Artificial Bee Colony Algorithm Based Maximum Power Point Tracking in Photovoltaic System

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Abstract- Maximum Power Point Tracking (MPPT) is used in Photovoltaic (PV) systems to maximize its output power. A new MPPT system has been proposed for PV-DC motor pump system by designing two PI controllers. The first one is used to reach MPPT by monitoring the voltage and current of the PV array and adjusting the duty cycle of the DC/ DC converter. The second PI controller is designed for speed control of DC series motor by setting the voltage fed to the DC series motor through another DC/ DC converter. The proposed design problem of MPPT and speed controller is formulated as an optimization problem which is solved by Artificial Bee Colony (ABC) to search for optimal parameters of PI controllers. Simulation results have shown the validity of the proposed technique in delivering MPPT to DC series motor pump system under atmospheric conditions and tracking the reference speed of DC series motor. Moreover, the performance of the proposed ABC algorithm is compared with Genetic Algorithm (GA) for different disturbances to prove its robustness.

Key-Words: Photovoltaic System; Optimization Algorithm; Maximum Power Point Tracking; PI Controller; Speed Control; DC Series Motor Pump System.

1. Introduction

Most of the energy is in the form of light and heat, which can be collected and used for generating electricity. Photovoltaic (PV) cells are large-area semiconductors that convert sunlight into electricity. PV systems become a very attractive solution due to the energy crisis and environment issues such as pollution and global warming effect. Recently, PV systems have been used in even more remote applications as cost comes down such as wireless highway call boxes, and standalone power generation units. PV generation is gaining attention as a renewable source due to its advantages [1, 2] such as the absence of fuel cost, little maintenance, no noise, and wear due to the absence of moving parts, etc.

The actual energy conversion efficiency of PV module is rather low and is affected by the weather conditions and output load. So, to overcome these problems and to get the maximum possible efficiency, the design of all the elements of the PV system has to be optimized. The PV array has a highly nonlinear current-voltage characteristics varying with solar illumination and operating temperature [3-5], that substantially affects the array output power. At particular solar illumination, there is unique operating point of PV array at which its output power is maximum. Therefore, for maximum power generation and extraction efficiency, it is necessary to match the PV generator to the load such that the equilibrium operating point coincides with the maximum power point of the PV array. The Maximum Power Point Tracking (MPPT) control is therefore critical for the success of the PV systems [6 -10]. In addition, the maximum power operating point varies with insolation level and temperature. Therefore, the tracking control of the maximum power point is a complicated problem. To mitigate these problems, many tracking control strategies have been proposed such as perturb and observe [11], incremental conductance [12], parasitic capacitance [13], constant voltage [14], reactive power control [15]. These strategies have some disadvantages such as high cost, difficulty, complexity and instability. In an effort to overcome aforementioned disadvantages, several researches have used artificial intelligence approach such as Fuzzy Logic Controller (FLC) [16-19] and Artificial Neural Network (ANN) [20-29]. Although these methods are effective in dealing with the nonlinear characteristics of the current-voltage curves, they require extensive computation. For example, FLC has to deal with fuzzification, rule base storage, inference mechanism, and defuzzification operations. For ANN, the large amount of data required for training are a major source of constraint. Furthermore, as the operating conditions of the PV system vary continuously, MPPT has to respond to changes in real time.

An alternative approach is to employ Evolutionary Algorithm (EA) techniques. Due to its ability to handle nonlinear objective functions [30-31], EA is visualized to be very effective to deal with MPPT problem. Among the EA techniques, Genetic Algorithm (GA) [32], Particle Swarm Optimization (PSO) [33-37], and Bacteria Foraging (BF) [38-44] have attracted the attention in MPPT and controller design. However, these algorithms appear to be effective for the design problem, these algorithms pain from slow convergence in refined search stage, weak local search ability and algorithms may lead to possible entrapment in local minimum solutions. A relatively newer evolutionary computation algorithm, called Artificial Bee Colony (ABC) has been presented by [45] and further established recently by [46-49]. It is a very simple, robust, and population based stochastic optimization algorithm. In addition, it requires less control parameters to be tuned. Hence, it is suitable optimization tool for locating the maximum power point (MPP) regardless of atmospheric variations.

The main objective of this paper is to design two PI controllers via ABC to increase the tracking response of MPP with high efficiency and to control the speed of DC series motor which is loaded by a water pump. A comparison with GA and open loop is carried out to ensure the robustness and effectiveness of the proposed algorithm. Simulation results have proved that the proposed controller gives better performance.

2. System under Study

Figs. 1-2 show the block diagram and the Matlab/Simulink of the proposed system. The system consists of PV system, MPPT controller, DC-DC converter for MPPT, speed controller and DC/DC converter to drive the DC series motor. In the MPPT control loop, the load resistance error signal obtained by comparing the reference load resistance and its actual values is driven to the first PI controller. In the speed control loop, the speed error signal obtained by comparing the reference speed and the actual motor speed is driven to the second PI controller. The following illustrates the overall system construction.

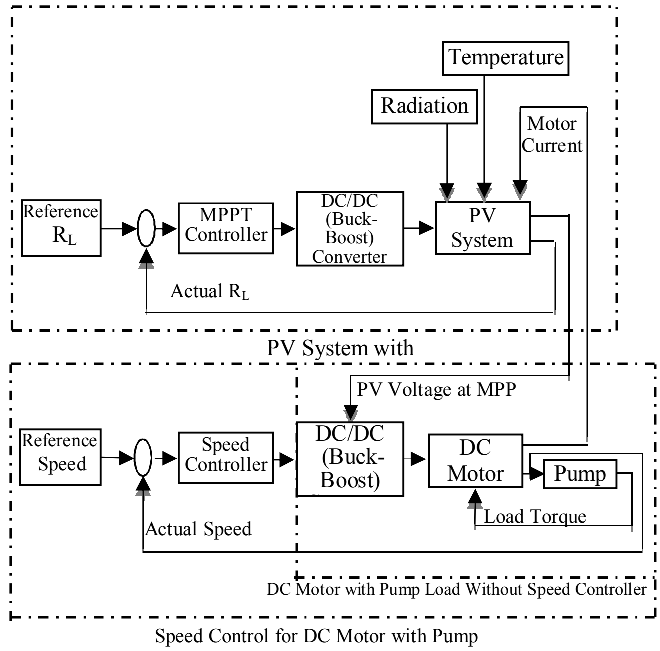

Fig. 1. Overall block diagram of DC control system supplied by PV system at MPPT.

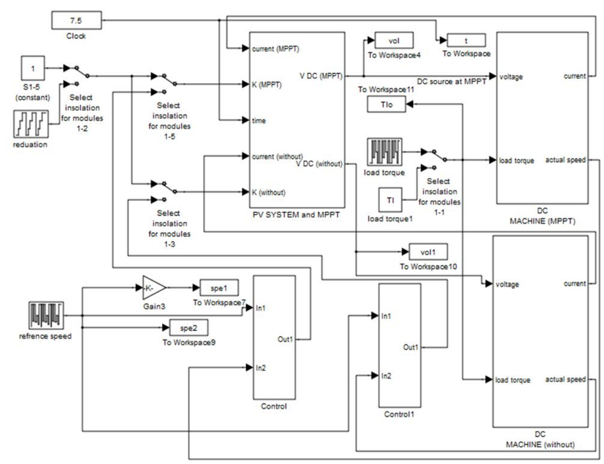

Fig. 2. Overall Matlab system of DC control system supplied by PV system at MPPT.

2.1 DC Series Motor

The DC series motor can be written in terms of equations as follows [50-51]. These nonlinear model equations can be simulated using Matlab/Simulink. The parameters of DC motors are given in appendix.

$$\frac{di_a(t)}{dt} = \frac{V_t(t)}{L_a+L_f} - \frac{R_a+R_f}{L_a+L_f} i_a(t) - \frac{M_{af}}{L_a+L_f} i_a(t)\omega_r(t) \quad (1)$$

$$\frac{d\omega_r(t)}{dt} = \frac{M_{af}}{J_m} i_a^2(t) - \frac{f}{J_m}\omega_r(t) - \frac{T_L}{J_m} \quad (2)$$

where

i_a	The armature current,
V_t	The motor terminal voltage,
R_a, L_a	The armature resistance and inductance,
R_f, L_f	The field resistance and inductance,
ω_r	The motor angular speed,
J_m	The moment of inertia,
T_L	The load torque,
f	The friction coefficient,
M_{af}	The mutual inductance between the armature and field.

2.2 Photovoltaic Generator

Solar cell mathematical modelling is an important step in the analysis and design of PV control systems. The PV mathematical model can be obtained by applying the fundamental physical laws governing the nature of the components making the system [1-4]. To overcome the variations of illumination, temperature, and load resistance, voltage controller is required to track the new modified reference voltage whenever load resistance, illumination and temperature variation occurs. I-V characteristics of solar cell are given by the following equations [1-4]:

$$I_c = I_{ph} - I_o \left\{ e^{\left[\frac{q_o}{AKT}\left(V_c + I_c R_s\right) \right]} - 1 \right\} \tag{3}$$

$$V_c = \frac{AKT}{q_o} \ln\left(\frac{I_{ph} + I_o - I_c}{I_o} \right) - I_c R_s \tag{4}$$

The module output current and voltage are given by the following equations.

$$I = I_{ph} - I_o \left\{ e^{\left[\frac{q_o}{n_s AKT}\left(V + n_s I R_s\right) \right]} - 1 \right\} \tag{5}$$

$$V = \frac{n_s AKT}{q_o} \ln\left(\frac{I_{ph} + I_o - I}{I_o} \right) - n_s I R_s \tag{6}$$

Where;

$$I_{ph} = \frac{G}{1000}\left[I_{sc} + k_i \left(T - T_r\right) \right] \tag{7}$$

$$I_o = I_{or}\left(\frac{T}{T_r}\right)^3 e^{\left[\frac{q_o E_g}{AK}\left(\frac{1}{T_r} - \frac{1}{T} \right) \right]} \tag{8}$$

The module output power can be determined simply from

$$P = V.I \tag{9}$$

where;

I , V	Module output current and voltage,
I_c , V_c	Cell output current and voltage,
I_{ph}, V_{ph}	The light generation current and voltage,
I_s	Cell reverse saturation current,
I_{sc}	The short circuit current,
I_o	The reverse saturation current,
R_s	The module series resistance,
T	Cell temperature,
K	Boltzmann's constant,
q_o	Electronic charge,
KT	(0.0017 A/◦C) short circuit current temperature coefficient,
G	Solar illumination in W/m^2 ,
E_g	Band gap energy for silicon,
A	Ideality factor,
T_r	Reference temperature,
I_{or}	Cell rating saturation current at T_r ,
n_s	Series connected solar cells,
k_i	Cell temperature coefficient.

Thus, if the module parameters such as module series resistance (R_s), reverse saturation current (I_o), and ideality factor (A) are known, the I-V characteristics of the PV module can be simulated by using equations (5 and 6). The parameters of PV system are given in appendix.

2.3 DC/DC Converter

Many converters have been used and tested; buck converter is a step down converter, while boost converter is a step up converter [52-54]. A hybrid (buck and boost) DC/DC converter is used in this paper. The equations for this converter type in continuous conduction mode are:

$$V_B = \frac{-k}{1-k} V_{ph} \tag{10}$$

$$I_B = \frac{k-1}{k} I_{ph} \tag{11}$$

where k is the duty cycle of the Pulse Width Modulation (PWM) switching signal. V_B, and I_B are the output converter voltage and current respectively.

2.4 Pump Load

The proposed controller is implemented for using the variable load torque to drive water pump system [55]. The pump load is represented as follows:

$$Tp_{de} = 0.005 + 0.00004\omega_r + 0.0001\omega_r^{1.8} \qquad (12)$$

3. Artificial Bee Colony Algorithm

Artificial Bee Colony (ABC) algorithm is discussed by Karaboga [45]. It imitates the activities and intelligent foraging behaviour of the honey bees swarms, while they are looking for the food sources and sharing the amount of sources with other bees [46].

The ABC consists of three groups of artificial bees: employed, onlooker and scouts. Every group has a different task in the optimization process. The employed bees exploit the food sources and carry the data about food source back to the hive. They share this data with onlooker bees by dancing in the designated dance area inside the hive. The nature of dance is proportional to the nectar content of food source just exploited by the dancing bee. The onlooker bees are waiting in the hive for the data and observing the dance of the employed bees within the hive, to select a food source. Therefore, good food sources attract more onlooker bees compared to bad ones. Whenever a food source is exploited fully, all the employed bees associated with it abandon the food source, and become scout. Scout bees search randomly for new food sources. Employed and onlooker bees can be seen as performing the job of exploitation, whereas scout bees can be seen as performing the job of exploration [47-48]. The flowchart of the proposed ABC algorithm is given in Fig. 3. The steps of the ABC algorithm are outlined as follows:

1. Initial food sources are generated for all employed bees.
2. Restore the next items:
   a. Each employed bee leaves to a food source and locates a neighbour source, then estimates its nectar value and dances in the hive.
   b. Each onlooker observes the dance of employed bees and chooses one of their sources depending on the dances, and then leaves to that source. After choosing a neighbour around that, the nectar value is estimated.
   c. Abandoned food sources are located and are exchanged with the new food sources found by scouts.
   d. The best food source is memorized.
3. Until (requirements are met).

The main advantage of the ABC-based algorithm is that it does not require expending more effort in tuning the control parameters, as in the case of GA [56-59], and other evolutionary algorithm. This feature marks the proposed ABC-based algorithm as being advantageous for implementation [49].

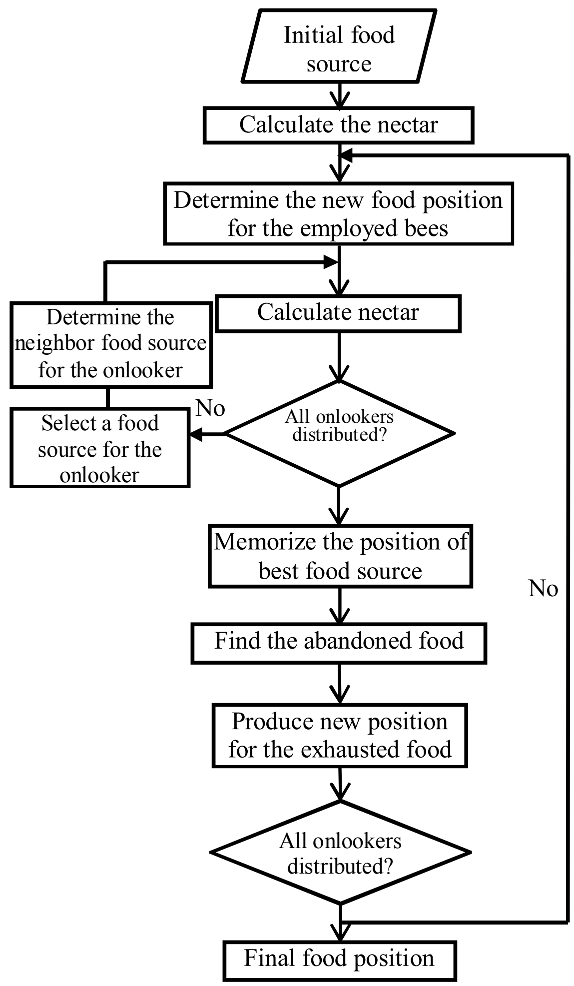

Fig. 3. Flowchart of the ABC algorithm.

4. Objective Function

A performance index can be defined by the Integral of Time multiply Absolute Error (ITAE). Accordingly, the objective function J [60-61] is set to be:

$$J = J_1 + \alpha J_2 = \int_0^{t_{sim}} t\left|e_1\right|dt + \alpha \int_0^{t_{sim}} t\left|e_2\right|dt \qquad (13)$$

where $e_1 = R_{L_{reference}} - R_{L_{actual}}$, R_L is the load resistance, α is scaling factor, $e_2 = w_{reference} - w_{actual}$ and t_{sim} is the time of simulation and equals to 5 second. Based on this objective function, optimization problem can be stated as: Minimize J subjected to:

$$K_{p1}^{\min} \le K_{P1} \le K_{p1}^{max} \;,\; K_{I1}^{\min} \le K_{I1} \le K_{I1}^{max}$$

$$K_{p2}^{\min} \le K_{P2} \le K_{p2}^{max}, K_{I2}^{\min} \le K_{I2} \le K_{I2}^{max} \qquad (14)$$

where K_{P1}, K_{I1} are the parameters of PI controller for MPPT control system, while K_{P2}, K_{I2} are the parameters of PI controller for speed control system. Ranges of the optimized parameters are [0.01- 20].

5. Results and Discussion

Different comparative cases are given in this section to show the effectiveness of the proposed ABC controller compared with GA under variations of ambient temperature and radiation. The designed parameters of PI controllers with the proposed ABC, and GA are given in Table 1. Fig. 4. shows the change of objective functions with two optimization algorithms. The objective functions decrease over iterations of ABC, and GA. Moreover, ABC converges at a faster rate (57 generations) compared with that for GA (66 generations). Furthermore, computational time (CPU) of both algorithms is compared based on the average CPU time taken to converge the solution. The average CPU for ABC is 42.3 second while it is 50.7 second for GA. The proposed ABC methodology and GA are programmed in MATLAB 7.1 [62] and run on an Intel(R) Core(TM) I5 CPU 2.53 GHz and 4.00 GB of RAM. The mentioned CPU time is the average of 10 executions of the computer code.

Table. 1. Comparison between various controllers.

	K_{P1}	K_{I1}	K_{P2}	K_{I2}
ABC	12.3417	0.1457	0.0948	2.1534
GA	6.99	0.1687	0.0815	2.0745

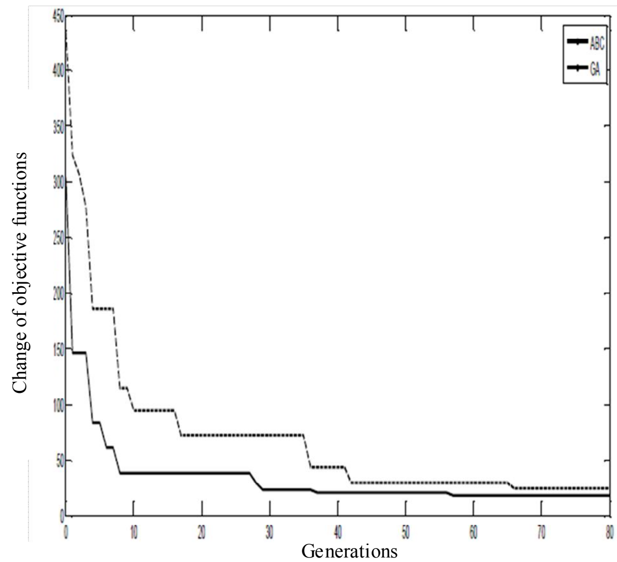

Fig. 4. Change of objective function.

5.1 Response under change of radiation

In this case, the system responses under variation of PV system radiation are illustrated. Fig. 5 shows the variation of the PV system radiation as an input disturbance while temperature is constant at 27 C. The relation between voltage, current and power of PV system is shown in Fig. 6. Moreover, the variations of PV system responses based on different algorithms are shown in Figs. 7-8. It is clear, that the proposed ABC based controller improves the MPPT control effectively w.r.t estimated value. Furthermore, the value of power per cell based on ABC algorithm is greater than twice its value at open loop (without MPPT controller). Also, an increment of 0.6 watt/cell over its value based on GA is achieved. Hence, ABC is better than GA in achieving MPP. In addition, PI controllers based ABC enhance the performance characteristics of PV system and reduce the number of PV cells compared with those based GA technique and open loop.

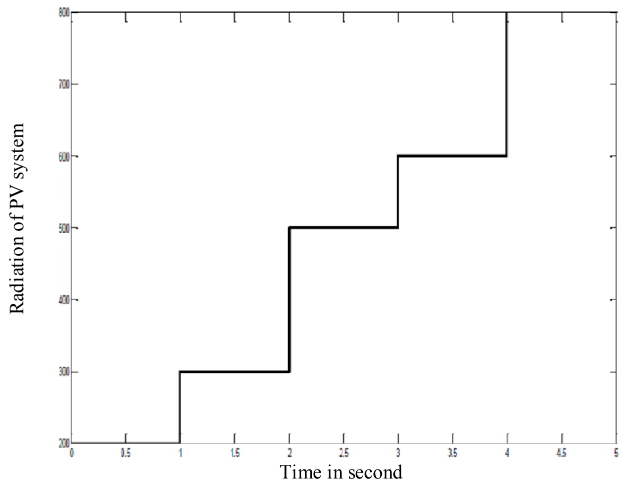

Fig. 5. Change of radiation.

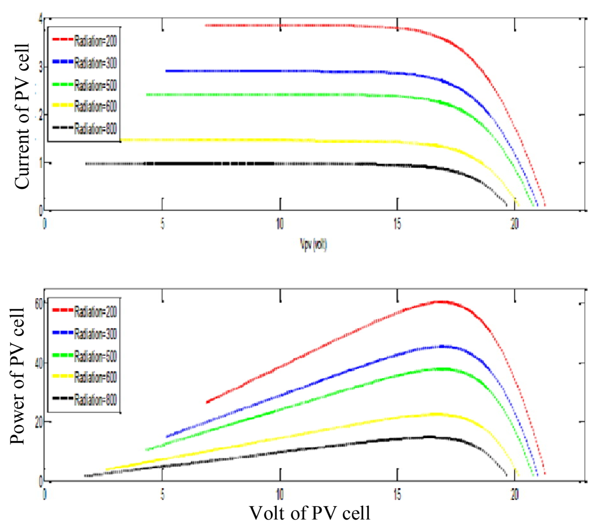

Fig. 6. Relation between volt, current, and power for different radiation.

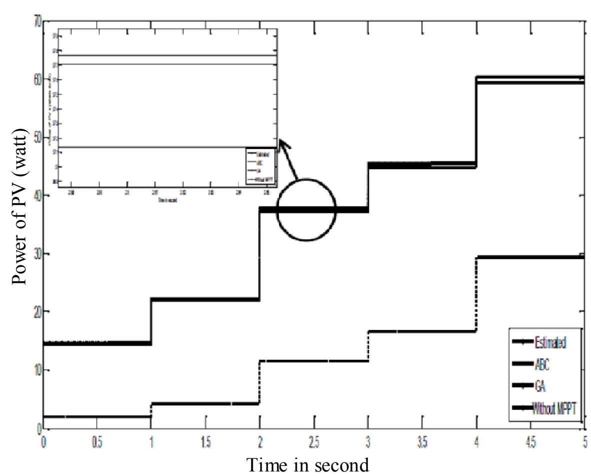

Fig. 7. Power of PV cell for different controllers.

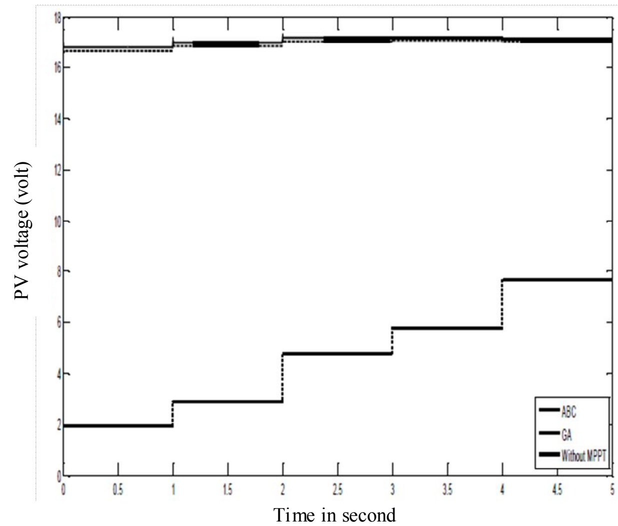

Fig. 8. Voltage of PV cell for different controllers.

5.2 Response under change of temperature

The system responses under variation of PV system temperature are discussed in this case. Fig. 9 shows the change of the PV system temperature as an input disturbance while radiation is constant at 800 W/m^2. The relation between voltage, current and power of PV system is illustrated in Fig. 10. Also, the variations of PV system responses based on different algorithms are shown in Figs. 11-12. It is clear from these Figs., that the proposed technique based controller enhances the tracking efficiency of MPP. Moreover, the proposed method outperforms and outlasts GA in designing MPPT controller. Also, the value of power/cell based on ABC algorithm is greater than GA and open loop case. As a result, the number of solar cells and cost are largely reduced. Hence, PI based ABC greatly enhances the performance characteristics of MPPT compared with those based GA and open loop.

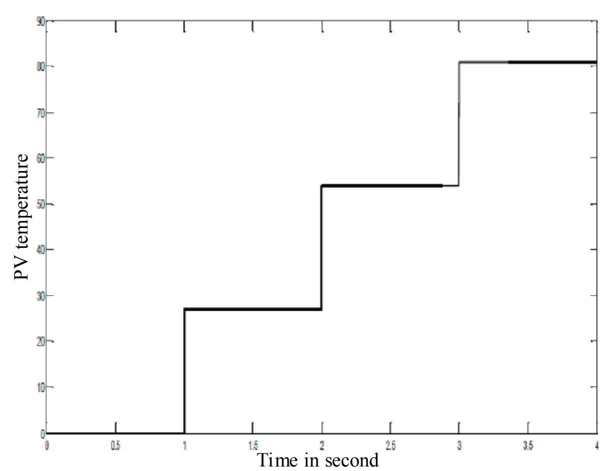

Fig. 9. Change of temperature for PV system.

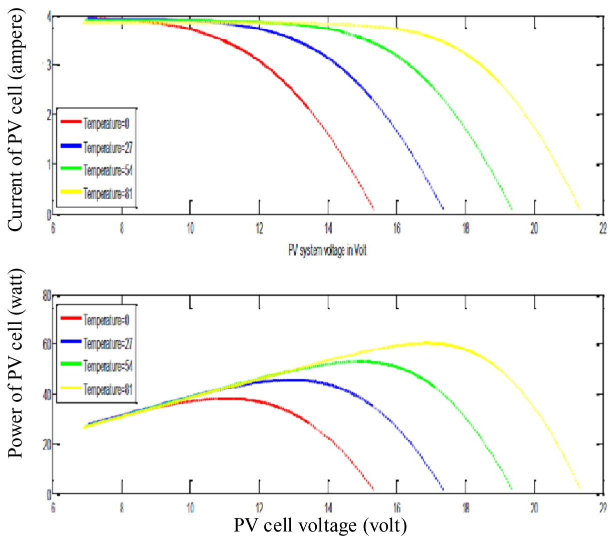

Fig. 10. Change of PV parameters with different temperature.

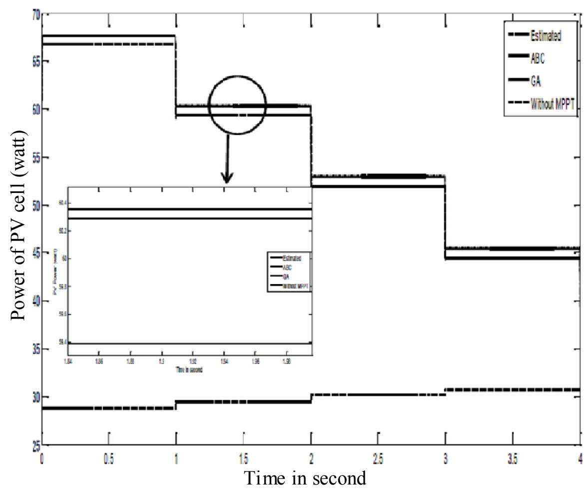

Fig. 11. Change of power for different controllers.

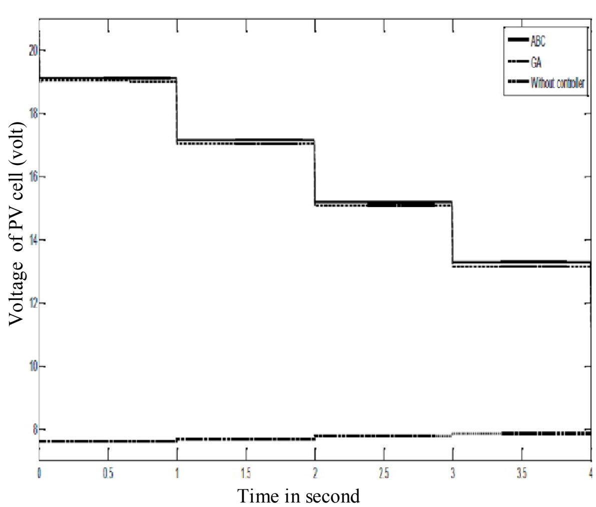

Fig. 12. Voltage of PV cell.

5.3 Response under change of radiation and temperature

In this case, the system responses under variation of PV system radiation and temperature are obtained. The variations of the PV system radiation and temperature as input disturbances are shown in Fig. 13. The characteristic of PV system is shown in Fig. 14. Moreover, the changes of PV system responses based on different algorithms are presented in Figs. 15-16. It is shown that the proposed ABC based controller increases power of PV system compared with GA and consequently reduces the number of solar cells and cost.

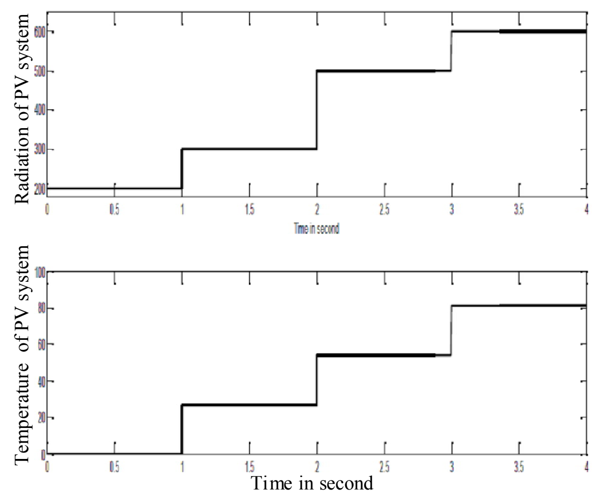

Fig. 13. Change of radiation and temperature of PV system.

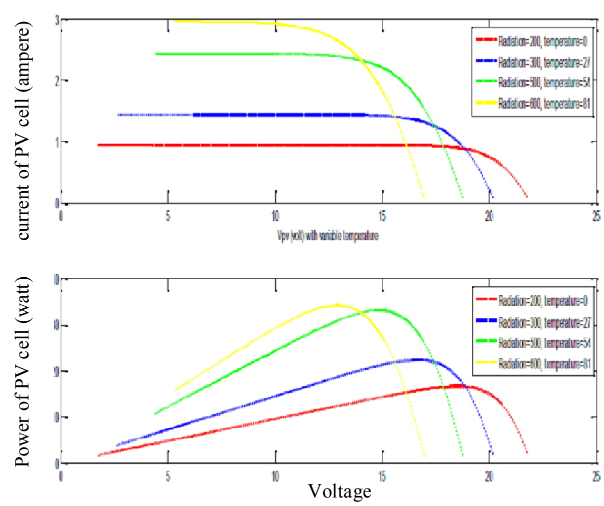

Fig. 14. Change of PV cell parameters with different radiation and temperature.

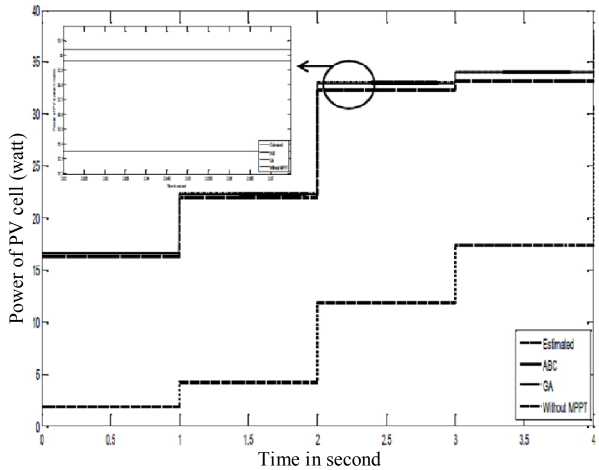

Fig. 15. Power of PV cell for different radiation and temperature.

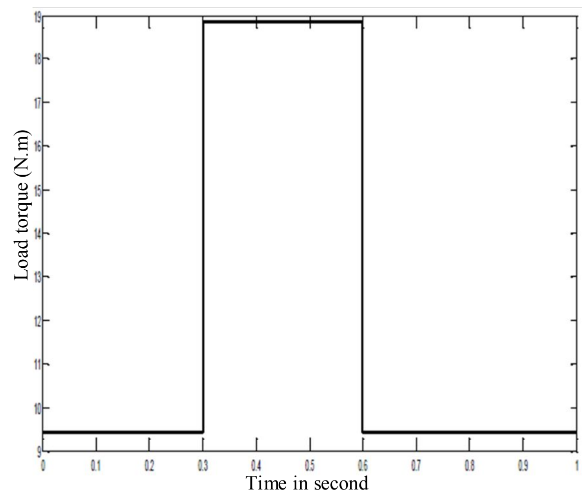

Fig. 17. Change of load torque.

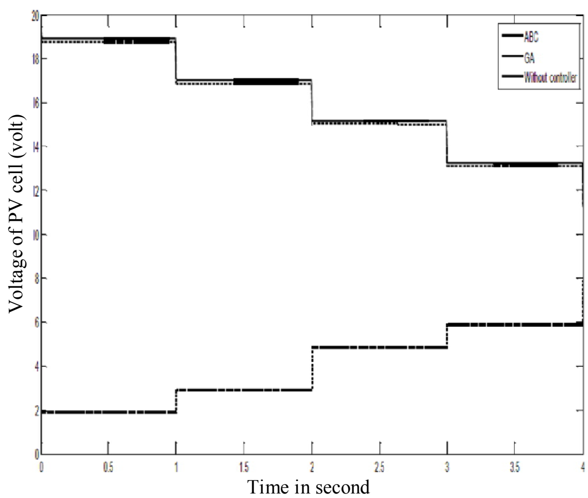

Fig. 16. Change of PV cell voltage for different radiation and temperature.

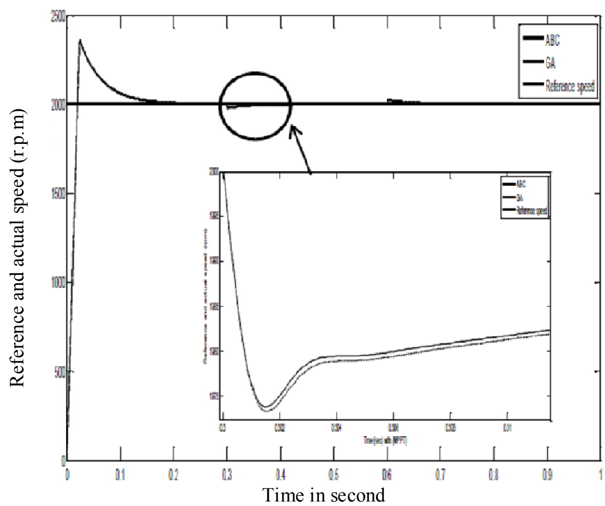

Fig. 18. Change of speed with different controllers.

5.4 Response under step of load torque

Fig. 17. shows the change of load torque of DC motor. The speed response under variation of the load torque while radiation and temperature are constant at 800 W/m^2 and 27 C respectively, is shown in Fig. 18. The actual speed tracks the reference speed with minimum overshoot and settling time. Moreover, the speed response is faster with the proposed controller than GA for the variation of load torque. In addition, the designed controller is robust in its operation and gives a superb performance compared with GA tuning PI controller.

5.5 Response under change of load torque, radiation and temperature

Fig. 19. shows the change of load torque, radiation and temperature. Fig. 20. shows the variation of motor speed with different controllers. It is clear from this Fig, that the proposed controller is efficient in enhancing speed control and tracking every change of reference speed of DC motor compared with GA. Hence, the superiority of the proposed controller over the GA is confirmed.

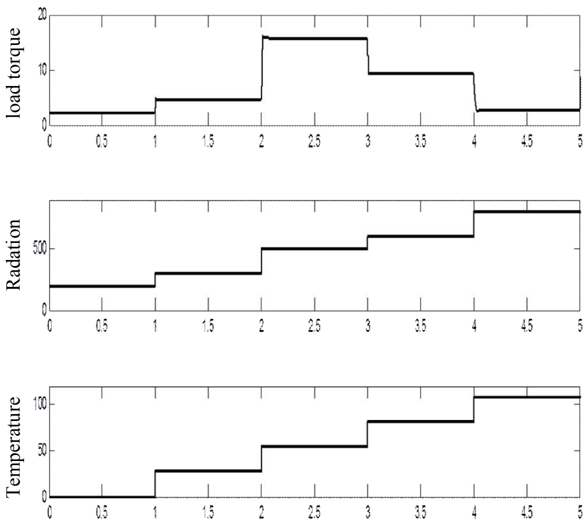

Fig. 19. Change of PV system parameters with load.

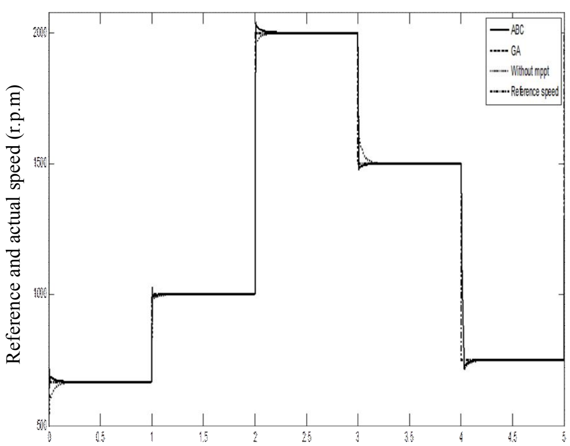

Fig. 20. Change of speed for various

6. Conclusions

In this paper, ABC algorithm has been used to design two PI controllers for a PV-DC pump system. The controlled system comprises of a PV generator that feeds a DC motor pump system through buck boost DC/DC converter. The proposed controllers aim to track and speed control of the motor pump system at MPPT of the PV generator. This is carried out through controlling the duty ratio of the converters. Simulation results show that the maximum power tracker is reached. Moreover, the designed ABC tuning PI controllers are robust in its operation and give a superb performance for the change in load torque, radiation, and temperature compared with GA and open loop. Furthermore, the saving of solar cells number and power are increased with ABC algorithm than GA.

Appendix

The system data are as shown below:

a) DC series motor parameters are shown below.

DC motor parameters	Value
Motor rating	3.5 HP
Motor rated voltage	240 V
Motor rated current	12 A
Inertia constant J_m	0.0027 Kg-m^2
Damping constant B	0.0019 N.m.Sec./rad
Armature resistance R_a	1.63 Ω
Armature inductance L_a	0.0204 H
Motor Speed	2000 rpm
Full load torque	19 N. m

b) The parameters of ABC are as follows: The number of colony size =50; the number of food sources equals to the half of the colony size; the number of cycles = 100; the limit = 100.

c) The parameters of GA are as follows: Max generation=100; Population size=50; Crossover probabilities=0.75; Mutation probabilities =0.1.

d) PV parameters: A = 1.2153; E_g = 1.11; I_{or} = 2.35e-8; I_{sc} =4.8; T_r =300; K= 1.38e-23; n_s =36; q_o =1.6e-19; k_i =0.0021.

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