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A Review on Optimization Algorithms for MPPT in Solar PV System under Partially Shaded Conditions

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Abstract: *The Photovoltaic (PV) power has rapid growth due to its clean, no noise and less maintenance. However, all PV systems have two major drawbacks, viz., the efficiency of PV power generation is very low and the output power of a PV system is nonlinear, which depends on weather conditions, such as ambient temperature and the solar irradiance. So, Maximum Power Point Tracking (MPPT) methods have been proposed for PV systems, such as constant voltage tracking (CVT) method, perturbation and observation (P&O) method, Incremental Conductance (INC) method, curve-fitting method, look-up table method, and so on. Under Partial Shaded Conditions (PSC) the Photovoltaic Generation System (PGS) may receive less intensity of sun light due to clouds, shadows of objects, which producing multiple peaks and making conventional methods to fail MPPT as they reach local MPP under PSC .Hence, biologically inspired algorithms like Ant Colony, Particle Swarm Optimization (PSO), Firefly, etc., are being introduced which are fast and effective in converging to global MPPT. This paper is to give a review on advancements on MPPT in solar PV systems to critically discuss the improvement of PGS efficiency*

Keywords: *Maximum Power Point Tracking (MPPT), Photovoltaic Generation System (PGS),Photovoltaic (PV), Partial Shaded Conditions (PSC), Particle Swarm Optimization (PSO).)*

I. Introduction

During the past few years, the production of electrical energy is largely increased through conventional energy sources. Due to ever increasing demands for electrical energy and increased dependence on fossil fuels, the cost of unit power become high and also has adverse effects on environment. In order to overcome these problems, non-conventional energy sources are being used which help in decreasing carbon emissions, exhaustion and soaring prices of fossil fuels. The PV power generation has shown a significant potential in fulfilling the world’s energy demand. The advantages of PGS include absence of fuel cost, low maintenance requirement, and environmental friendliness. Due to these environmental and economic benefits, PV systems are being widely deployed as distributed energy resources in distribution generation systems and micro grids.

However, the implementation and integration of PV systems still remains a great challenge due to very high investment cost. Furthermore, there is no guarantee that the energy produced from PV array keeps constant, because it depends entirely on the solar irradiance and ambient temperature. Second, the energy produced by the sun is restricted by the low conversion efficiency of PV module. So it is essential to make use of most of available solar energy. As solar insolation and panel temperature vary with time, it is necessary to develop a MPPT algorithm to extract maximum power from PV system at real time. The main objective is to extract maximum power generated by the PV systems under varying condition of temperature and solar insolation. PV modules are generally interconnected in series and parallel to create a system with the desired voltage and loading current capacity respectively. PSC is sometimes inevitable because some parts of the module or the PGS may receive less intensity of sunlight due to clouds or shadows of trees, buildings, and other neighboring objects. The PSC can have significant impact on the power output of PGS, depending on the system configuration, shading pattern, and the bypass diodes incorporated in the PV modules. Under PSC, PV modules belonging to the same string experience different insolation, resulting P-V characteristics more complex and exhibits multiple peaks [1]. Many methods have been proposed for MPPT like the Perturb and Observation (P&O), the Hill Climbing (H&C), the incremental conductance algorithm, Ripple Correlation Control (RCC), etc., performs well at high solar irradiance but the tracking efficiency drops at low sun irradiance.

In recent years, further research on PV MPPT has been conducted and the effect of partial shading condition has been taken in to account and have found that conventional methods show very poor tracking performance. Many of them are not even able to track the true MPP under partially shaded PV array. Due to the inefficiency of these methods, several stochastic-based algorithms and artificial intelligence techniques have been developed, which are inspired by nature and biological structure. These include Particle swarm Optimization (PSO), Differential Evolution (DE), Genetic Algorithm (GA), Artificial Neural Network (ANN), Firefly, Fuzzy Logic Controller (FLC), etc., can find solution to extract the maximum power under partially shaded and rapidly varying atmospheric condition.

This paper explains briefly about the characteristics of PV cell models including under PSC followed by explanation of the MPPT techniques. These techniques are divided in to conventional methods for uniform solar irradiance, stochastic-based and artificial intelligence techniques. Finally, comparison among all the techniques is done and conclusions are drawn.

II. PV cell modeling and Characteristics

The PV cell is made up of semiconductor materials which convert solar irradiance into electrical energy. Based on electronics theory of semiconductor p-n junction, it can be described by a current source. The circuit model of PV cell [2] is shown in Fig. 1.

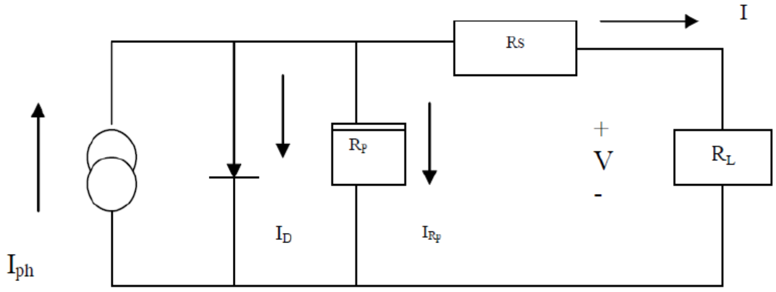

Fig. 1: Equivalent circuit model of PV cell.

I_{ph} is the PV generated current which is relative to the solar radiation and temperature. The stronger the irradiance is, the greater the I_{ph} will be. The output is described as

$$I = I_{ph} - I_0\left[\exp\left(\frac{V + I.R_S}{V_T}\right) - 1\right] - \left[\frac{V + I.R_S}{R_p}\right] \quad \text{……………………………………… (1)}$$

Where, I_{ph} is the Insolation current
I is the Cell current
I_o is the Reverse saturation current
V is the Cell voltage
R_S is the Series resistance
R_p is the Parallel resistance
V_T is the Thermal voltage $\left(\frac{KT}{q}\right)$
K is the Boltzmann constant
T is the cell temperature in Kelvin
q is the Charge of an electron

The PV mathematical model used to simplify our PV array is represented by the equation:

$$I = n_p I_{ph} - n_p I_o\left[\exp\left(\frac{q}{KTA} \times \frac{V}{n_s}\right) - 1\right] \quad \text{…………………………………………………. (2)}$$

Where, I is the PV array output current
V is the PV array output voltage
n_s is the number of cells connected in series
n_p is the number of cells connected in parallel
A is the p-n junction ideality factor
I_o is the cell reverse saturation current.

The factor ‘A’ determines the cell deviation from the ideal p-n junction characteristics; it ranges from 1 to 5. The cell reverse saturation current I_o varies with temperature according to the following equation:

$$I_o = I_{rr}\left[\frac{T}{T_r}\right]^3 \exp\left(\frac{qE_G}{KA}\left[\frac{1}{T_r} - \frac{1}{T}\right]\right) \quad \text{……………………………………………………. (3)}$$

Where,

T_r is the cell reference temperature

Irr is the cell reverse saturation temperature at T_r

E_G is the band gap of the semiconductor used in the cell

The temperature dependence of the energy gap of the semiconductor is given by:

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

The photo current I_{ph} depends on the solar radiation and cell temperature as follows:

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

Where,

I_{scr} is the cell short-circuit current at reference temperature and radiation

K_i is the short circuit current temperature coefficient

S is the solar radiation in mW/cm^2

The PV power can be calculated using equation given below:

$$P = VI = n_p I_{ph} V\left[\left(\frac{q}{KTA} \times \frac{V}{n_s}\right) - 1\right] \quad \ldots (6)$$

1.1 PV array characteristics:

Generally V-I characteristics of a PV array are non-linear so it is difficult to track the MPPT. Fig.2 shows V-I characteristics and fig.3 show characteristics of P-V under fixed irradiation and temperature conditions.

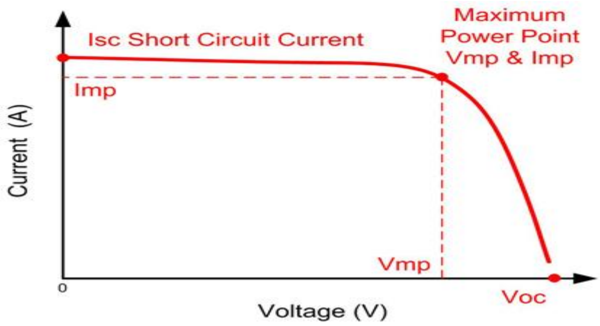

Fig. 2. V-I characteristics

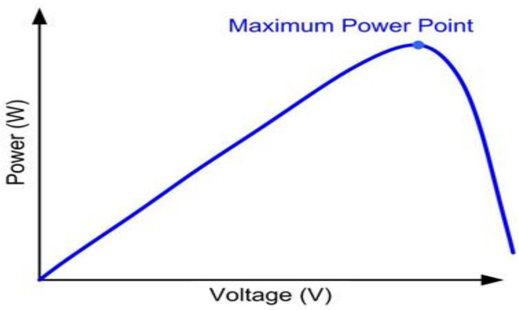

Fig. 3: V-P characteristics

2.2 Partially Shaded Condition:

In large PV systems, partial shaded conditions (PSC) occur wherein PV modules receive different solar insolation due to shadow of buildings, moving clouds, and other neighboring objects like trees. Non-uniform irradiation produces the hotspot problem, i.e., effect of a potential difference between the PV strings. The hotspot problem can occur in a PV array, where a single PV module in an array which is in series is less illuminated, and dissipate some of the power generated by the rest of the modules. To protect the PV modules from this problem, the bypass diodes are connected in parallel with each PV module as shown in Fig. 4. The output power of the PV array decreases largely due to PSC and the quantum of power lost depend on system configuration, shading pattern and the bypass diodes incorporated in the PV modules [1]. The immediate effect of PSC is that the resulting PV characteristic curve becomes complex with multiple peaks as depicted in Fig. 5.

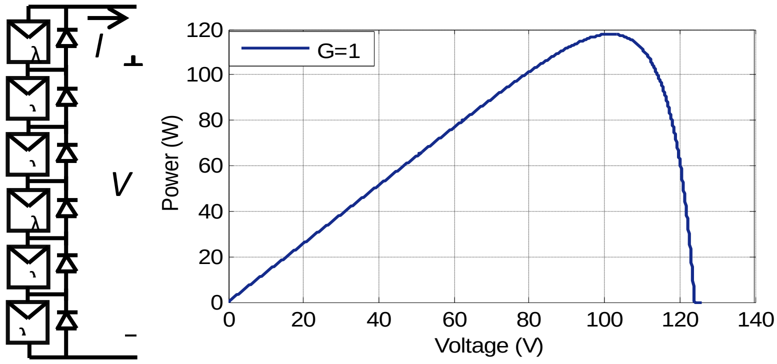

Fig. 4. V-P curve under uniform insolation

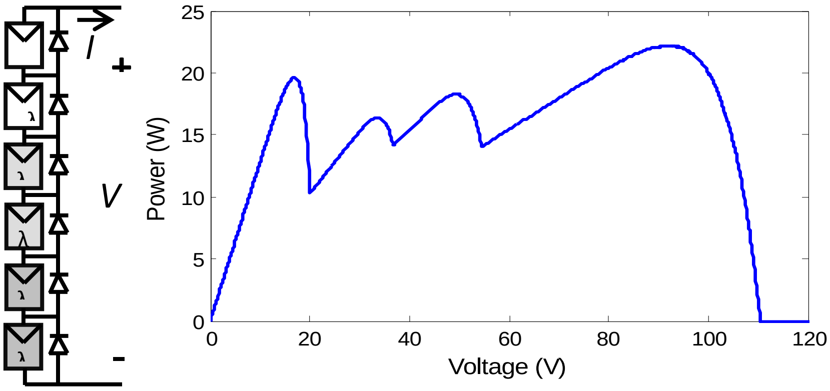

Fig. 5. V-P curve under partial shaded condition

It is seen from the P-V characteristics shown in Fig. 4, that the presence of the diodes allows the unshaded modules to conduct their maximum power at a given irradiation and temperature. On the other hand, if the bypass diodes are not present, the shaded modules will limit the current output of the unshaded modules. This may not only lead to a thermal destruction of the PV modules, but may also decrease the available output power from the PV array. The blocking diodes will prevent the reverse current. This reverse current may cause excessive heat generation and thermal breakdown of the PV modules.

II. Mppt Techniques

2.1 conventional methods:

Both P&O and Incremental Conductance (INC) methods are based on the "hill-climbing" principle, which consists of moving the operation point of the PV array in the direction in which power increases. Hill-climbing techniques are the most popular MPPT methods due to their ease of implementation and good performance when the irradiation is constant [3]. The advantages of both methods are the simplicity and low computational power they need. The shortcomings are also well-known: oscillations around the MPP and they can get lost and track the MPP in the wrong direction during rapidly changing atmospheric conditions.

The P&O and the INC algorithms are the most common methods which are in use. These techniques have the advantage of an easy implementation but they also have drawbacks, as will be shown later. Other techniques based on different principles are fuzzy control, neural circuit, fractional open circuit voltage or short circuit current, current sweep, etc. Most of these methods yield a local maximum and some methods like the fractional open circuit voltage or short circuit current; give an approximated MPP not the exact one. In normal conditions the V-P curve has only one maximum, so it is not a problem. While, if the PV array is partially shaded, there are multiple maxima in these curves. According to order to relieve this problem, some algorithms have been implemented. These techniques differ in many aspects such as required sensors, cost, complexity, convergence speed range of effectiveness, correct tracking when irradiation and/or change in temperature, hardware needed for the implementation or popularity.

2.1.1 Perturb and observe:

In P&O method, the MPPT algorithm is based on the calculation of the PV output power and the power change by sampling both the PV array current and voltage [4]. The tracker operates by periodically incrementing or decrementing the solar array voltage. If a given perturbation leads to an increase in the output power of the PV, then the subsequent perturbation is generated in the same direction and vice versa [5]. The duty cycle of the DC chopper is varied and the process is repeated until the maximum power point has been reached. Actually, the system oscillates about the MPP. Reducing the perturbation step size can minimize the oscillation. However, small step size slows down the MPPT. For different values of irradiance and cell temperatures, the PV array would exhibit different characteristic curves. Each curve has its MPP, where the corresponding maximum voltage is supplied to the converter [6].

2.1.2 Incremental conductance:

The purpose of the Incremental Conductance method offers good performance under rapidly changing atmospheric conditions. The basic equations of this method are given below [7]:

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

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

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

Where I and V are PV array output current and voltage respectively, the left hand side of equations represents Incremental conductance of PV module and the right hand side represents the instantaneous conductance. It is obvious that when the ratio of change in the output conductance is equal to the negative output conductance, solar array will operate at the maximum power point. By comparing the conductance at each sampling time, the MPPT will track the maximum power of the PV module. In both P&O and INC schemes, how fast the MPP is reached depends on the size of the increment of the reference voltage.

The drawbacks of these techniques are mainly two. The first and main one is that they can easily lose track of the MPP if the irradiation changes rapidly [8]. In case of step changes they track the MPP very well, because the change is instantaneous and the curve does not keep on changing. However, when the irradiation changes following a slope, the curve in which the algorithms are based changes continuously with the irradiation. So, the changes in the voltage and current are due to the perturbation of the voltage. As a consequence it is not possible to determine whether the change in the power is due to its own voltage increment or due to the change in the irradiation. The second is oscillations of the voltage and current around the MPP in the steady state. This is due to the fact that the control is discrete so the voltage and current are not constant at the MPP but oscillating around it. The size of the oscillations depends on the size of the rate of change of the reference voltage. The greater it is, the higher is the amplitude of the oscillations.

2.1.3 Fractional open circuit voltage:

This method uses the linear relationship between the MPP voltage and the open circuit voltage, which varies with the irradiance and temperature [3 - 4].

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

Where k_1 is a constant depending on the characteristics of the PV array and it has to be determined before by determining the V_{MPP} and V_{oc} for different levels of irradiation and different temperatures. The constant k_1 has been reported to be between 0.71 and 0.78.

Once the constant of proportionality, k_1, is known, the MPP voltage V_{MPP} can be determined periodically by measuring V_{oc}. To measure V_{oc} the power converter has to be shut down momentarily. So, in each measurement a loss of power occurs. Another problem of this method is that it is incapable of tracking the MPP under irradiation slopes, because the determination of V_{MPP} is not continuous. One more disadvantage is that the MPP reached is not the real one because the relationship is only an approximation.

2.1.4 Fractional open circuit voltage:

In the fractional short circuit voltage method [3 - 4], there is a relationship between the short circuit current I_{sc} and the MPP current I_{MPP} under varying atmospheric conditions as is shown in equation

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

The coefficient of proportionality k_2 has to be determined according to each PV array, as in the previous method happened with k_1. The constant k_2 is generally found lying between 0.78 and 0.92.

Measuring the short circuit current while the system is operating is a problem. It usually requires adding an additional switch to the power converter to periodically short the PV array and measure I_{sc} by shorting the PV array with an additional field-effect transistor added between the PV array and the DC link capacitor.

2.2 Artificial intelligent techniques:

2.2.1 Genetic algorithm:

The genetic algorithms are a family of computational models inspired by evolution. They are parallel global probabilistic search techniques based on the principle of population genetics. These algorithms encode a potential solution to a specific problem on a single chromosome and apply recombination operators to them so as to preserve critical information

The PID controller genetic algorithm is used for MPPT in solar PV system [9] where the parametersK_p,K_i and K_d are encoded into binary strings known as chromosomes. The length of the strings is set to 48 and the selection is applies on a population of chromosomes to form a mating pool. The crossover operator is applied next to produce new chromosomes. The fitness of each chromosome is evaluated by converting its binary string into a real value which represents PID gains. Each set of PID parameters is passed to PID controller in order to compute a complete response of the system.

This process will go through GA steps sequentially and repeat until the end of generations reached where the best fitness is achieved and optimal PID parameters found.

2.2.2 Artificial Neural Network:

A multi-layer feed-forward neural network (MFFNN) will be used to track the MPP. The network consists of three layers: input layer, hidden layer and output layer [11]. The number of neurons in hidden layer will be determined by trial and error. The input variables can be PV array parameters like V_{OC} and I_{SC}, atmospheric data like irradiance and temperature, or any combination of these. The output is usually one or several reference signals like a duty cycle signal used to drive the power converter to operate at or close to the MPP.

2.2.3 Fuzzy Logic Controller:

The Fuzzy logic controller uses the fuzzy logics to make the decisions and to control the output of the controller. The main components in fuzzy logic based MPPT controller are fuzzification, rule-base, inference and defuzzification. There are two inputs to the controller – error e(k) and change in error Δe(k) [12] . The Fuzzification block converts the crisp inputs to fuzzy inputs. The rules are formed in rule base and are applied in inference block. The defuzzification converts the fuzzy output to the crisp output. The fuzzy inference is carried out by using Mamdani's method, and the defuzzification uses the centre of gravity to compute the output of this FLC which is the change in duty cycle.

2.2.4 Differential evolution (DE):

DE can be used to obtain the solution for practical problems which have non-differentiable, non-continuous, nonlinear, noisy, flat, and multi-dimensional or have many local minima, constraints, or stochasticity [11]. DE is easy to be implemented as it only requires a few parameters in the algorithm. Basically, a population of particles is required in DE and a few iterations are needed in order to generate the final solution. The differences in the particles are used to mutate each other in every iteration.

The process starts with initialization of initial population of target vectors within the boundary constraints. The population vector of this system could be the reference voltage or current or duty cycle.

$$P^G = x_i^G = d_i^G \vee I_{pv_i^G} \vee V_{pv_i^G} = [x_1, x_2, \ldots. x_i] \qquad (12)$$

i = 1, 2, ……….. NP

Next the fitness of all individual vectors in the population is assessed by measuring the current and voltage of PV arrays to see its response on the array power since the output of the array power is normally used as the fitness values in MPPT application.

$$Fit = f(pop_i) \qquad (13)$$

After all the fitness of each individual vector will be evaluated by eqn (7), the process of mutation and crossover will be performed. For every target vector x_i^Gin the population, its respective mutant vector is generated by employing one of mutation strategies. Next the crossover operation is carried out to create a trial vector u_i^{G+1}. In the end, the selection process is done by one to one competition of individual fitness values for each target and trial vector in the population. A vector with better or same fitness value will be in the next population for the next generation or iteration. The process is repeated until real MPP is achieved or a termination criterion is met.

2.3 Biologically inspired algorithms:

2.3.1 Ant colony optimization algorithm:

Ant colony MPPT is implemented by making most out of the ant's behaviour .The process starts with randomly initializing the ants. The objective function is framed by including each panel's exposure to irradiation and temperature. The pheromone concentration is given by the formula:

$$T_{ij} = \rho T_{ij}(t-1) + \Delta T_{ij} \; ; \qquad t = 1,2,3 \ldots . T \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (14)$$

Where

T_{ij} - Revised concentration of pheromone

ΔT_{ij} - Change in Pheromone concentration

ρ - Pheromone concentration rate (0-1)

The pheromone rate 'ρ' plays a crucial role as absurd values. Concentration rate would wrongly direct the convergence to happen at local maximum.

2.3.2 Cuckoo search (CS):

CS is an optimization algorithm, inspired by the parasitic reproduction strategy of cuckoo birds. It is observed that several species of cuckoos perform brood parasitism, i.e. by laying their eggs in other birds' (host birds) nests. Usually three types of brood parasitism are seen (1) intra specific, (2) cooperative and (3) nest takeover. Some cuckoo species such as Tapera are intelligent enough to mimic the shape and colour of the host bird to increases its reproduction probability.

Three idealized rules for CS based on cuckoo's brood parasitic behaviour:
(1) Each cuckoo lays one egg at a time and places it in a randomly chosen nest,
(2) The best nest with the highest quality of eggs will carry over to the next generation
(3) The number of available nests is fixed and the number of eggs (laid by a cuckoo) discovered by the host bird maintains a probabilityP_a, where 0 <P< 1. If the cuckoo's eggs are discovered, the host bird can abandon its nest or destroy cuckoos' eggs. Either way a new nest will be generated with a probability of Pa for a fixed number of nests. Based on these three rules, the CS algorithm can be summarized in a pseudo code.

To use CS for designing MPPT, appropriate variables have to be selected for the search. Voltage, current, power, number of samples and the value of β are initialized. Using the present value of voltage and current, the power is calculated. The new value of voltage and power are stored in the voltage V_i^t and fitness j_i^t arrays, respectively. Furthermore, before the start of every iteration, a check is performed to determine if the samples have already achieved convergence or otherwise. If the samples have converged to MPP, they will merge as a same value and so does the respective power. If the samples do not converge, all the power values of the corresponding samples are measured and are stored in the j_i^t array. By evaluating the array, the sample with highest power is chosen as the best sample. Thereafter, all other samples are forced to go towards this best value. The step sizes are calculated by performing the Levy flight. Consequently, a new set of samples are found. Afterwards the corresponding powers of these new samples are measured from the PV panel. On the other hand, if any samples results in a lesser power, then that particular sample is discarded and a new sample is generated. This iteration continues until all the samples converge to the optimum point, i.e., MPP.

2.3.3 Firefly algorithm (FA):

Firefly algorithm is a new meta heuristic algorithm inspired by a flashing of fireflies, for optimization problems. In this algorithm, randomly generated solutions will be considered as fireflies [12]. Brightness is assigned depending on their performance on the objective function. One important rule of this algorithm is all fireflies are unisex. It means that regardless of sex, any firefly can be attracted to any other brighter one. Second rule is that flashing light (brightness) is determined from the objective function. Light intensity at a particular distance 'r' from light source obeys inverse square law. Attractiveness is directly proportional to brightness and it decreases with distance.

Firefly algorithm is superior to other methods in terms of tracking speed, convergence to track global MPP and possesses good tracking efficiency. The efficiency can be calculated by taking the ratio between output power and maximum power of the PV array under steady state conditions. The advantages of these methods are simple computational steps, faster convergence and implemented in low cost microcontroller.

Application of Firefly algorithm to MPPT:

STEP 1: Parameter Setting: Fix the constants of the FA, namely, βo, γ, n, α, population size N, and the termination criterion. In this algorithm, the position of the firefly is taken as a duty cycle d of the dc–dc converter.

The brightness of each firefly is taken as generated power P_{pv} of the PV system, corresponding to the position of this firefly.
STEP 2: Initialization Of Fireflies: In this step, the fireflies are positioned in the allowable solution space between dmin to dmax, where dmin and dmax represent the minimum and maximum values of the duty ratio of the dc–dc converter. Thus, position of each firefly represents the duty ratio of the dc–dc converter. It may be noted that increased number of fireflies results in higher computing time while, a lesser number of fireflies will result in a local maximum.
STEP 3: Brightness Evaluation: In this step, the dc–dc converter is operated corresponding to the position of each firefly (i.e., duty ratio) sequentially. For each duty ratio, the corresponding PV output power is taken as the brightness or light intensity of the respective firefly. This step is repeated for position of all fireflies in the population.
STEP 4: Update The Position of Fireflies: The firefly with maximum brightness remains in its position and the remaining fireflies update their position.
STEP 5: Terminate the program if the termination criterion is reached; else go to step 3. The optimization algorithm is terminated once the displacement of all fireflies in consecutive steps reaches a set minimum value. Once the program is terminated, the dc–dc converter operates at the optimum duty cycle corresponding to GMPP.
STEP 6**:** Reinitiate the FA if the solar insolation changes, which is detected by the digital controller by sensing the change in the power output.

2.3.4 Particle swarm optimization (PSO):

PSO is a stochastic search method, modelled after the behaviour of bird flocks. The PSO algorithm maintains a swarm of individuals called particles, where each particle represents a candidate solution [14]. Particles follow a simple behaviour: emulate the success of neighbouring particles and its own achieved successes. The position of a particle is influenced by the best particle in a neighbourhood P_{best} as well as the best solution found by all the particles in the entire population G_{best} [15].

The PSO algorithm is applied to realize the MPPT control of a PV system, where in the P-V characteristics exhibits multiple local MPP. When two PV modules are connected in series and one of them is partially shaded, the shaded module's terminal voltage is different from that of the unshaded module. The PV array contains N number of modules. So, each individual module voltage must be controlled.
Algorithm [16]:
Step 1- Set the number of particles and searching parameters along with the limit for position and velocity
Step 2- Randomly initialize Position and velocity of each particle.
Step 3- Compute the fitness value of each particle.
Step 4- The particle having the best fitness value is set asG_{best} .
Step 5- Update the position and velocity of each particle with respect to the G_{best}.
Step 6- Repeat Step 3 & 4 till the optimum solution is reached.
Step 7- G_{best} at the end of the last iteration gives the optimized value.
Step 8- Compute the Duty-cycle

III. Comparison and Discussion

The competence of conventional MPPT techniques (i.e., P&O, Incremental Conductance and short circuit current method etc.,) have been known over 99% under unvarying solar irradiance condition [17]. However, the usefulness of conventional MPPT techniques might be lessened under PSC due to the multiple local maxima. The tracking disappointment of conventional MPPTs under PSC can be shown in the Fig. 6. The operating point is moved to "point B". In this case, the real MPP is to be found on "point C". Nevertheless, because of the conventional methods the operating point changes due to predetermined voltage reference step (ΔV), the operating point is oscillated on vicinity of "point B". At the same time, the difference in power capacity between P_C and P_B is lost due to this MPPT failure. To prevent this power loss, MPPT methods have to move the operating point to "point C".

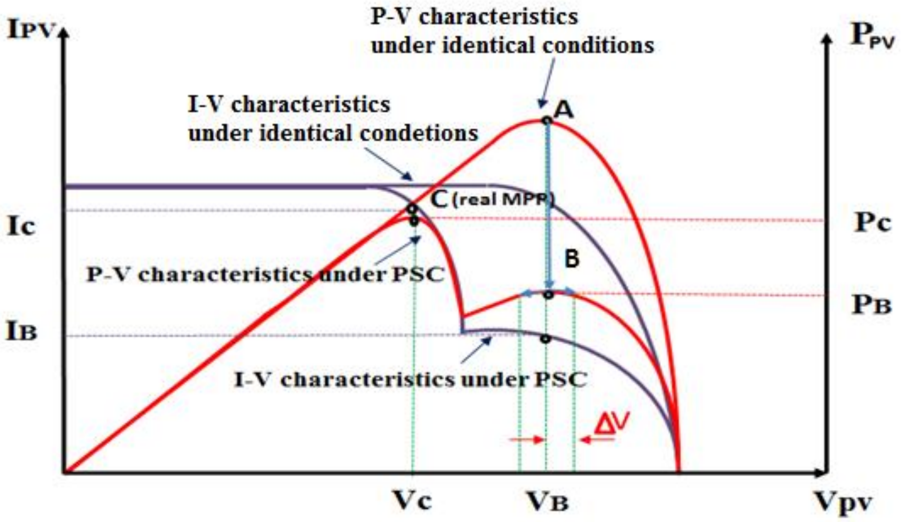

Fig. 6. P-V and V-I characteristics of PV cell under shaded and unshade conditions

The drawbacks of the conventional methods can be overcome with biologically inspired algorithms like PSO and FA etc., as they converge to MPP under PSC very effectively
Comparison among conventional, artificial intelligence and biologically inspired methods with respect to different parameters like speed of convergence, accuracy, complexity etc, is shown [18] in table 1.

Table 1: Qualitative comparison between the methods

Type	**Biologically inspired methods**	**Artificial intelligence methods**	**Conventional methods**
Tracking Speed	Fast	Medium	Slow
Tracking Accuracy	Accurate	Accurate	Low
Implementation complexity	Medium	Low	Low
Dynamic response	Good	Oscillatory	Oscillatory
Periodic tuning	Not Required	Not Required	Not Required
Steady State Oscillations	Zero	Zero	Zero

IV. Conclusion

In this paper, a general presentation of the photovoltaic cell characteristics and various MPPT techniques has been discussed. Some comparisons are made, which give an indication on the MPPT response time to a solar irradiance step. The performance of biologically inspired algorithms under PSC's is effective compare to conventional and artificial intelligent techniques. Finally, among the compared MPPT Methods, PSO and FA seems to be more accurate, fast and stable.

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