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Research Article

Performance Enhancement of PID Controllers by Modern Optimization Techniques for Speed Control of PMBL DC Motor

[1]M. Antony Freeda Rani and [2]B. Sankaragomathi
[1]Department of Electrical and Electronics Engineering, Udaya School of Engineering, Nagercoil, Tamil Nadu, India
[2]Department of Electronics and Instrumentation Engineering, National Engineering College, Kovilpatti, India

Abstract: Permanent Magnet Brushless DC motor (PMBL DC) is used in a large number of industrial and automotive applications because of their high efficiency, compactness and excellent reliability. However to design an efficient PMBL DC motor, it is necessary to provide an effective controller that has to reduce the overshoot, settling and rise time. In this study, an improved PID controller has been designed by optimizing the parameters of PID controller based on two advanced optimization techniques ANFIS and Cuckoo Search optimization for speed control of a PMBL DC motor. The proposed approach has superior features, including easy implementation, stable convergence characteristic and good computational efficiency. The PMBL DC motor is modeled in SIMULINK implementing the algorithms in MATLAB and the performance evaluation has been studied.

Keywords: ANFIS, cuckoo search optimization, permanent magnet brushless DC motor, PID controller

INTRODUCTION

Brushless DC (BLDC) motors are increasingly replacing brushed DC motors due to their superior efficiency, long life, smooth torque delivery and high speed operation. Among them Permanent Magnet Brushless DC (PMBLDC) motors are the latest choice of researchers due to their high efficiency, silent operation, compact size, high reliability and low maintenance requirements (Singh and Singh, 2009). Fly back converters are mostly used in PMBLDC motor because of the simplest topology with structural advantages and dynamic behavior (Rodriguez and Emadi, 2007; Zhang and Yan, 2009).

In order to achieve high performance, many conventional control schemes are employed for controlling the fly back converter. The control of BLDC motors can be done in sensor or sensorless mode, but to reduce overall cost of actuating devices, sensorless control techniques are normally used. The advantage of sensorless BLDC motor control is that the sensing part can be omitted and thus overall costs can be considerably reduced (José Carlos *et al*., 2010).

PID controller is commonly used controller in process industries. This is because of their various merits such as it can be easily be understood by plant operators, near optimal performance, wide applicability etc (Mitra and Singh, 2013). Moreover conventional PID controller is very sensitive to step change of command speed, parameter variation and load disturbances (Febin Daya *et al*., 2013). However to improve performance of PID controller, it is necessary to tune the parameters of PID controller (Bindu and Namboothiripad, 2012). There are several techniques which are used for tuning of PID controller to control the speed control of PMBL DC motor.

Tuning of PID parameters is considerable because these parameters have an admirable effect on the stability and performance of the control system (Amanullah *et al*., 2014). Nowadays, optimization methods have been proposed as an alternative to conventional methods. These optimization methods are nature inspired methods that are stimulated by natural and biological events (Kishnani *et al*., 2014). Optimization considers the load and speed variations and provides appropriate gains to the speed controller to obtain good dynamic performance of the motor (Aggrawal *et al*., 2014; Gadoue *et al*., 2007).

Navidi *et al*. (2012) proposed an approach for designing of PID controller for a linear Brushless DC motor using Ant Colony Search Algorithm for determining the optimal PID controller parameter. From (Emami *et al*., 2008) it can be inferred that a Particle Swarm Optimization has been proposed for improved performance of PID controller on Buck converter. Ibtissem Chiha *et al*. (2012) carried out work on tuning of PID controllers method using multi objective ant colony optimization. The design objective

Corresponding Author: M. Antony Freeda Rani, Department of Electrical and Electronics Engineering, Udaya School of Engineering, Nagercoil, Tamil Nadu, India

was to apply the ant colony algorithm in the aim of tuning the optimum solution of the PID controllers (*Kp*, *Ki* and *Kd*) by minimizing the multi objective function.

The previous work (Ali and Majhi, 2006) modeled the design of optimum PID controller by Bacterial Foraging Strategy. Pooja and Rajeev (2014) proposed tuning of PID Controller for a Linear Brushless DC Motor using Swarm Intelligence Technique. The work carried out in Chan *et al*. (2007) proposed a modular design of embedded feedback controller using FGPA were the modules can be reused in several applications.

On analyzing the above discussed methods, several drawbacks can be noticed as PSO based PI controller optimization struck in selection of single optimized values. The problem with ACO is the time to convergence is uncertain and no centralized processor to guide the AS towards good solutions. Bacterial Foraging Strategy suffered from the weak ability to perceive the environment and vulnerable to perception of local extreme.

To overcome the above said drawbacks, new optimization techniques such as ANFIS and Cuckoo Search has been proposed for determining the optimal Proportional-Integral Derivative (PID) controller parameters for speed control of Permanent Magnet Brushless DC motor. The proposed system designed under this topology works well in reduction of settling time, rise time and overshoot also improves the performance of the entire setup.

MATERIALS AND METHODS

Problem formulation: Consider the standard PMBLDC motor with PID controller shown in Fig. 1.

The PID controller is used to improve the dynamic response as well as to reduce the steady state error. The PID controller transfer function is:

$$TF(x) = K_p + K_i/s + K_d s \quad (1)$$

where,

K_p = The proportional part
K_i = Integral part
K_d = The derivative part
s = The steady state error with respect to the selected set point value

The performance criteria considered in this study is:

$$\text{Min}\ \{O(t)|Sp(t)\} \quad (2)$$

and,

$$\text{Min}\ \{St(t)|Sp(t)\} \quad (3)$$

where, O (t) represents the overshoot time to be reduced and St (t) denotes the settling time for the system and Sp represents the set point value. The main aim of this study is to seek for the optimal parameters for PID controller that should meet constraints (2) and (3) based on the optimization algorithm used. Also the algorithm should depict the optimized values in short span of time.

Evaluation of performance in PID controller: Conventional PID controller can be formulated as minimizing the Integral Square Error (ISE) as it is well known that ISE gives better output for both set point, overshoot and disturbance rejection time. The ISE function can be represented in the general form as:

$$I_{se}(x) = \int_0^{\infty} |e(\beta, t)|^2\, dt \quad (4)$$

where, β is the parameters of the PID controller that have to be tuned for improving the performance of PID controller. In general the proposed system can be modulated in such a way as based on the transfer function, the controller parameters K_p and K_i can be better tuned such that minimizing (4). The fitness of the solution set can then be given as:

$$\lambda_{min} = \frac{1}{E(x)} \quad (5)$$

The optimized parameter value can be obtained by using the advanced optimization algorithms that should work effectively in delivering optimized values for PID

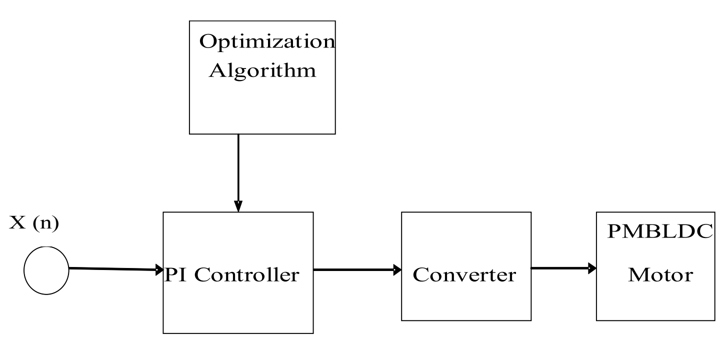

Fig. 1: Block diagram of PID controller in PMBLDC motor

controller parameters to reduce overshoot and settling time.

ANFIS PID controller algorithm: The algorithm is discussed here in brief.

Algorithm 1: ANFIS PID controller algorithm:

Step 1: Load the initial set of training and testing data and generate initial FIS model.

Step 2: Initialize the solution set SS $\{x_1, x_2, \ldots, x_n\}$ and the parameters to be optimized.

(a) Assign membership function based on Eq. (4)
(b) Assign constraints based on Eq. (2) and (3)
(c) Select FIS model optimization method
(d) Assign the parameters to be trained and tested

Step 3: Input the training data into ANFIS system.

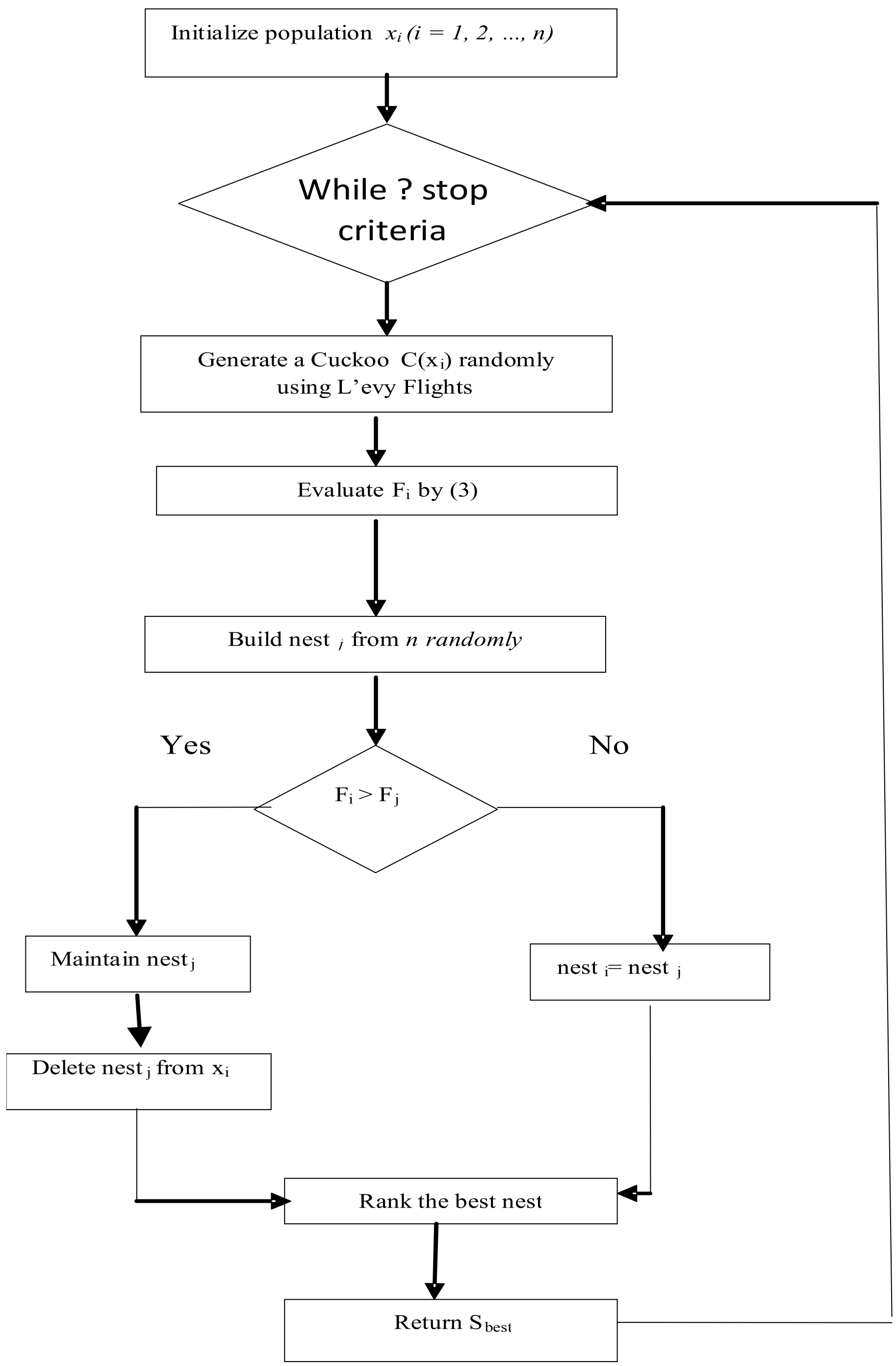

Fig. 2: Cuckoo search optimization

(a) Force error minimization by $\Delta e = e_1 - e_2$.

Repeat Step 3 till training finishes and output the optimum parameter values.

Step 4: Input the testing data into ANFIS system.
Step 5: Track the optimized values for K_p and K_i and return the result.

Structure of ANFIS: ANFIS incorporates artificial neural network with Fuzzy Inference System (FIS). The analysis has two inputs, error (e), rate of change of error (Δe) and the output is optimized K_p and K_i values. The ANFIS controller is trained by the data of closed loop BLDC motor drive system simulated with PI controller. The ANFIS controller avoids the selection of fuzzy control rules and tuning of membership functions in the manual manner as done in FLC.

Cuckoo search algorithm: The Cuckoo Search optimization algorithm works effectively for tuning the PID controller parameter and the way of optimization is discussed in Fig. 2.

ANFIS and Cuckoo Search optimization algorithm discussed above yield tuned values for the parameter K_p and K_i and based on this tuned value simulation result can be carried on to reduce overshoot and settling time.

RESULTS AND DISCUSSION

Simulation model: The system is designed in MATLAB and it is shown in Fig. 3.

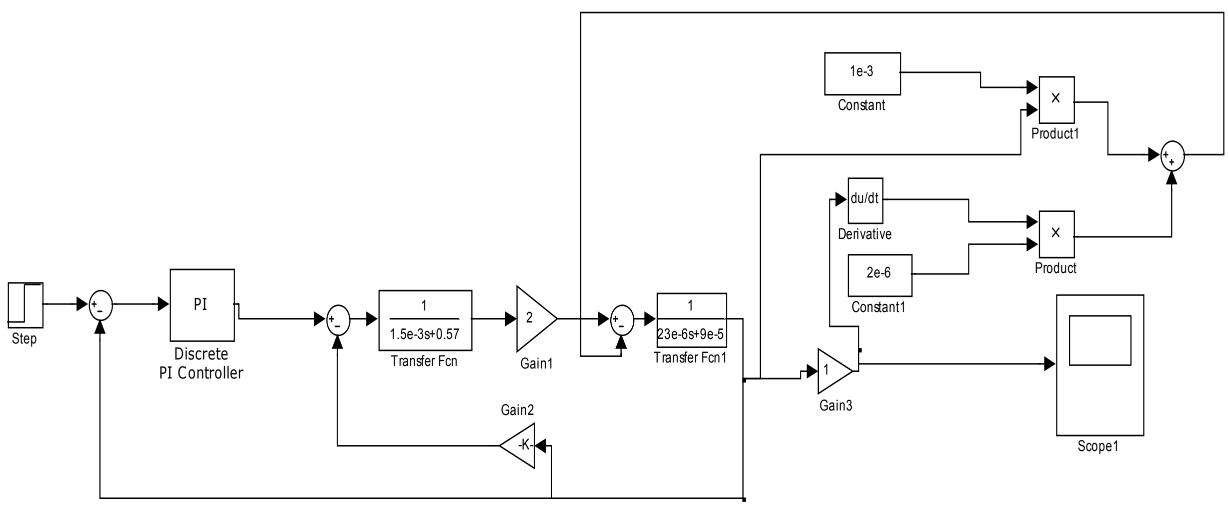

Fig. 3: Simulation block diagram of permanent magnet brushless dc motor drive system for proportional-integral controller

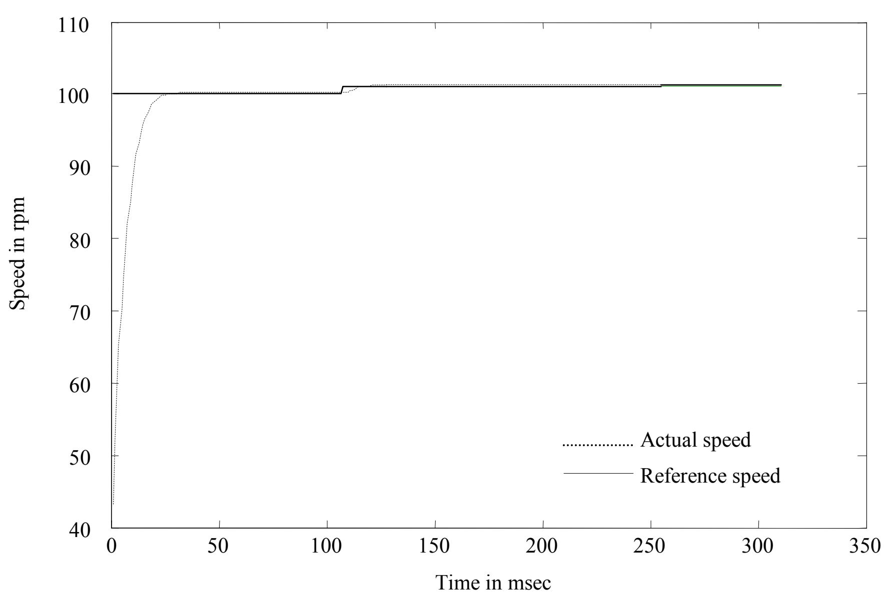

Fig. 4: Waveforms of BLDC motor at 100 rpm for PI controller

Simulation result:

Simulation result for cuckoo search optimization: On invoking the Cuckoo Search Optimization algorithm, the optimized K_p value obtained is 0.6300 and for K_i the value is 0.0504. Using these optimized values reduction in settling time and overshoot can be obtained well than the traditional way which is clearly elaborated in the following simulation result.

Simulation result with increase in speed: Increase in speed generally reduces the error rate as it can be noted that when speed is 100 rpm, the error rate is around 2.18212 and when the speed increases to 150 rpm, the corresponding error rate decreases to 1.84373. Figure 4 demonstrates that error rate is high when speed is 100 rpm and it deviates more from the settling point and finally settles at 141 msec.

Figure 5 shows that the error rate is reduced much when compared to Fig. 1 due to increase in speed from 100 to 150 rpm and the settling time is around 125 msec noting that it settles fast than the previous speed.

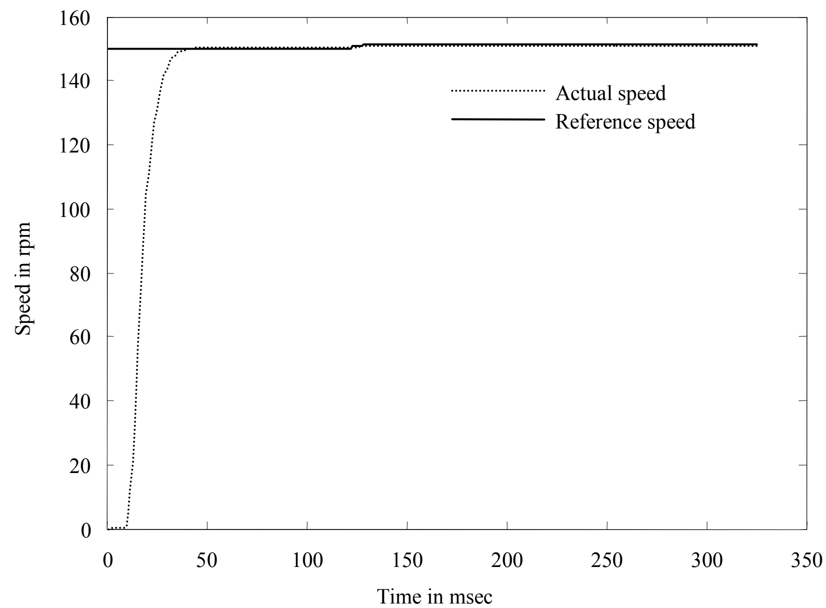

Fig. 5: Waveforms of BLDC motor at 150 rpm for PI controller

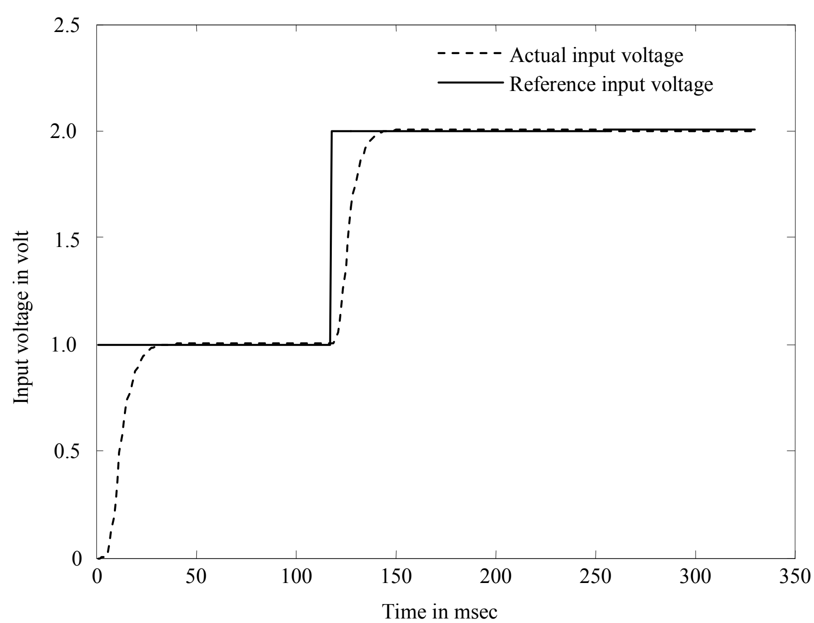

Fig. 6: Set point tracking performance of BLDC motor for an input of 5V; (1 unit = 2.5 v)

Simulation result with respect to input voltage variation: From Fig. 6, it can be seen that when the input voltage is varied from 5 to 10 v at time 125 msec, variations in settling time and overshoot occurs and it settles at time 150 msec.

Figure 7 show that when the input voltage variation occurs at time 125 msec, the system deviates from the reference point and it settles at time 149 msec.

Simulation result with respect to load torque variation: Using cuckoo search algorithm, when load torque of 5 Nm is applied variations in settling time occurs and it finally settles at 30 msec as shown in Fig. 8. Similarly from Fig. 9, it can be inferred that when a load torque of 25 Nm is applied at time 2 msec, the system deviates from the reference point and it settles at 2.7 msec.

Simulation result for ANFIS algorithm: Using ANFIS algorithm the optimized parameter values obtained is for K_p it is 0.694 and for K_i it is 0.0723.

Simulation result with increase in speed: In the same way as Cuckoo Search algorithm, here also the error rate increases with decrease in speed and

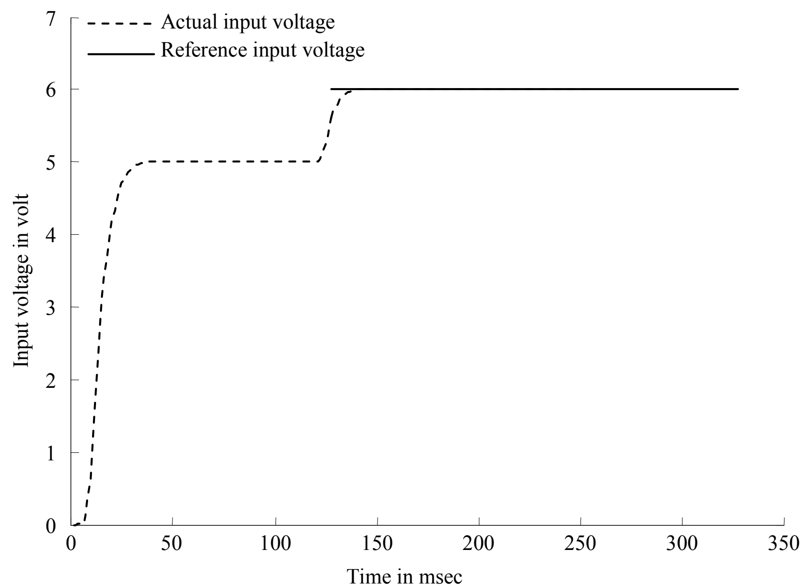

Fig. 7: Set point tracking performance of BLDC motor for an input of 25 V (I unit = 5 v)

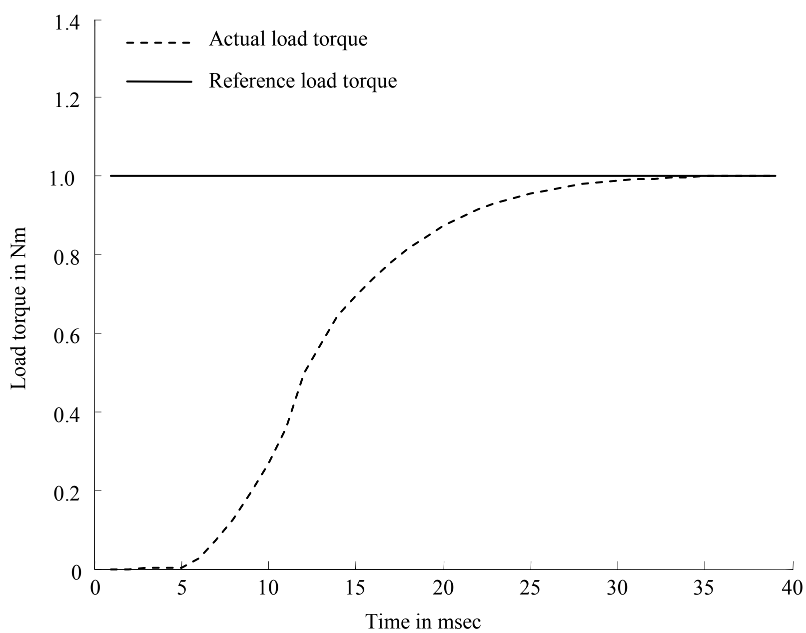

Fig. 8: Waveforms of BLDC motor at a load torque 5 Nm

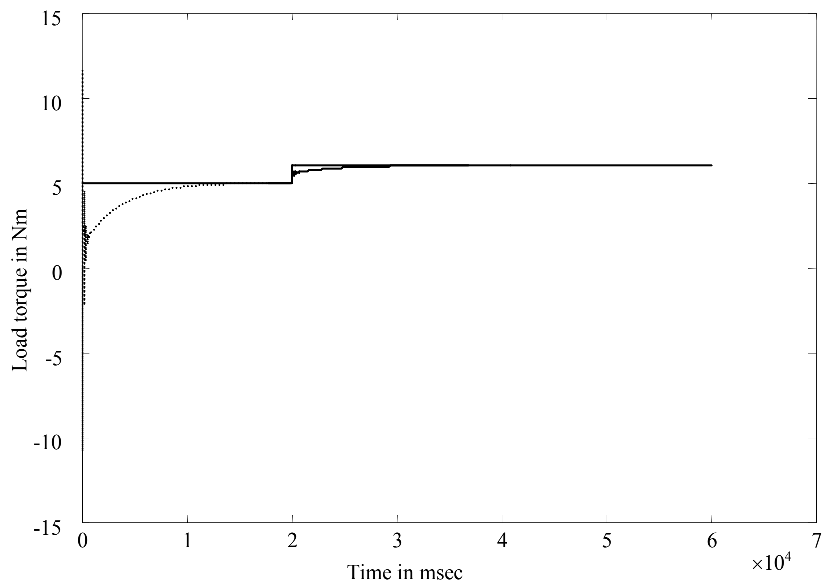

Fig. 9: Waveforms of BLDC motor at a load torque 25 Nm

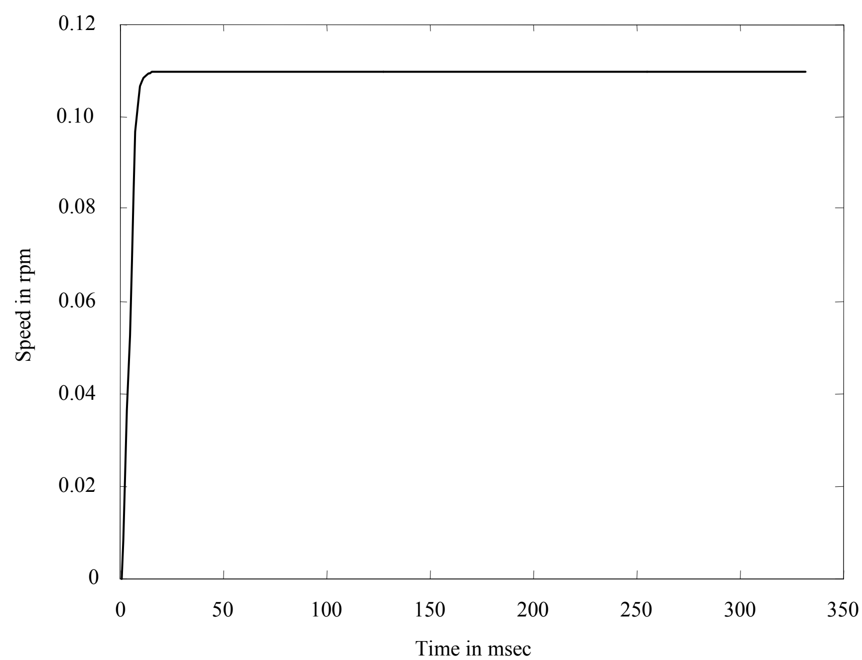

Fig. 10: Waveforms of BLDC motor at 100 rpm for ANFIS controller

get an error rate of 3.194 for 100 rpm speed shown in Fig. 10 and 2.186 for 150 rpm shown in Fig. 11.

Figure 10 and 11 shows the performance of brushless drive system with the adaptive ANN-PID controller which is examined for two different operating speed conditions such as 100 and 150 rpm.

Simulation result with load torque variation: The responses obtained from Fig. 12 and 13 shows that whenever the load changes, the load torque input to the neural network also changes and as a result the neural network computes the desired gain parameters for the PID controller so as to improve the performance of the system.

The responses obtained from different input voltages are shown in Fig. 14 and 15.

It is found that the neural network provides gain parameters for the PID controller according to the change in load torque. The PID controller tracks the change in error and takes necessary control action. The

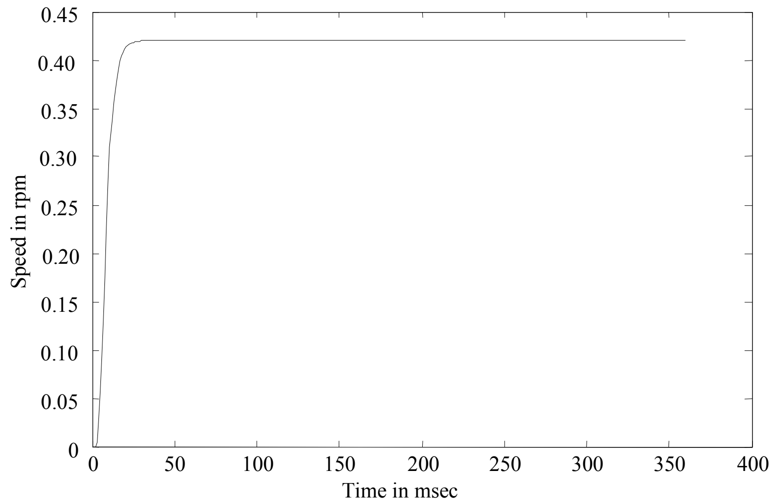

Fig. 11: Waveforms of BLDC motor at 150 rpm for ANFIS controller

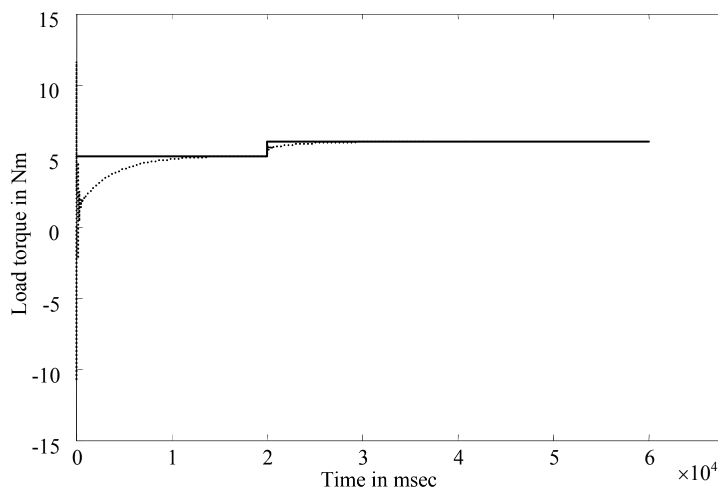

Fig. 12: Waveforms of BLDC motor at a load torque 5 Nm

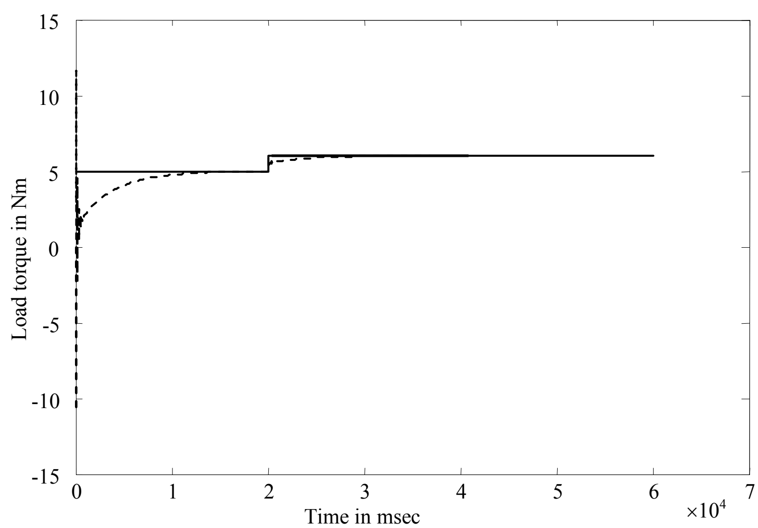

Fig. 13: Waveforms of BLDC motor at a load torque 5 Nm

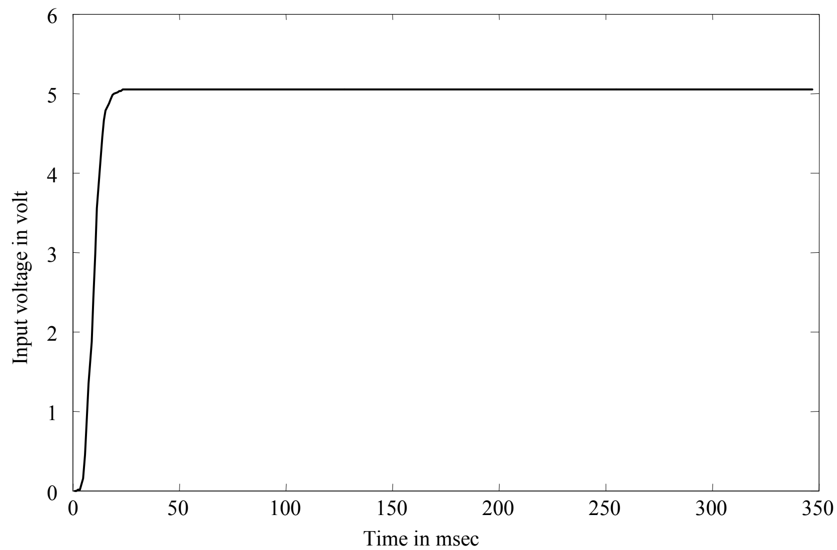

Fig. 14: Waveforms of BLDC motor at an input voltage of 5 V (1 unit = 2.5 v)

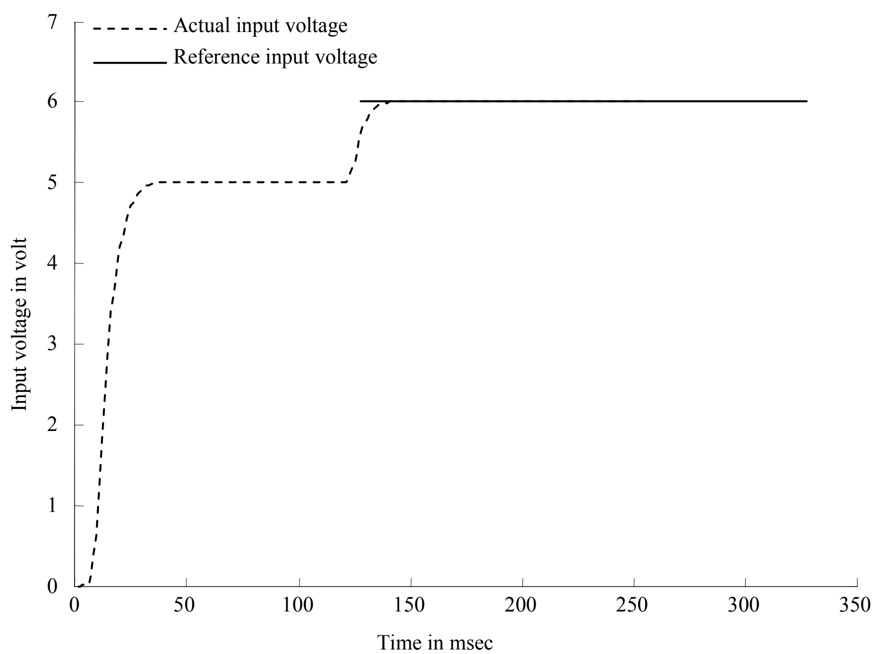

Fig. 15: Waveforms of BLDC motor at an input voltage of 25 V (1 unit = 5 V)

Table 1: Comparison of cuckoo search and ANFIS algorithm

Algorithm	Speed variation	Input voltage variation	Load torque variation
Cuckoo search	23	25	29
ANFIS	19	24	23

system responds faster and reaches steady value without any steady state error.

Comparison of ANFIS and cuckoo search in case of settling time (msec): From Table 1, it can be clear that the performance of Cuckoo Search algorithm is much better than the performance of ANFIS in case of reduction in settling time and overshoot.

CONCLUSION

In this study an efficient design method for determining the PID controller parameters of a PMBLDC Servo motor by using ANFIS and Cuckoo Search method is presented. In order to emphasize the advantages of proposed method, the result are compared with conventional controller. Through the simulation result, it is shown that the proposed method is able to obtain the optimal PID controller parameter to achieve better performance. The comparison result shows that ANFIS tuned controller yields better result in terms of overshoot and settling time than Cuckoo Search.

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