I_{sc} by short circuiting the PV module with a field-effect transistor that connected additionally between the PV module and the DC link capacitance.

Evolutionary Algorithms

Genetic Algorithm (GA)

The genetic algorithm belongs to a class of stochastic models motivated by biological evolution. It is a global probabilistic exploration method on the basis of population genetics. This algorithm encodes a capable solution to address a particular issue using chromosomes and applies recombination operators over them in order to hold crucial information The PID based genetic algorithm controller is employed for MPPT in PV module [8] in which the Kp, Ki and Kd parameters are encrypted in the form of binary sequences termed chromosomes. The sequence length is fixed to a value of 48. The selection is applied on chromosomal population to build a breeding group. Then the operation of crossover is employed to generate fresh chromosomes. The fitness of every chromosome is determined by translating its bit sequence into a real value which denotes the gains of PID. Each group of PID parameters is applied to the PID controller so as to calculate a full system response. This procedure will undergo GA operations successively and recur till the last generation attained so that the best fit individual is obtained. Thus, the optimal parameters of PID is finally achieved.

Differential Evolution (DE)

DE is applied to find the solution for realistic issues which is non-differentiable, discontinuous, non-linear, noisy, and has multidimensional or several regional minima, constraints, and stochastic [10]. DE is simple to implement since it just needs a limited number of parameters for algorithm. Fundamentally, the particle population is needed for DE with lesser number of iterations are required so as to result the final solution. The dissimilarity in the particles are employed to evolve each particle for every iteration. The task begins by setting an original population of target vectors under limit conditions. The population vectors may be the duty cycle or reference voltage or current.

The individual's fitness of whole population is determined by using the voltage and current of PV system to observe its power performance being the power output is generally employed as a fitness measure for MPPT use. Once the fitness of every individual evaluated, the mutation and crossover operations will be carried out. For each individual in the population, its corresponding mutant is created by using any one of mutation methods. After that, the crossover is performed to create a trial vector. Finally, the process of selection is carried out by individual competition based on fitness values of target and trial vectors of the population. The better or identical fitness valued vectors are passed from present population to next as next generation through iteration. This process is performed repeatedly as long the true MPP is reached or a stopping condition is encountered.

Artificial Intelligent Techniques

Artificial Neural Networks (ANN)

A manifold feed-forward neural network (MFFNN) is employed in tracking the MPP. This neural network contains three layers namely input, hidden and output layers [10]. The neuron count of hidden layer is founded on for the process of trial and error. The factors that act as input may be parameters like V_{OC} and I_{SC}, weather information namely irradiation and panel temperature, or composite of them. The output is generally one or many reference parameters namely the duty cycle is employed to trigger the dc-dc converter so as to work at or nearer to the MPP.

Fuzzy Logic Controller (FLC)

To make judgments and regulate the controller output, the FLC uses fuzzy logic. The rule-base, fuzzification, inference, and defuzzification are the main components of every fuzzy logic controller. The controller's inputs are e(k) error and e(k)change in error [4]. The Fuzzification process converts fixed inputs to fuzzy inputs. The rules are built as a rule basis and are utilised in the inference process. The defuzzification technique converts the fuzzy output to a fixed output. The fuzzy inference process uses Mamdani's approach, and the defuzzification process uses the centre of gravity to estimate the output of the FLC, which modifies the duty cycle.

Biologically Inspired Algorithms

Ant Colony Optimization algorithm (ACO)

Colorni, Dorigo, and Maniezzo proposed ACO firstly [20]. ACO is a stochastic dependent algorithm applied in solving the problem. ACO is motivated based on the behavior of real ants that seeking the shortest route from their nest or colony to an accessible source of food. The ants will track the shortest length between food and their nest [21]. In the beginning, if the ants seek food, they dump a pheromone trail for the rest of the ants to pursue the same path. The pheromone is a chemical substance that the colony members belong to the same species react [22More members of ants exposed to pheromone trail will get thicken. The member ants can also pursue the identical path when coming back to their nest, thus causing the pheromone track thicker. Therefore, most of the ants will be following the same path until they discover any further shortest route by communicating details about the pheromone. When the path to a food source is longest, then in due course the pheromone vanishes [21, 23, 24].

Realizing ACO for MPPT application, the behavior of most of the ants is taken. with initializing the ants, the process starts [22]. The goal function is framed by taking into account each panel's irradiation and temperature exposure. The formula calculates the pheromone concentration.

$$T_{ij} = \rho T_{ij}(t-1) + \Delta T_{ij} \qquad (12)$$

In which, $T_{ij}$is a updated pheromone concentration, $\Delta T_{ij}$is a change in concentration of pheromone and ρ is a concentration rate of pheromone with a value ranges from 0 to 1. The concentration rate of pheromone, ρ, contributes a significant part for deviation. This parameter may misdirect the convergence to attain local maximum.

Cuckoo Search (CS)

CS [25] is a nature-inspired development, motivated from the parasitic brooding policy adopted by cuckoo birds. It has been seen that many cuckoo species carry out parasitic brooding. It means that they lay their eggs in other species nests (host birds). Commonly three kinds of parasitic brooding strategies are observed: They are intra specific, cooperative and nest takeover.

Certain species of cuckoo namely Tapera are so quite clever to imitate the shape and color of the host bird to improve its breeding likelihood. Three theoretical rules for CS on the basis of cuckoo parasitic brooding behavior are: firstly, every cuckoo chooses other bird’s nest randomly and lays an egg at a moment, secondly, the best nest with high quality eggs will continue to the immediate future generation, and thirdly the available number of nests is remained fix and the maintenance probability of number of eggs laid by a cuckoo bird by the host bird. When the eggs of cuckoo are detected, the host bird may destroy cuckoo’s eggs or desert its nest. In one way or another a fresh nest will be created at a probability P_a in addition to the fixed nests count. In order to employ CS algorithm [26] in developing MPPT, suitable variables are to be chosen for exploration. Voltage, current, power, sample size and the β value are initially set. Applying the present measure of current and voltage, the power will be estimated. The fresh measure of current, voltage and power are memorized in V_i^t voltage and fitness f_i^t array values, correspondingly. Additionally, prior to initiation of each iteration, an inspection is carried out to find whether the sampling is reached the convergence already or stopping condition is met. Once the convergence of samples attained MPP, they will take the same maximum power value. While the samples are not converging, entire power values for respective samples are estimated and are memorized in the f_i^t vector. On assessing the vector, the sample with peak power is selected as a best sample. Subsequently, rest of the samples is directed to reach the best value. The step size is computed by carrying out Levy flight. Accordingly, a fresh sample set is determined. Later the respective powers of these fresh samples are computed. At the same time, if the samples of any provide reduced power, then the specific sample is abandoned and a fresh sample is created. This iteration is continued until whole samples reach optimal MPP.

Firefly Algorithm (FA)

FA is a recent meta-heuristic method, motivated by a glittering light by fireflies, used in solving optimization problem. In FA, randomly generated vectors will be regarded as firefly’s population [27]. The flashing brightness is designated based on their performance with the goal function. A main rule in FA is that entire fireflies are single sex. It refers that irrespective of sex, some firefly can be gravitated to some other brightly glittering firefly. Secondly the rule is that brightness of flashing light is decided based on goal function. The intensity of light at a specific distance from the light source complies law of inverse square. Attraction has constant relation with brightness and it reduces with distance. FA is best on comparing with other algorithms by way of convergence to track global MPP, tracking speed and thus bears effective tracking. The ratio of output to maximum powers under steady-state is termed as efficiency. The benefits of FA are easy computing procedures, rapid convergence and inexpensive realization with microcontroller. FA is used in MPPT by setting the parameter initially i.e., fixing the constants involved in algorithm such as population size N, βo, γ, n, α, and the halting condition. The firefly position is derived from the duty cycle applied to the dc-dc converter

The produced power P_{pv} of a PV module is treated as brightness of each firefly, based on its position. The position

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of fireflies occupies within the space in the range from d_{min} to d_{max}, in which d_{min} and d_{max} depict the minimum and maximum duty ratio values of the dc/dc converter. Hence, each firefly position depicts the dc–dc converter duty ratio. It is observed that the large firefly count will be resulting for higher computational time whereas the lesser firefly will be resulting at a local maximum. The dc–dc converter is functioned in accordance with each firefly position (duty ratio) consecutively. For every duty-ratio, the respective output power of PV system is considered as corresponding firefly light intensity or brightness. This process is operated repeatedly for the whole firefly positions of the population. The firefly with a maximum luminosity continues its position and the rest fireflies refurbish their positions. The algorithm gets termination when the stopping condition is attained. The algorithm gets stopped once the displacement of whole firefly population in sequential steps attains a set with minimum values. Once the algorithm gets stopped, the dc–dc converter functions at an optimal duty cycle in proportion to global MPP. Resume the FA when the solar insolation varies, which is identified by perceiving the variation in output power using discrete controller.

Particle Swarm Optimization (PSO)

PSO is another type of stochastic exploration algorithm, configured on the basis of the swarm behavior of bird clusters. The algorithm of PSO involves a swarm of several individuals termed particles, in which every particle typifies a possible candidate solution [11]. Particles show a basic behavioral pattern which mirror the performance of proximate particles and its own attained successes. The particle position is largely affected by the best particle in a locale. The best solution along with particle best can be determined from entire population particles as a global best [12]. The PSO is used to implement the control for MPPT in a PV system, in which the P-V characteristics shows several regional MPP. If the two PV modules are serially connected and one among two is shaded partially, the output port voltage of shaded module will be non-identical in comparison with unshaded module. The PV system consists several numbers of modules. Hence, the voltage of each particular module has to be controlled.

Artificial Bee Colony (ABC)

ABC is also swarm based meta-heuristic algorithm and it is employed in solving multidimensional and multimodal issues. Karaboga [28] proposed this algorithm. It is motivated from honeybee behaviors namely learning, foraging, memorizing, and information sharing while optimizing [29]. In ABC, the food sites are taken as useful solutions and the nectar quantity it generates describes the food site quality (i.e., food site fitness) [30]. The honeybees are grouped into three classes, first type termed as worker, second type termed as onlooker, and the third type termed as sentry, and all these bee kinds carry out majorly three sorts of foraging behavior. The types of foraging behavior are seeking the food sites, deploying the worker bees for gathering the meal from the sites, and abandoning the food sites because of their shortage of nectar quality [21, 23]. Food sites are discovered and sought by the workers. The bee type regards the decision on the food site is termed as the onlooker. The food sited found by the workers that are unimproved are abandoned, and the workers that discovered them turn into sentries. In ABC, the bees count will be equal to the number of workers, sentries, and onlooker bees.

In applying ABC algorithms as MPPT method, the duty cycle of the dc–dc converter is taken for each candidate solution. Thus, in this algorithm, optimizing function has duty cycle as only one parameter for optimization. The *d*-dimension problem possessing food sites has to be optimized, by considering bee numbers in the exploratory space. Thus, by presuming that every food site has one worker bee, subsequently the i^{th} location of food site on i^{th} iterative is determined. Firstly, generate the food sites randomly using upper and lower limits of problem dimensions, and using a random value in the range from 0 to 1. The worker bees seek a fresh food site closer to old food sites on randomly chosen dimensional space by setting choosing random value between 1 and -1.

When it is determined that the fresh food site outperforms the older, then the fresh one will be included, while the worst older one is dropped. Else, the older food site continues to be in next iterative [21]. Moreover, the accessible food site detail is distributed to onlookers and the food site is chosen by the onlookers on the basis of probability conditions of ratio of individual food site fitness value to collective fitness values of total available food sites.

The workers also get included on the basis of a greedy selection method. Once the specified iteration count or the limit measures for the fresh food site quality are unimproved, then the food site is discarded and put stop. The bees connected to the discarded food sites turns into sentries and seek for fresh accessible food sites and tests for stopping conditions. If the obtainable solutions are reasonable or required iterations are attained, then the operation ends; otherwise, it keeps the hunt. The detailed performance deliberated in [31]. In this, the performance comparison of ABC with DE, PSO and other evolutionary algorithms is carried out for multimodal and multifunctional problems in which ABC is observed in producing best outcome in comparison with others. ABC algorithm has been effectively realized also for leaf-limited minimal spanning problems

[32]. In [33], a comparative analysis of the ABC algorithm with certain population-based algorithms is performed to solve a wide range of numerical optimization and the outcomes achieved are contrasted. It was observed that the outcomes achieved through ABC are excellent, and in certain instances, similar to the population-based algorithms in which ABC got benefit of comprising less number of controlling parameters than rest. ABC supported MPPT method for PV system are stated in [68] and the outcomes of it are contrasted with the P&O technique in which ABC supported MPPT contributes a better operation. As a result of several kinds of research, the strength of the ABC algorithm applied for MPPT under identical and cloud over partially are depicted and determined to be overcome in comparing with other prevailing methods [34, 35]. In [36], modified ABC algorithm (MABC) is discussed and its performance is contrasted against the GA, PSO and ABC, and determined that it is more appropriate in decreasing the energy loss due to partial shading.

Bacteria Foraging Optimization Algorithm (BFOA)

BFOA is too a bio-inspired algorithm which is motivated by foraging activities of Escherichia Coli (E. coli). E. coli live in humans and animals intestinal region and has several multifunctional foraging activities in order to maximize the energy consumption rate as one specific foraging activity. If the foraging activity happens because of environmental factors, the bacterium with a high fitness measure and an ability to endure the environmental variations continues to exist and the rest get removed [37]. This type of bacteria adopts four fundamental means for reaching to a nutritious abundant site. These four means are chemo-taxis, bustling, reproduction, and elimination dispersal [38].

With the help of locomotive organelles known as flagella, the E. coli bacterium moves about within the gut in search of a nutrient-rich location. Chemo-taxis is the term for bacteria's search for nutrition. The bacteria can tumble or swim thanks to its flagella, and these fundamental motions are caused by the chemo-taxis phenomenon [39]. In the swimming type, the bacterium changes location constantly in a unique direction however, in the tumbling type it varies randomly in the direction

Both the E. coli and Salmonella typhimurium exhibit swarm behavior where steady spatial-temporal swarms are developed in a semi-rigid nutritious environment. The E. coli bacteria swarm in the midst of a semi-rigid substance with a particular chemical effector locate themselves in the journeying annular, thus advancing according to the gradient of nutrient. The intestinal cells will discharge an aspartate while it becomes stimulated for large amount of succinate, and by means of this, the bacteria will shape into several groups and will transit in a concentric arrangement of groups with an intensive bacterial concentration.

The bacteria of low fitness measure or unhealthy bacteria are removed, which includes one-half of the bacterial population. Subsequently, the healthy bacteria or high fitness valued bacteria, will asexually divide into two daughter cells. By this method, replication happens and the population in an exploration space continues to be fixed.

An abrupt variation in the ambience in which the bacteria survives might happen because of several grounds and this occurrence is termed elimination- dispersal. The bacteria will be thriving in an improved nutrient gradient ambience, however because of changes of environment, certain bacteria may be destroyed or distributed to a newer place. Because of this, several bacteria are dispersed everywhere in the environment from the intestine to thermal springs and too to a subsoil environment. To implement this bacterial performance as BFOA, certain bacteria are randomly settled with very lesser probability, while the fresh substitutes are created randomly in an exploration space. These occurrences have the chance of destruction by chemo-taxis method, or they may support the chemo-axis method since the bacterial distribution may locate it in a fresh better food site. The discussed BFOA spots its use in several domains. In [37], a hybrid based least square of fuzzy dependent BFOA is suggested for a harmonic evaluation of voltage and current signal profiles in power system. Because of its handling capability of nonlinear optimization, the estimation of phase is performed by BFOA and the linear based least-square technique is applied in evaluation of amplitude of the harmonic element. In [40], the chemo-taxis process of BFOA was studied using simple gradient descent. The speed for convergence of BFOA is improved in this method. BFOA is also applied successfully in cancellation of active noise [41]. In [42], a grid-connected PV system founded on an active shunt power filter (ASPF) method is presented. In controlling the dc-link voltage with PI controller, it is quite tough because of the presence of changing loads, BFOA is applied to determine the optimal parameters of PI controller in this paper. A PSO directed BFOA is used to estimate the parameters of PV system in [43]. In this, the problem in optimization is solved applying PSO, BFOA, and PSO directed BFOA in an LDK solar and it is determined that the PSO directed BFOA contributes the best value of fitness. In [44], both traditional and computing methods on combination of the algorithms are employed for maximum extraction of power from PV systems and the algorithmic performance is contrasted. In this, P&O, fuzzy dependent P&O and BPSO based parameter tuning of fuzzy P&O are researched for MPPT of PV systems, in particular, the BPSO based parameter tuned fuzzy P&O was assessed as

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a best type. BFOA is employed as an effective method in extracting parameter for PV systems. It showed increased accuracy over outcomes in comparison with traditional Newton–Raphson technique, PSO, and improved simulated annealing (SA) for various PV systems on various test basis [45]. It is observed that BFOA is successfully used for different global exploration challenges in determining the best possible solution.

In choosing an algorithm for any problem during optimization, several features must be examined namely the reliability, practical expense, converging speed, algorithm complexity and so on. The evolution-based algorithms have significant role when regarding the partially shading conditions of PV systems. It is observed from several research papers that several MPPT methods are at hand with various control methods, and lot is to be explored yet. The deeper investigation of the algorithms provides thorough understanding about the latest progress in this domain. It depicts that the multiple factors influence in attaining the goal of optimization and further it depicts their constraints. In the midst of several algorithms for MPPT that mentioned here, PSO is observed to be more commonly applied method. Simple PSO got a basic coding mechanism and is very productive in tracking global MPP however occasionally because of swiftly varying climatic conditions, it may decrease the speed of its convergence and begin fluctuating around global MPP. Thus, on a survey of several kinds of literature, it is seen that several researchers have published modified PSO or hybridized PSO to reach the boost in optimization. It is observed that PSO-DE, PSO-P&O, PSO-INC [46], PSO-GA and so on, have been employed which provides a better speed in convergence and better stability with lesser fluctuation. The other swarm intelligence-based algorithms namely ACO and ABC include basic, easy and profitable realization, and operate well over the regular PSO. But, at certain instants, these algorithms trap the value to local maxima. Those algorithm performances can be enhanced further by uniting them with machine learning or deep learning or soft computational methods. This may decrease the converging speed while tracking the global MPP. The DE algorithm is much the same to the swarm intelligence techniques however occasionally, it collapses to track the global MPP since the parameters are directionless. Thus, it may guide to a false path. This algorithm may be enhanced by combining it with the soft computational methods. BFOA on the basis of bacteria foraging activity contributes a huge exploration space and easy computations, and the algorithmic constraints can be subdue by improving the choosing method of parameter or uniting it with other optimization methods. The methods can be enhanced further by contracting the exploration space, by restricting the number of parameters for optimization and by choosing appropriate controlling parameters. This, on its part, can improve converging speed and can determine the value of best fitness too. Both the traditional and soft computational algorithms can be amalgamated in such a way their weaknesses can be lowered and the consequent hybridized algorithm shall increase the MPPT performance. But this may grow the expense of implementation and the system complexity. From this literature review, it is observed that many algorithms are identical and differ on a narrower sense. Hence, algorithm choice mainly relies on the optimization conditions set by the researchers, which might be an objective function, implementation methods and so on. Hence, an effective, stable, inexpensive, and easy algorithm has to be designed that, on its part, can improve the application in hunting for global MPP of a PV system. The authors of [47 - 50] have employed the latest neural networks called as capsule network and CNN for several tasks which finds its application in PV systems.

Table 1. Merits and demerits of meta-heuristic algorithms

Sl.No	Algorithms	Merits	Demerits
1	PSO	Rapid convergence while tracking true global MPP under shading partially. Higher efficiency	Expensive. High system complexity. Fluctuates on drastically changing climate
2	DE	Independence of initially setting parameters while determining true global MPP. Rapid convergence. Used lesser number of controlling parameters	Particles are directionless while converging. Particles must be improved for convergence in order to obtain best solution
3	ABC	Independent to the initial setting of system parameters.	It collapses in tracking the true global MPP at certain instant.

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		Easy arrangement. Simple to realize	
4	ACO	Easy and inexpensive method to practically implement. Better converging speed and effective under partial shading	Operation is time consuming and complex computation since more number of parameters involved
5	BFOA	Independent to the memory size and nonlinearity. Handle complex goal function. Rapidly converging	Collapses in attaining global maximum. Complex computing

Table 2. Comparative table of surveyed literature

Ref	Technique	Year	Observed	Merits
[51]	PSO	2015	Partial Shading	High efficiency
[52]	PSO and P&O	2015	Partial Shading	Rapid convergence, Decreased fluctuation, Performing better than regular PSO
[46]	PSO and INC	2017	Partial Shading	Inexpensive implementation High efficiency
[53]	Enhanced PSO	2017	Partial Shading	Speedier than traditional PSO Performing well over PSO and P&O
[54]	Hill Climbing PSO	2018	Partial Shading	Decreased exploration space Reduced algorithm complexity Increased performance
[55]	DE	2010	Partial Shading	Rapid response Precise outcomes
[56]	DE	2012	Partial Shading	Precise outcomes Rapid convergence Removes fluctuations for tracked MPP
[57]	Improved DE	2018	Partial Shading	Efficiency more than99% Rapid response
[58]	ACO	2013	Partial Shading	Inexpensive Basic design Effectively detects global MPP
[22]	ACO	2016	Partial Shading	Performing well over traditional MPPT methods
[59]	Enhanced ACO dependent P&O	2016	Partial Shading	Convergence increased both statically and dynamically
[60]	ACO- New Pheromone	2017	Partial Shading	Decreased computing time
[61]	ABC	2015	Partial Shading	Less control settings are required. The starting state of the system has no bearing on convergence. GMPP has a better tracking system than PSO.
[35]	ABC	2015	Partial Shading	Faster tracking of GMPP Reduced output power oscillation Energy saving improves Increased revenue generation
[36]	Modified ABC	2015	Partial Shading	The power loss limitation is optimised. Shade effects are reduced.
[42]	BFOA to tune PI	2016	Partial Shading	Reduced harmonics Meets the load demand Robust system
[44]	BPSO Fuzzy P&O	2017	Partial Shading	More effective than traditional methods System performance has improved.

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The merits and demerits of some basic meta-heuristic algorithms are tabulated in Table 1 and merits of those algorithm implementations are described in Table 2. The application of biologically motivated to control PV systems for maximum power are studied. Studied methods may be enhanced by restricting the exploration landscape, restricting optimizing variables and choosing appropriate controlling variables. Further, the proposing algorithms must improve converging speed and determine the fittest value.

Conclusions

In this paper, traditional, evolutionary and swarm-based algorithms were studied and discussed. The reviewed methodology and algorithms are quite capable to acquire global maximum power indeed in speedily changing climatic conditions and too under partial shading. The mode of functioning of mentioned algorithms changes in addition to their functional parameter’s selection. Also discussed many review papers about the combination of algorithms and their application of those for implementing MPPT. The hybridization technique increases the performance on comparison with regular stand-alone versions. Every algorithm has its own pros and cons, which are reviewed to acquire a brief idea concerning in selection of algorithm for MPPT under shaded partial PV systems. The practical use of discussed algorithms continues to be more complex because of their performance, reliability, implementation cost, coding style and so on. With the appearance of modern processors and simulation supportive hardware has produced effective design process. Considering the importance of MPPT under partial shading conditions of PV systems, there is a possibility of research in broader spectrum for developing novel effective MPPT methods. This paper outlined important global exploration algorithms that can capture attention among the scholars to revise the reviewed algorithms or suggest a novel algorithm.

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