# Artificial Bee Colony Integrated P&O Algorithm for Single Phase Grid Connected Photovoltaic Application

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*Abstract:* - Energy harvesting is an emerging field in power electronic industry. Extracting energy from the environment, especially from non conventional energy sources has becoming highly demanded nowadays. From this point of view, solar energy plays a most promising role as a non conventional energy source. In this paper, a small scale grid connected solar power generation system with a maximum capacity of 1KW power output with a single phase AC has been considered for study. For the improved system performance, an Artificial Bee Colony integrated Perturb & Observe (ABC-PO) algorithm is used to track the Maximum Power Point (MPP) of solar panels. ABC-PO is capable of tracking Global Maximum Power Peak (GMPP) even under Partial Shading Condition (PSC). A DC-DC boost converter followed by a single stage H-bridge inverter along with LC filter is utilized to feed an RMS voltage of 230V to the grid. The simulation results clearly show the tracking of true MPP under varying irradiance conditions and 230Vrms at the grid side.

*Key-Words:* - Artificial Bee Colony (ABC) Algorithm, Grid connected systems, Maximum Power Point Tracking (MPPT), Partial Shading Condition (PSC), Perturb and Observe (P&O) algorithm, Solar PV systems.

# **1** Introduction

The production of electricity with least pollution is becoming more and more important when considering the environmental hazards. In the recent years the Building Integrated Photovoltaic technology (BIPV) is gaining popularity among the developing countries due to the latest improvements in Photovoltaic (PV) technologies such as enhanced structural incorporation to buildings, cost reduction, and efficiency improvements. Moreover, in the power systems and distribution sectors the demand for PV power generation is drastically increasing.

There are many filed of engineering where solar energy is utilized as primary source of energy. Charging batteries using solar power and application of solar energy in domestic use are increasing day by day. Nowadays, research is more attracting towards the grid connected PV systems. In the case of a PV system, the DC power generated by the PV panel is converted into ac power using a Voltage Source Inverter (VSI). In order to meet the minimum voltage requirement, PV panels are connected in series, because a single PV panel can offer only a small amount of voltage [1].

The efficiency of a solar panel depends on various factors such as irradiance, temperature, shadow, dirt etc. Moreover, the climatic changes and variation in ambient temperature will reduce PV arrays output power [2]. In order to increase the efficiency of a PV panel, several Maximum Power Point Tracking (MPPT) methods are developed by many researchers in worldwide. Various conventional MPPT techniques includes Perturb and Observe (P&O) [3] [4], Incremental conductance (INC) [5][6], open circuit voltage [7], fractional short circuit current [8], fuzzy logic control [9] and so on. The non-linear characteristics of PV system causes multiple maximum power peaks (MPP) in the power-voltage (P-V) and current-voltage (I-V) curves under varying irradiance and temperature conditions [10]. Conventional MPPT techniques sometimes fail to track true MPP under such conditions. Recently many biological optimization techniques are developed by experts in this field in order to track the global MPP

(GMPP). Ant Colony Optimization (ACO) [11], Artificial Bee Colony algorithm (ABC) [12], Artificial Fish Swarm Algorithm (AFSA) [13], Grey Wolf Optimization (GWO) [14], Whale Optimization Algorithm (WOA) [15], Dragonfly Algorithm (DA) [16] etc are some of the recently developed optimization algorithms used under partial shading conditions (PSC).

In this paper, the advantages of the simplest conventional MPPT technique, ie, P&O, and the honey bee inspired ABC algorithms are integrated together and developed a new MPPT algorithm called ABC-PO to track the GMPP under PSC. Among the many local MPPs in the P-V curve, GMPP is located by ABC in the first step followed by local optimum power peak is tracked by P&O in the next step. This paper is organized as follows. Section 2 describes the general block diagram of the proposed PV system. The newly developed ABC-PO MPPT algorithm is described in section 3. The section 4 is dedicated for mathematical modeling of the PV system under PSC. Simulation results and conclusion are given in section 5 and section 6 respectively.

# 2 Block Diagram Description of the

### proposed system

Fig. 1 shows the block diagram of the grid connected PV system used in the present study. The current and voltage from the PV array is given as the input to the MPPT controller as well as to the DC-DC boost converter. With the help of MPPT controller duty cycle of the boost converter is adjusted so as to match the load and source impedance to get maximum power from the PV array. Here ABC-PO is used as the MPPT algorithm for the controller to track the optimum duty cycle even under PSC. The boost converter is designed such that to produce a constant voltage of 335V.

The regulated 335V dc voltage from the boost converter is given to a single phase DC-AC inverter, where, it produces a 335V square wave. The dc contents of the inverter output waveforms are removed using an LC filter and produces a 230Vrms, 50Hz pure sine wave which is fed to the utility grid.

### **3** ABC-PO algorithm

Flowchart of the proposed ABC-PO algorithm is given in Fig.2. The first section is the general ABC algorithm for tracking GMPP. The different steps involved in ABC algorithm are as follows.

- a) Initialization phase
- b) Evaluation phase
- c) Employed bee phase
- d) Onlooker bee phase
- e) Finishing phase

Initialization phase : Let the size of the colony be 's'. One half of the colony is termed as employed bees  $(N_p)$  and the other half is termed as onlooker bees. Different food source positions are chosen by the employed bees using the following formula.

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

where  $d_{min}$  and  $d_{max}$  represent minimum and maximum values of duty ratio of the DC–DC converter and i=1, 2, ..., N<sub>p</sub>. dmin and dmax is taken as 0.1 and 0.9 respectively.

b) Evaluation phase : After the initialization phase, Maximum Cycle Number (MCN) is set. For each cycle the quantity of nectar (output power) is evaluated. MATLAB/Simulink model and mcode is used to calculate the output power in each cycle. Tracking of GMPP is performed in two phases as explained below.

c) Employed bee phase: In this phase new position is updated by each employed bees using equation (2).



Fig. 1 Block diagram of the proposed grid connected PV system



Fig.2. Flowchart of ABC-PO Algorithm [16]

$$x_{i-new} = x_i + \phi_i[x_i - x_k] \qquad (2)$$

where  $k = (1,2,...,N_p)$  which is a random index and is not equal to i.  $\emptyset_i$  is an arbitrarily selected value between [-1, 1]. If the power output in the new position is more than that of the previous position, then the employed bee will remain in the new position. Otherwise employed bee shifts back to the previous position.

d) Onlooker bee phase: The value of power output present at various locations is conveyed by the employed bees to the onlooker bees. The location with maximum power is determined by comparing the probability factor associated with various locations. The probability is calculated with the help of Eq. (3).

$$p_{i} = \frac{fit_{i}}{\sum_{N=1}^{N_{p}} fit_{N}}$$
(3)

Where fit is the fitness factor of  $i_{th}$  location.

e) Finishing phase: The entire procedure stops when there is no further enhancement in the power output of the PV system or when the MCN number is met. Then the DC-DC converter operates with the acquired duty cycle.

After completing these five steps in each iteration, the algorithm is settled at GMPP. Then it checks whether there is any change in irradiance by calculating the variation in output power of PV array using the following equation.

$$\left|\frac{P_{pv} - P_{pv_old}}{P_{pv_old}}\right| \ge \Delta P_{pv}\% \tag{4}$$

If there is any change in the power output, the algorithm reinitializes to locate the present GMPP. If there is no change in the irradiance level, the ABC algorithm is switched onto P&O algorithm so as to track the LMPP. Thus the global tracking ability of ABC and local tracking ability of P&O are combined together to get fast and efficient tracking of the GMPP under varying irradiance conditions. The working principle of ABC and P&O algorithm are clearly explained in paper [17].

# 4 Mathematical modeling of PV system under partial shading conditions





The current generated by the PV system can be represented by equation (5) using the equivalent circuit of the solar cell shown in Fig. 3.

$$I_{PV} = N_P. I_{ph} - N_P. I_0 \left[ exp \left\{ \frac{q(V_{PV} + I_{PV}R_s)}{N_S.A.k.T_{op}} \right\} - 1 \right] \quad (5)$$

Where  $I_{PV}$  and  $V_{PV}$  respectively are the output current and voltage of the PV array.  $N_p$  and  $N_s$ represents the number of parallel and series connected cells respectively.  $I_o$  is the reverse saturation current,  $I_{ph}$  is the light generated photon, q is the electron charge,  $R_s$  Series resistance of PV module, A is ideality factor, k is Boltzman constant (1.38\*10<sup>-23</sup> J/K) and T is temperature in Kelvin.



Fig. 4. PV array with four series connected modules (a) all modules with uniform irradiation (b) and (c) all modules are partially shaded with unequal irradiation levels

In the case of PSC, the mathematical model in equation (5) is no longer applicable because dissimilar irradiance levels are scattered among the PV array as shown in Fig.4. For easiness, four series-connected PV modules are examined. Three shading conditions are considered for the current study. The first case is standard test condition (STC) in which all modules are getting rated uniform irradiance level  $(1000 \text{W/m}^2)$  as shown in Fig 4(a). In the second (PSC2) and third case (PSC3) all modules are getting different irradiance levels a shown Fig 4(b) and 4(c). One PV module receives rated irradiance of 1000W/m<sup>2</sup> while the other three modules are partially shaded with  $700 \text{W/m}^2$ ,  $800 \text{W/m}^2$  and  $900 \text{W/m}^2$ for PSC1. Similarly for PSC2, three modules receive  $400W/m^2$ , 680W/m<sup>2</sup>, 850W/m<sup>2</sup> respectively and one module receives rated 1000W/m<sup>2</sup>. Because of the shading effect the I-V and P-V characteristic of the PV system becomes more complex with multiple peaks as shown in Fig.5. The true MPP among these multiple MPPs is termed as global MPP (GMPP) and all other peaks are referred as local MPPs (LMPP).



Fig. 5. PV output characteristics under three different PSCs. (a) I-V characteristics (b)P-V characteristics

Consequently, a new mathematical model is essential to characterize the PV systems under PSC. Alajmi *et al.* in 2013 undertaken an extensive study on different irradiation conditions for different PV module connection [18]. The authors derived a general mathematical model of n series connected PV modules under partial shading conditions which is given in equation (6).

$$V_{PV} = \begin{cases} \sum \frac{AkTn_{s}^{us}}{q} \ln\left(\frac{I_{sc} \lambda^{un} - I_{PV}}{I_{o}}\right), & I_{PV} > I_{Nstep} \\ \vdots & \vdots \\ \sum \frac{AkTn_{s}^{us}}{q} \ln\left(\frac{I_{sc} \lambda^{un} - I_{PV}}{I_{o}}\right) + \frac{AkTn_{s}^{us1}}{q} \ln\left(\frac{I_{sc} \lambda^{s} - I_{PV}}{I_{o}}\right), & I_{1step} < I_{PV} < I_{2step} \end{cases}$$
(6)  
$$\sum \frac{AkTn_{s}^{us}}{q} \ln\left(\frac{I_{sc} \lambda - I_{PV}}{I_{o}}\right) + \frac{AkTn_{s}^{s1}}{q} \ln\left(\frac{I_{sc} \lambda^{s1} - I_{PV}}{I_{o}}\right) + \dots + \frac{AkTn_{s}^{sN}}{q} \ln\left(\frac{I_{sc} \lambda^{sN} - I_{PV}}{I_{o}}\right), & I_{PV} < I_{1step} \end{cases}$$

Where  $n_s^{us}$  is the number of unshaded PV modules and  $\lambda^{un}$  is the unshaded radiation.  $n_s^{sN}$  is the number of partially shaded PV modules with the highest radiation level and  $\lambda^{sN}$  is the highest radiation level. N is the number of distributed radiation levels. I<sub>sc</sub> is the short-circuit current of the unshaded PV modules. I<sub>1step</sub> is the short-circuit current of the shaded PV module. I<sub>2step</sub> is the short-circuit current of the shaded PV modules with the highest radiation level.

### **5** Simulation Results

The proposed system is implemented using MATLAB version 2015. Four series connected Vikram solar Eldora 270W panels are used to get 1KW power output. Specifications of the Eldora-270W module are given in Table 1.

Table 1: Specifications of Vikram Solar Eldora-270 Module

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Description	Specification	
Maximum Power (Pmax)	270.66 W	
Open circuit voltage (Voc)	44V	
Short circuit current (I <sub>SC</sub> )	8.1 A	
Maximum Power Point voltage (Vmpp)	34.7V 7.8A	
Maximum Power Point Current (Impp)		
Short Circuit Current Temperature Coefficient	0.024 % / <sup>0</sup> C	

The three different shading patterns considered for the current study is termed as STC, PSC1 and PSC2 and the corresponding  $V_{MPP}$  and GMPP values are tabulated in Table 2. Uniform irradiance at standard test condition (1000W/m<sup>2</sup> at 25°C) is termed as STC and the other 2 conditions are partially shaded patterns PSC1 and PSC2 with bypass diodes. The effect of bypass and blocking diodes on the PV characteristics under PSC is detailed in paper [19].

Table 2: Shading patterns taken for the study

Case	Shading pattern	Vmpp (V)	GMPP (W)
STC	[1000, 1000,1000,1000]	138.8	1072.5
PSC1	[700,800,900,1000]	147	828.9
PSC2	[400,680, 1000,850]	109.8	598.9

The DC-DC boost converter is designed to produce an output voltage of 335V with the help of an MPPT controller. ABC-PO algorithm is used as MPPT algorithm to track the optimum duty cycle in this work. Fig.6 shows the variation of voltage, power and duty cycle of the PV module as well as the DC-DC boost converter. From Fig. 6(a) it is clear that the V<sub>MPP</sub> values for all the three conditions are obtained. The boost converter output voltage of 334.5V is obtained as shown in Fig. 6(b). With the help of ABC-PO MPPT algorithm the GMPP value is effectively tracked instead of LMMP as in the case of conventional MPPT algorithms. This is shown in Fig. 6(c). Fig. 6(d) shows the corresponding boost converter output power. The corresponding duty cycle is shown in Fig. 6 (e).

To facilitate the advantages of ABC-PO it is executed under all the three shading conditions for a time span of 10s. Fig. 7 shows the output voltages of boost converter, inverter, LC filter and RMS voltage for all the three shading conditions named STC, PSC1 and PSC2. From 0 to 3s STC, from 3s to 6s PSC1 and from 6s to 10s PSC2 is performed. The boost converter maintains an output voltage of around 335V for all the three conditions which is shown in Fig.7(a). This is given as input to the DC-AC inverter. The inverter produces an output voltage of around 325V square wave signal as shown in Fig. 7(b).



(e) Fig. 6. Variation of PV panel and boost converter outputs (a) Panel voltage (b) Boost converter voltage (c) Panel power (d) Boost converter power (e) Duty cycle



Fig. 7. Output voltages of (a) Boost converter (b) Inverter (c) LC filter and (d) RMS voltage

An LC filter is used to filter out the dc components in the inverter output voltage. Fig. 7(c) shows a pure sine wave with amplitude of around 325V produced at the output side of the LC filter. The RMS voltage obtained is 229.4V at the grid side as shown in Fig. 7 (d).

## 6 Conclusion

An improved Artificial Bee Colony algorithm named as ABC-PO for tracking true maximum power point of a solar panel under partial shading condition is proposed in this paper for grid connected application. The main advantage of this algorithm is elimination of the convergence at local maximum power point during partial shading condition. In the proposed ABC-PO MPPT method, the conventional Perturb and Observe (P&O) MPPT and swarm intelligence based MPPT Artificial Bee Colony (ABC) is combined together to get the advantages of both algorithms. To validate the effectiveness of the ABC-PO algorithm three different shading conditions are simulated in MATLAB/SIMULINK. In all the three conditions boost converter and inverter outputs are also obtained with the designed values. Also the RMS voltage of 230V is obtained at the grid side for all the PSCs.

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