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Performance Evaluation of Control Strategy on Buck-Boost Converter Fed DC Motor Using Artificial Bee Colony Algorithm

[1]S. Ben John Stephen and [2]T. Ruban Devaprakash

[1]*Assistant Professor, Electrical and Electronics Engineering, Noorul Islam University, Tamil Nadu, India*
[2]*Professor & Principal, Heera College Of Engineering & Technology, Kerala, India*

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ABSTRACT

This paper presents comparison of the performance of buck-boost converter fed DC motor using Artificial Bee Colony algorithm with that of Pulse Area Modulation controller. It presents the use of Artificial Bee Colony algorithm in the controller applied to ac-dc buck-boost converter fed dc motor. The proposed technique improves the performance of Buck-Boost converter fed DC motor. The performance of the algorithm is quite comparable with the results of the well-developed PAM Technique. The simulation models of buck-boost converter fed dc motor are used to investigate the performance of the proposed configuration. Comparisons between responses of the proposed Artificial Bee Colony algorithm and conventional controller techniques are provided through simulation.

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INTRODUCTION

Generally, a diode bridge and a capacitor connected across the output terminals are employed for the conversion of ac to dc. In this conversion, the harmonic components present in the input current are high and we cannot vary the output dc voltage. Buck-Boost converter is used to decrease or increase the output voltage level in proportion to input and so it is called or known as step-down/step-up converter also. Since these converters have power devices, effect of switching and passive components like inductors and capacitors, they are non-linear systems (Prabha, D.M.M.S., S.P. Kumar, G.G. Devadhas, 2011). Many techniques have been proposed to improve the input power factor and reduce the input current harmonic components (Prasad, A.R., P.D. Ziogas, S. Manias, 1990). The conversion of ac to dc using a diode bridge and a dc chopper has the advantage of higher input power factor [Lee, Y.J., K.Y. Suh, D.W. Chung, 1987] than that of the thyristor bridge. But, due to the lower-order harmonics, the source current is distorted. Pulse Width Modulation technique (Mechi, A., S. Funabiki, 1993) is also used in many attempts to improve the performance of the switching device.

This paper describes the Artificial Bee Colony Algorithm for the buck-boost converter fed dc motor. The Artificial Bee Colony Algorithm is based on pulse area modulation. The performance and adaptability of speed control systems are improved by using this controller. The ABC-PAM controller is simulated and the simulation results are presented.

Mathematical Model of Buck-Boost Converter:

A. Principle of Operation of Buck-Boost Converter:

A configuration of ac-dc buck-boost converter fed dc motor is shown in Fig.1. In this configuration, separately excited dc motor is used. This converter configuration consists of a diode bridge, an IGBT (switching device), an inductor, a diode and an output capacitor.

The output voltage magnitude of Buck-Boost converter is either greater than or less than the input voltage magnitude. Hence this converter is also called as step-down or step-up chopper. In this converter configuration, the energy will be stored in the inductor when IGBT is ON and energy will be transferred to the load (dc motor) when IGBT is OFF. By appropriately switching the IGBT, the step-up and step-down characteristics of the output voltage can be easily obtained.

The proposed configuration of buck-boost converter is appropriate for low and medium power applications, such as power supplies and motor drives. The ac-dc buck-boost converter can be especially suited as a front-end power source in variable-speed drive systems.

Corresponding Author: S. Ben John Stephen, Assistant Professor, Electrical and Electronics Engineering, Noorul Islam University, Tamil Nadu, India.
Tel: +919952262775 E-mail: benjohnstephen@gmail.com

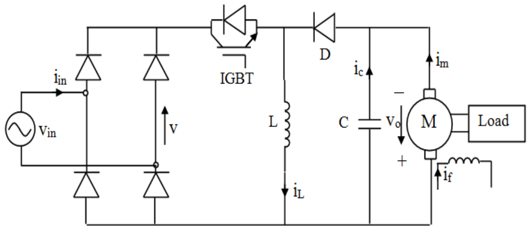


Fig. 1: Schematic diagram of AC-DC buck-boost converter fed dc motor.

There are two different power stages in the conversion process, which are the rectification and the control stages. In the first stage, a simple diode bridge rectifier is used to unify the direction of motor current and the supply voltage. In the second stage, an IGBT operating in the chopping mode is used to control the amplitude of the output average voltage. As a result of the rectification stage, the waveforms of the load voltage and current are repetitive at a frequency equals double the supply frequency.

B. Transient Analysis:

In the model formulation of Buck-Boost Converter, the assumptions are (a) power electronic components are ideal (b) switching frequency is much greater than the supply frequency. So, the input and output voltages can be considered constant in each switching period.

The state variables can be obtained from the IGBT and diode switching conditions. These state variables describe the dynamic behavior of buck-boost converter fed dc motor.

The output voltage of the diode bridge is given by the expression

$$v = |v_{in}| = |v_{in,m}\sin(wt)| \quad (1)$$

The voltage equation of a separately excited dc motor is given by

$$v_o = R_m i_m + L_m \frac{di_m}{dt} + k_m w_m \quad (2)$$

and the electromagnetic torque equation is

$$T_{electro} = T_{Load} + J\frac{dw_m}{dt} + Bw_m \quad (3)$$

where km is the motor constant which is given by

$$k_m = k_v i_f \quad (4)$$

and the electromagnetic torque developed is

$$T_{electro,develop} = k_m i_m \quad (5)$$

The analysis is formed in a generalized form that is applicable irrespective of the number of pulses per supply cycle. For this purpose, the supply voltage is assumed sinusoidal.

According to the selected current directions in the three modes, the following state/performance equations can be formed:

Mode 1 (Charging Mode)

$$v = L\frac{di_L}{dt} \quad (6)$$

$$i_{in} = i_L \quad (7)$$

$$i_{cap} = -i_{motor} \quad (8)$$

$$i_{cap} = C\frac{dv_o}{dt} \quad (9)$$

Mode 2 (Discharging Mode)

$$L\frac{di_L}{dt} = -v_o \quad (10)$$

$$i_{in} = 0 \quad (11)$$

$$i_L = i_{cap} + i_{motor} \quad (12)$$

$$i_{cap} = C\frac{dv_o}{dt} \quad (13)$$

Mode 3

$$i_{cap} = -i_{motor} \quad (14)$$

$$i_{in} = i_L = 0 \quad (15)$$

$$i_{cap} = C\frac{dv_o}{dt} \quad (16)$$

C. Steady State Analysis:

An approximate equivalent circuit can be obtained using steady state analysis. During the switching period of the switching device IGBT, the input voltage can be assumed constant due to high switching frequency.

The average inductor voltage can be written as a function of the IGBT duty cycle D during each switching cycle and is given by

$$v_L(t) = Dv(t) + (1-D)v_o(t) \quad (17)$$

where v(t) is the average output voltage of the diode bridge and v_o(t) is the average output voltage of the dc converter during one switching period. The voltage across the inductor is given by

$$v_L(t) = L\frac{di_L(t)}{dt} \quad (18)$$

where $i_L(t)$ is the average current through the inductor during each switching period.

From the above equations, we can obtain the following relation

$$Dv(t) = L\frac{di_L}{dt} - (1-D)v_{out}(t) \quad (19)$$

During the charging mode, energy is stored in the inductor. During the discharging mode, the inductor current produces an output current. Hence, the average input and output currents during one switching period are written as

$$i_{in}(t) = Di_L(t) \quad (20)$$

$$i_{out}(t) = (1-D)i_L(t) \quad (21)$$

Substituting Eq. (21) into Eq. (19) gives

$$\frac{D}{1-D}v(t)=\frac{L}{(1-D)^2}\frac{di_{out}}{dt}-v_{out}(t) \tag{22}$$

The steady state equivalent circuit for the ac-dc buck-boost converter is represented by the Eq. (22) and is shown in Fig. 2. From the equivalent circuit, we can obtain the current relation as

$$C\frac{dv_{out}(t)}{dt}=i_{out}(t)-i_{motor}(t) \tag{23}$$

In order to obtain a smooth dc voltage, the output capacitor value should be high. Due to the large capacitor value, we can assume that the average values of the $v_{out}(t)$ and $i_{out}(t)$ are constant and the average value of the second component of (22) is equal to zero. The relation between the output voltage and the input voltage as a function of duty cycle is given by

$$\left|\frac{v_{out}(t)}{v(t)}\right|=\frac{D}{1-D} \tag{24}$$

From this equation, it is clear that the proposed converter functions as a boost converter for duty cycle greater than 0.5 and as a buck converter for duty cycle less than 0.5. For duty cycle equal to 0.5, the output voltage is equal to the dc rectified voltage.

In practice, for high switching frequency, the duration of mode 3 is very short. In such a case, we can neglect the mode 3. Fig. 2 represents the approximate dc equivalent circuit of ac-dc buck-boost converter. The input to the dc–dc converter is the fully rectified voltage v(t) and D is the duty cycle of IGBT. In this converter, the polarity of output voltage is opposite to that of fully rectified voltage. So, this converter is also called as inverting converter.

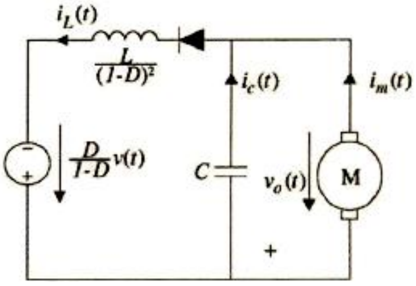


Fig. 2: Approximate dc equivalent circuit of ac-dc buck-boost converter.

Controller Based on Pulse Area Modulation:

This section describes the use of Pulse Area Modulation technique in the controller for Buck-Boost converter fed DC Motor. The proposed configuration using Pulse Area Modulation control circuit has been simulated and the waveforms have been presented.

A. Pulse Area Modulation Technique:

The implementation of control circuit using Pulse Area Modulation technique is shown in Fig. 3.

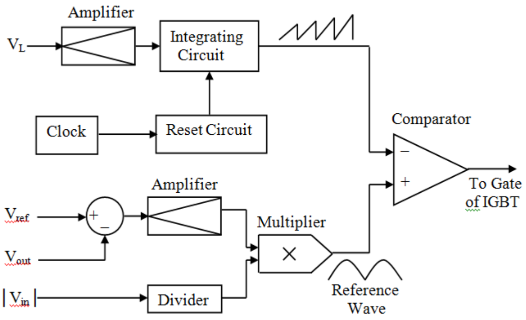


Fig. 3: PAM Control Circuit.

When IGBT is on, energy will be stored in the inductor. The inductor voltage is amplified and this voltage is applied into the integrating circuit. In order to get a saw-tooth wave, the integrating circuit is reset at a constant interval. The gradient of this saw-tooth wave is proportional to the amplitude of the inductor current. PWM pulses can be obtained by comparing the saw-tooth wave with the full-wave rectified input voltage. These PWM pulses are used to drive the switching device IGBT. In the PAM based control circuit, the amplitude of the reference wave can be controlled by the multiplier. Since the DC output voltage V_{out} is compared to the reference voltage V_{ref}, the value of V_{out} will be maintained at a constant voltage.

B. PAM Gating Signals Generation:

The generation of pulses using PAM technique is illustrated in Fig.4. The switching device IGBT is controlled by using these gating signals. When the current in the inductor increases gradually, the current becomes a saw-tooth wave whose gradient increases gradually as shown in Fig. 4. If the reference voltage is constant, the duty ratio decreases gradually. So, the waveform of source current becomes square wave whose pulse width decreases gradually and peak value increases gradually.

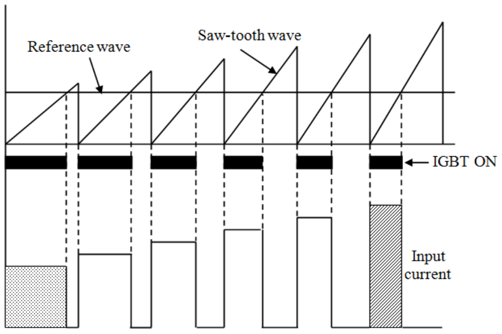


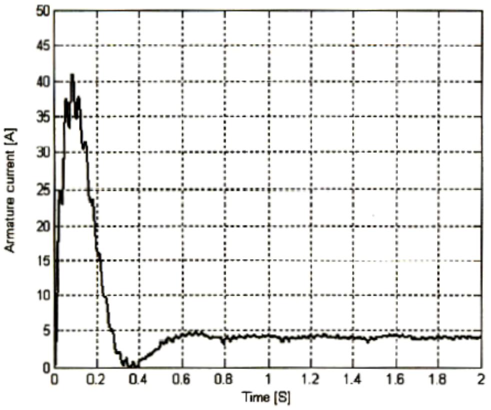
Fig. 4: PAM Gating Signals.

If the reference voltage is constant, there will be no change in the areas of the pulses. But if the reference voltage waveform increases or decreases, there will be proportional changes in the area of pulses. The pulse area is equal to the instantaneous value of the input current. Thus, if sine wave is used as reference waveform instead of constant voltage waveform, the input current waveform will be changed into a sine wave. By using this concept, we can improve the input power factor.

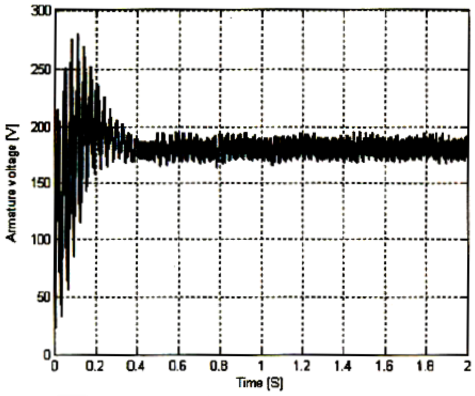
C. Simulation of PAM Controller:

To study the performance of buck-boost converter fed dc motor, simulation has been done. For the simulation, a dc motor of rated Voltage=180 V, Current=8.5 A, power=1.5 kW and rated speed of 735 rpm having armature resistance R_m=2.85 Ω, armature inductance L_m=5.5mH, motor constant K_m=2.22V/(rad/s) and J=0.26 kgm^2 is used. In order to apply a rated voltage of 180 V to the motor at a duty cycle of 0.8, the maximum source voltage is selected as 70.70 V. In this configuration, capacitor C of 333 μF, inductor L of 96 mH and switching frequency of 1.80 kHz have been chosen.

The simulated characteristics of the motor armature voltage, armature current and speed using PAM technique is shown in Fig.5.



(a)



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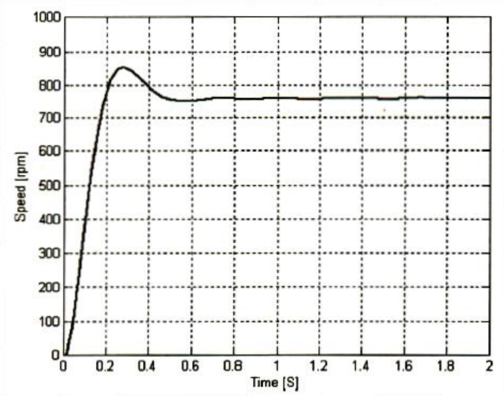


(c)

Fig. 5: Simulated characteristics of motor armature current, armature voltage and speed using PAM technique

Artificial Bee Colony-PAM Based Control Method:

This section describes the use of Artificial Bee Colony algorithm in the controller for buck-boost converter fed dc motor.

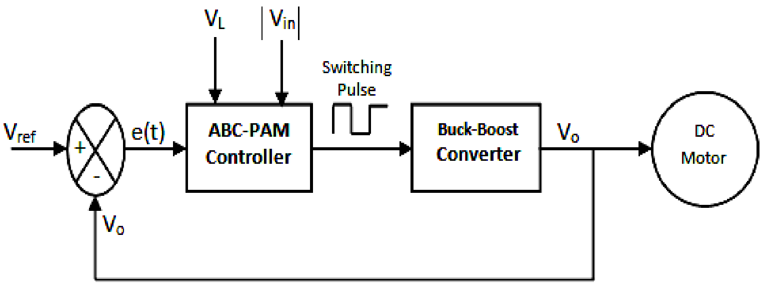


Fig. 6: Block Diagram of ABC-PAM Controller.

The block diagram of ABC-PAM control model for the proposed converter is shown in Fig. 6. Error, e(t) is the difference between the output voltage of the converter and a desired voltage value. Error is the input of the ABC-PAM controller.

$$e(t) = V_{ref} - V_o(t) \tag{25}$$

In the above equation, e(t) is the error signal and V_{ref} is the reference voltage.

In the ABC-PAM control, the voltage across the reactor and full wave rectified input voltage are the controller parameters. ABC algorithm is used to define these parameters optimally to make the system stability and obtain an effective or robust transient response.

A. Artificial Bee Colony Algorithm to Optimize the Parameters:

ABC is a robust optimization method is based on the foraging behavior of honey bees. It consists of two phases i.e., exploitation phase performed by employed & onlooker bee and exploration phase performed by scout bee (Karaboga, D., B. Akay, 2012). In the ABC algorithm, artificial bees which are employed, onlooker and scout search the food source which has the highest nectar amount by modifying the food positions by time. In the ABC, while a possible solution of the problem corresponds to position of a food source, fitness of the association solution corresponds to nectar amount of this source. ABC algorithm works at 10 steps described below (Sönmez, Y., 2013).

Step1: Input data:

Limits of the controller parameters are read at this step. In this study, used limits for the controller parameters are given in Table 1.

Table 1: Limits of ABC-PAM parameters.

Controller Parameters	Range	
	Minimum	Maximum
V_L	0	65
V_{in}	0	70

Step 2: Initialization of ABC parameters:

ABC parameters like maximum cycle number, colony dimension, limit parameter and number of variables are initialized.

Step 3: Initial population:

A set of initial population with M solutions x_k (k=1,2,…M) is produced randomly and their fitness are determined. Here each solution of x_k represented by D-dimensional vector corresponded to number of controller parameters optimized.

Step 4: Fitness evaluation of the population:

At this step, fitness values obtained from the fitness function belong to each solution is evaluated. The fitness function used in this study is described as follows.

$$fit_i = \sum_{t=1}^{n} e^2(t) \tag{26}$$

where e(t) is the error value described in Eq. (25) and n is the maximum iteration number in simulation of operating buck-boost converter for determined controller parameters at one cycle of ABC algorithm.

Step 5: Set the cycle counter to 1:

Step 6: Modification of solutions (food source positions):

In order to get better nectar amount, food sources are modified and replaced by a new one via employed bees. Then the nectar amounts of modified food sources are tested. If the new source has better nectar amount than old one, the new food source are kept the memory, otherwise it discards. This process is described as follows.

$$v_{kl} = x_{kl} + \beta_{kl}(x_{kl} - x_{nl})\, k \in (1,2,.....,M) \quad and\ j \in (1,2,.....,D) \tag{27}$$

where v_{kl} is the new food source position, n and l are randomly determined indexes, β_{kl} is a number determined randomly between -1 and +1.

Step 7: Employing of onlookers and calculation of probabilities:

After the search process is over, the onlookers wait at the dance area for the nectar amount and position information. The position information and nectar amount are shared with the onlookers by the employed bees. According to a probability value P_k , onlooker bees prefer a food source. The probability value P_k is described as follows.

$$P_k = \frac{fit_k}{\sum_{l=1}^{M} fit_l} \tag{28}$$

where fit_k is the fitness value of the k^{th} solution described in Eq. (26) and M is the total number of food sources. Then, at this step, onlooker bees modify the food sources given in Eq. (27) and test the nectar amount as in the case of Step 6.

Step 8: Abandoning from the exploited source:

At this step, the food source is abandoned and replaced with a new one by scout bees if there is no further improvement in a food source. In the Artificial Bee Colony algorithm, abandoning the food source is done based on the “limit” parameter which is predetermined number of cycles. Discovering a new food source by a scout is described as follows.

$$x_k^l = x_{\min}^l + rand(0,1) \times \left(x_{\max}^l - x_{\min}^l\right) \tag{29}$$

$x_{\max}^l$ *and* $x_{\min}^l$ are maximum and minimum limits of the parameter to be optimized.

Step 9: Memorize the best solution so far

Step 10: Increase the cycle counter

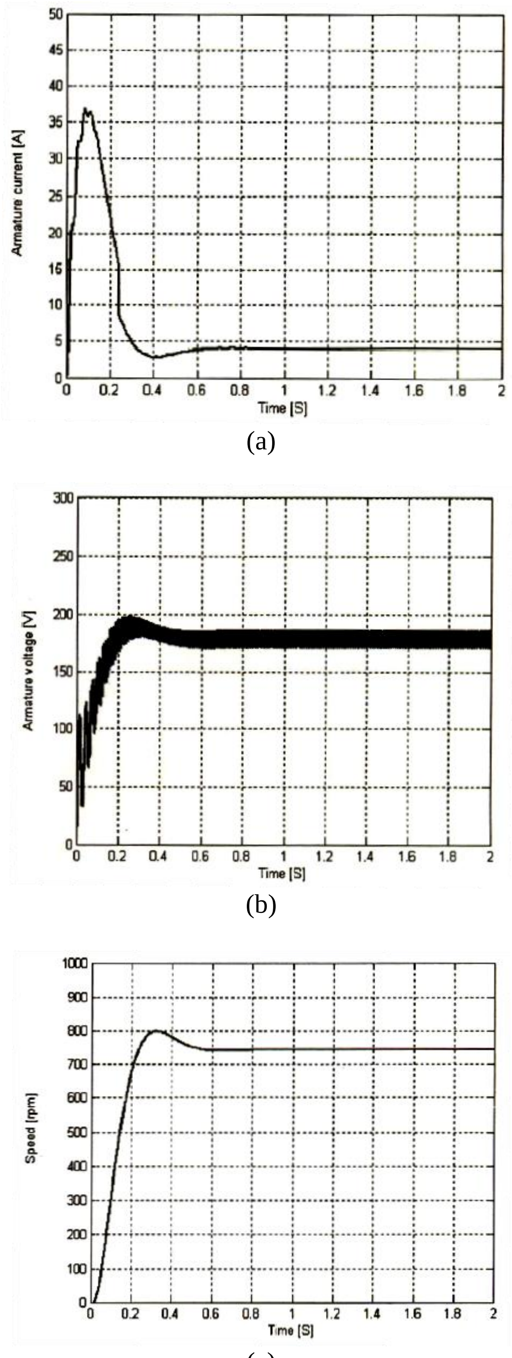
Step 11: Stopping the algorithm

Steps between 6 and 10 are repeated until reach the Maximum Cycle Number (MCN) determined before. Then, the searching process is stopped.

B. Simulation of ABC-PAM Controller:

ABC-PAM Controller for buck-boost converter fed DC Motor is simulated in order to investigate performance of the proposed algorithm. The results obtained in PAM Controller are compared with that of ABC-PAM algorithm to show the effectiveness of the ABC-PAM.

For simulation, the same dc motor parameters are chosen as in section III. Simulated characteristics of motor armature voltage, armature current and speed using ABC-PAM Controller are shown in Fig.7.



(a)

(b)

(c)

Fig. 7: Simulated characteristics of motor armature current, armature voltage and speed using ABC-PAM Controller.

C. Advantages of ABC-PAM Control:

Comparing the simulated characteristics of the dc motor shown in Fig.5 and Fig.7, it is clear that the peak overshoot of speed is less in model using ABC-PAM controller than that of Controller based on PAM technique for the same dc motor and load conditions.

Conclusion:

This paper presented the application of Artificial Bee Colony algorithm in the control of buck-boost converter fed dc motor, highlighting its superior performance compared to the conventional methods.

The proposed converter configuration uses only one power switching device. Due to this, the size of the proposed converter is small and the energy loss is less. Since it uses only one IGBT, it is convenient for an economical variable dc voltage supply.

The effects of the ABC-PAM algorithm on system performance of the buck-boost converter are investigated. Results show that ABC-PAM controller produces better results than PAM based controller to control the buck-boost converter in the way of settling time, and peak overshoot.

The settling time and peak overshoot of the speed of motor is less in models using ABC-PAM controller when compared to other conventional control techniques. Thus, the performance of the ABC-PAM Controller is superior to the conventional control techniques.

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