INDIAN JOURNAL OF SCIENCE AND TECHNOLOGY

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Competing Interests: None

Speed control of BLDC motor with neural controller

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Abstract

Objective: BLDC motor specifically used for high speed applications and needs sophisticated speed control. Conventional controls techniques require more physical involvement for assisting BLDC motor to operate with precise speed value. However, soft tuning based controller may give comparatively better results for that and the same has been elaborated in present paper using neural controller of speed as per requirements.the main objective of this study may be summarized as (i) MATLAB simulink model for BLDC motor incorporated with soft tuned controller and inverter simultaneously, (ii) development of neural controller for BLDC motor control, and (iii) validation of results developed through proposed controller with the available results using PI, PID and fuzzy logic controller. **Methods:** The speed obtained through simulink model with input supply voltage variations are used as a reference signal for the training and testing purpose of neural controller. With the help of these reference signals, neural control executes and gives optimum values of external parameters such as speed and electromagnetic torque. **Result:** The study outcome provides dynamic execution of proposed controller based on neural network. The proposed controller's results are validated with the reference results obtained mathematically for the system. The controller efficiency and sensitivity has been checked by MATLAB-Simulink software. **Novelty**: comparative study for mathematically obtained reference values and neural controller based results are proposed in this paper. The results are validated with the help of Matlab produces tables and figures.

Keywords: BLDC Motor; speed control; neural network controller

1 Introduction

In the current world scenario, BLDC (Brushless DC) motors are highly used in current days and it is having several applications as per to its terribly high speed with an extremely compact size compared to the opposite motors with brushes, furthermore

the importance of being energized by direct current (DC) and without all disadvantages of using brushes, that is convenient to several applications. A precise speed control is among the most challenging task and this paper proposes the advance soft controlling for the same. In this research study authors had tried to bring out the performance based design in spite of regular sophisticated design, along with this the performance of neural network based controller were tested for the maintaining speed control of a BLDC motor. Manufacturing companies utilize generally two types of motors: (i) dc motors wherever the current flows through the field winding of the static pole, the flux is created. (ii) PMBLDC (Permanent Magnet Brushless DC) motors wherever the permanent magnet supplies the required air gap flux rather than field winding poles. BLDC motors have their applications in wide range of industrial sectors due to its structure and suitability in handling any critical situations[1]. Brushes are not available in BLDC motors, therefore electronically arrangements provide for commutation. BLDC motor is in fact a PMSM (Permanent Magnet Synchronous Motor) motor with trapezoidal back electromotive force[2].

BLDC motors comprise many several striking properties like as easy speed control and torque –speed characteristics[1,3]. Furthermore, the control of DC motor is also easy and no need of complex Hardware[4]. But, DC motors have main disadvantages relating to lifespan of brushes are the limited. A lower reliability happens caused by the brushes and therefore, the operation requires time to time maintenance of replacement[5]. ANN (artificial neural network) is a highly interconnected processing element which processes the information using their dynamic characteristics to the external input[6]. ANN can efficiently approximate dynamics without requiring detailed knowledge of the plant. Another advantage of ANN is their possibility of learning, which can reduce the human effort during the design of the controllers and allows discovering more effective control structures[7].

2 BLDC motor operational principle

The operating rule of a BLDC and conventional DC motor is same; i.e. based on internal shaft position feedback. In conventional DC motor, brushes and mechanical commutator maintains the feedback, while BLDC motor use Hall Effect sensors and optical encoders for feedback. Hall sensors works on the principle that when a conductor that is carrying current is placed in a magnetic field, a force is experienced by charge carriers depending upon the potential difference between both sides of the conductor. The developed voltage will be reversed if magnetic field direction is changed. Whenever rotor passes a hall sensor, it develops either a HIGH or a LOW level signal to indicate which rotor pole (N or S) has passed and hall sensors also monitor the position of the shaft.

The three phase brushless dc motor, the back- EMF and its phase current waveforms are shown in Figures 1 and 2 respectively[8].
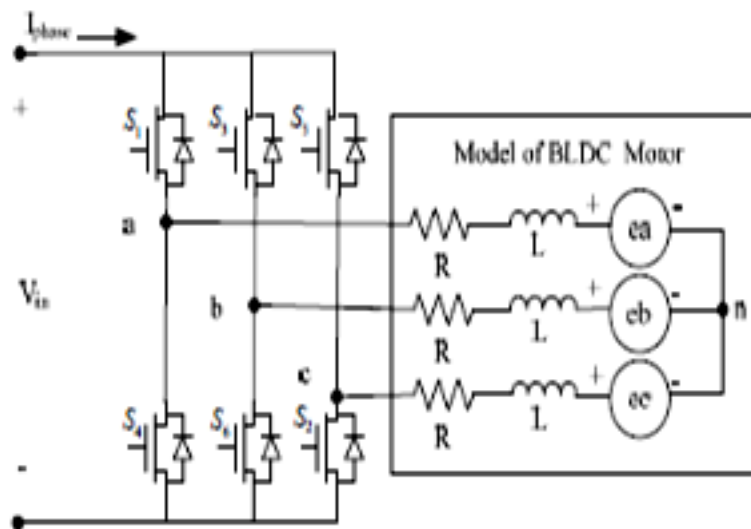

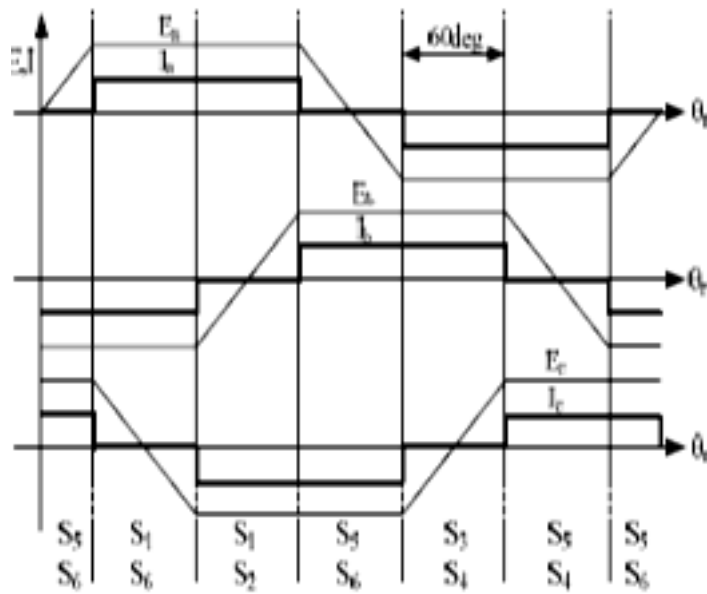**Fig 1.** Circuit Diagram of Brushless DC Motor Drive System

Fig 2. Trapezoidal back emf and reference current

3 Mathematical modeling of Brushless DC motor

Dynamic equations BLDC motor is described as following:

$$\begin{bmatrix} v_a \\ v_b \\ v_c \end{bmatrix} = \begin{bmatrix} R & 0 & 0 \\ 0 & R & 0 \\ 0 & 0 & R \end{bmatrix} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} + \begin{bmatrix} L-M & 0 & 0 \\ 0 & L-M & 0 \\ 0 & 0 & L-M \end{bmatrix} \frac{d}{dt} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} + \begin{bmatrix} e_a \\ e_b \\ e_c \end{bmatrix} \tag{1}$$

In Eq. (1), three phases voltages, three phases currents, three phases back emfs are represented by v_a, v_b, v_c, i_a, i_b, i_c and e_a, e_b, e_c respectively. The phase resistances, self-inductance and mutual inductance between phases are considered to be same in each phase and represented by R, L and M respectively.

The value of electromagnetic torque is with these parameters is

$$T_e = \frac{1}{\omega_r} \left(e_a i_a + e_b i_b + e_c i_c \right) \tag{2}$$

Here, parameter ω_r is used for mechanical speed of the rotor.

The motion equation is given by:

$$\frac{d}{dt} \omega_r = \left(T_e - T_L - B\omega_r \right) / J \tag{3}$$

The relation between electrical speed ω_e and mechanical speed ω_r of a motor with P poles is given as[6]:

$$\omega_e = (P/2)\omega_r \tag{4}$$

4 BLDC motor speed control

Figure 3 shows the structure of the planned neural network control of a brushless dc motor, which depend on the number of neurons in each layer of the planned ANN (Artificial Neural Network) architecture[9].
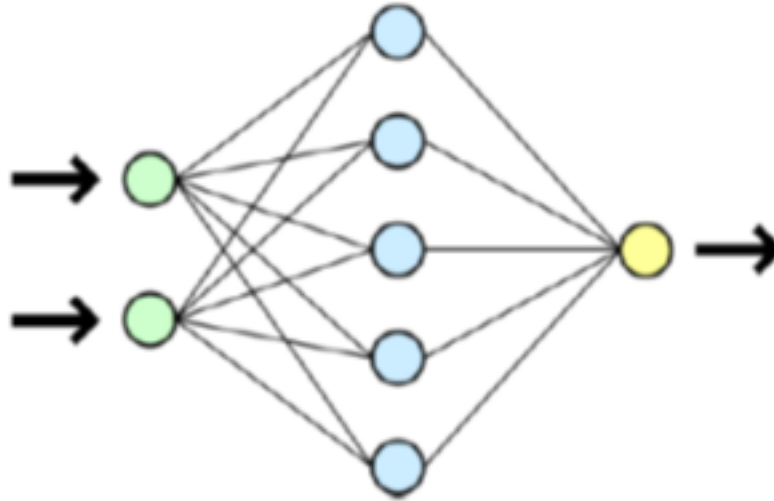
Fig 3. Proposed architecture for ANN Controller

The w_{ij} is the link of weight parameter among j_{th} and i_{th} neuron at m_{th} layer, b_{mi} is the bias parameter of that layer at i_{th} neuron. Transfer function of the system at t_{th} neuron in m_{th} layer is represented as[10].

$$n_i^m = \sum_{j=1}^{S^{m-1}} w_{ij}^m a_j^{m-1} + b_i^m \tag{5}$$

The resulting activation function of neuron at m_{th} layer is represented by

$$a_i^m = f^m\left(n_i^m\right) \tag{6}$$

5 Simulation results of BLDC motor

MATLAB/SIMULINK software is used to simulate the BLDC motor as discussed in previous sections. PWM (Pulse Width Modulated) inverter is used for supply of BLDC motor. Hall Effect signals are decoded to develop gate signals of inverter. Various parameters for BLDC motor is shown in Table 1.

Table 1. BLDC motor parameters

Parameter	Value
Phase resistance of stator	2.8750 ohm
Phase inductance of stator	8.5 mH
Number of poles	4
Number of phases	3
Input voltage	24 V
Torque Constant	1.4 N-m/A
Voltage constant	40 V/krpm
Inertia Constant	0.8 X 10-3 Kg-m2
Proportional constant	0.0015
Integral constant	0.25

To understand the system, a MATLAB designed simulink block, a schematic block diagram is shown in Figure 4 which has several blocks for all necessary components used in this study for validating the speed control of BLDC motor using ANN.
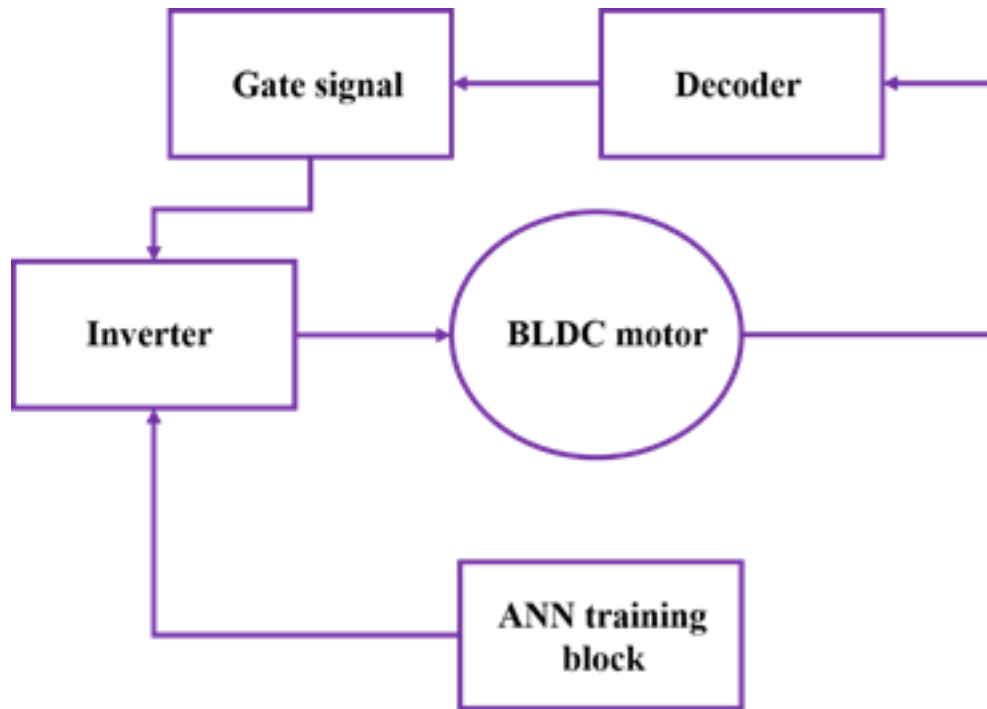
Fig 4. Schematic block diagram for MATLAB designed model

ANN training block trains the system and its training window and validating the result is shown in Figures 5 and 6 respectively.

Data has been collected for training ANN for speed control of BLDC motor. After collecting data, Correlation between speed and voltage is 0.99999255 and Correlation between speed at (t-1) and voltage is 0.999992578. Correlation refers to the connection of two variables or more. Correlation is statistical tool that measures the strength of association between two variables and the direction of the relationship. Scatter diagram is a type of mathematical diagram using Cartesian coordinates to display both variables graphically [11]. In this process, the value of Karl Pearson correlation coefficient is more than 0.9 in each case, which advise a mathematical method for computing the magnitude of linear relation between the both variables. It means that data is correct to train the ANN for speed control of BLDC motor.

Neural networks will have lots of parameters and learning the optimum value of all parameters from large datasets in a serial implementation can be a very time-consuming task [12,13]. For ANN learning process, multilayer feed forward back-propagation with gradient descent method is used. Multilayer feed forward networks are good for approximating any continuous function. Back propagation algorithm is simply iterative gradient descent on the empirical risk under squared error loss. This enables efficient calculation of the gradient.

Figure 5 represents the training of the system with the help of ANN training tool block available in MATLB model library. For this training, ANN architecture is designed with '3' inputs, '10' hidden layer and '1' output.

In ref.[5], results for BLDC motor control is obtained with the help of conventional and fuzzy logic controller however this paper proposes the superiority of artificial neural network over conventional PI and PID controller and fuzzy logic controller. To validate the results obtained through neural network in this study, a tabular form is given which compares the result of ANN with PID controller and fuzzy controller as in ref.[5].
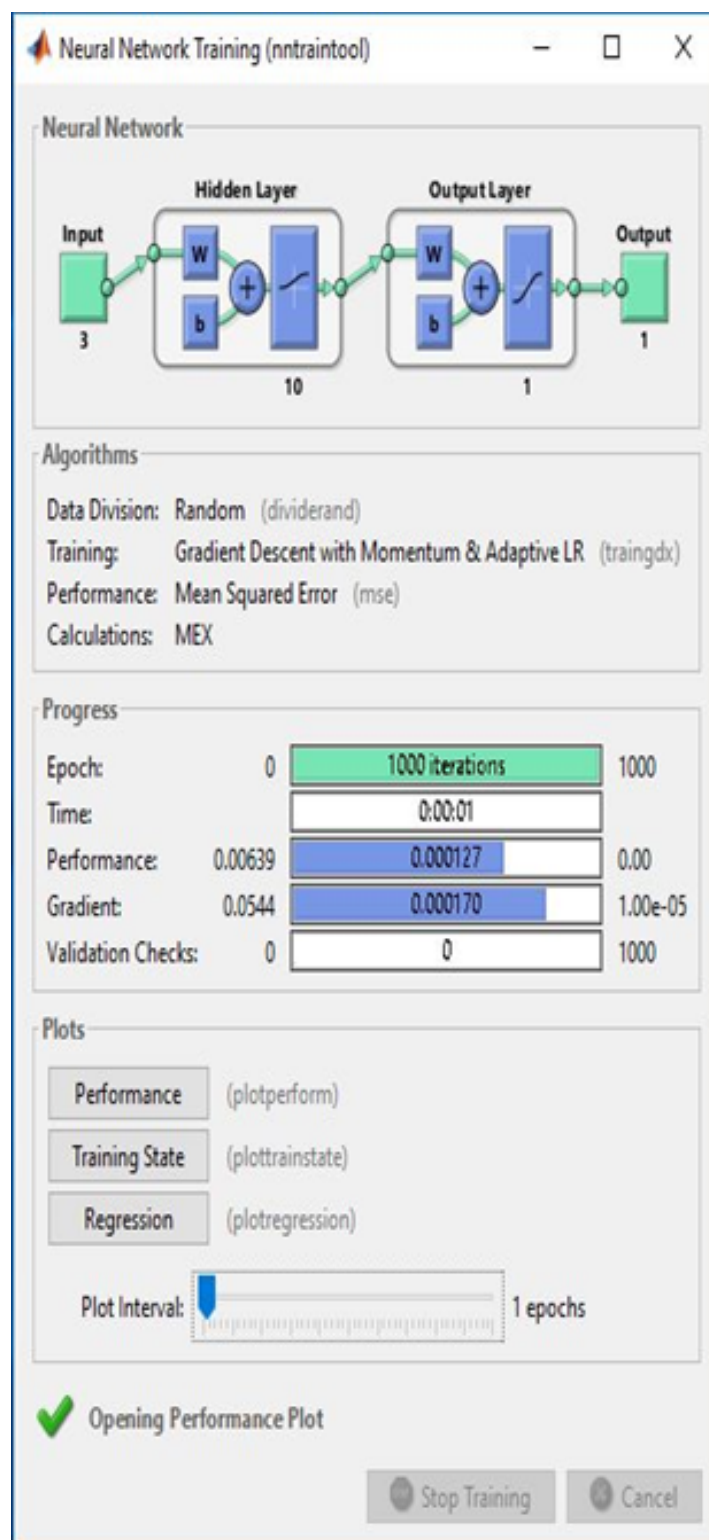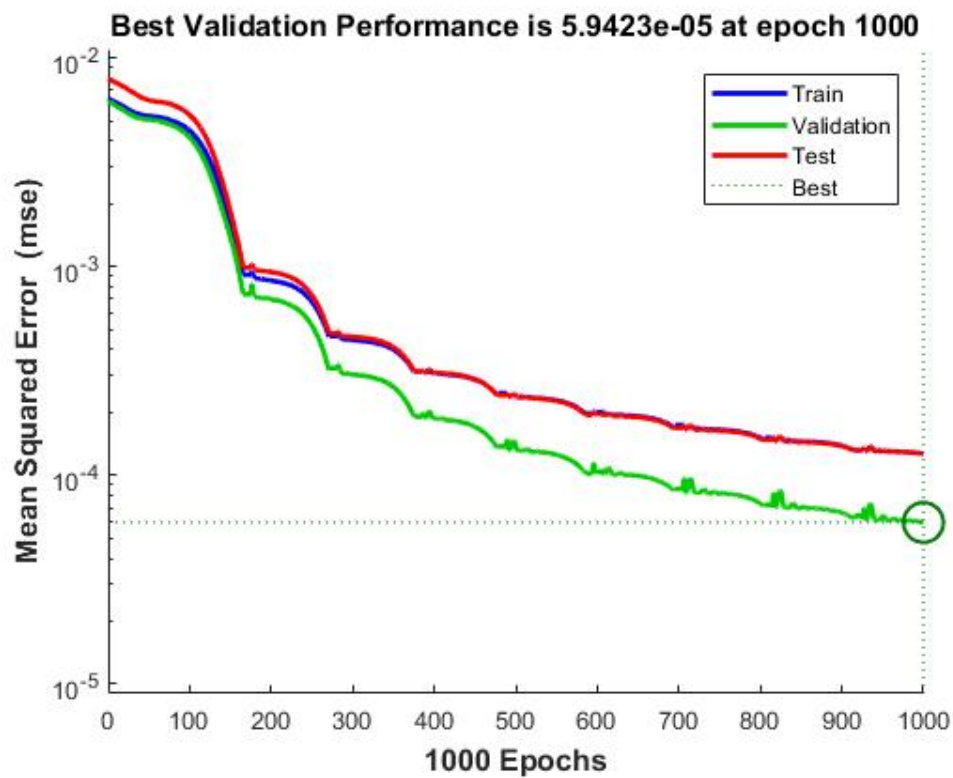
Fig 5. ANN training toolbox

Fig 6. Performance curve for result validation
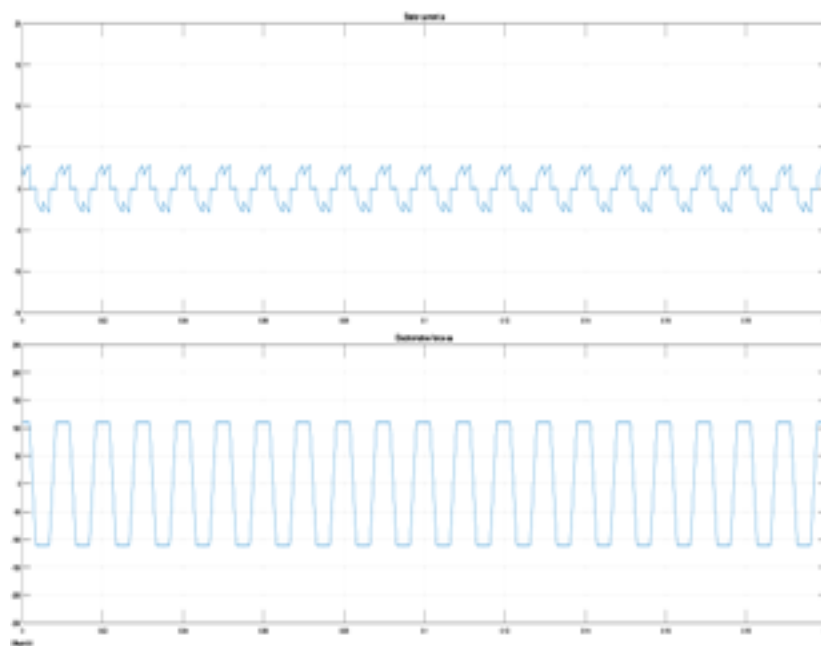

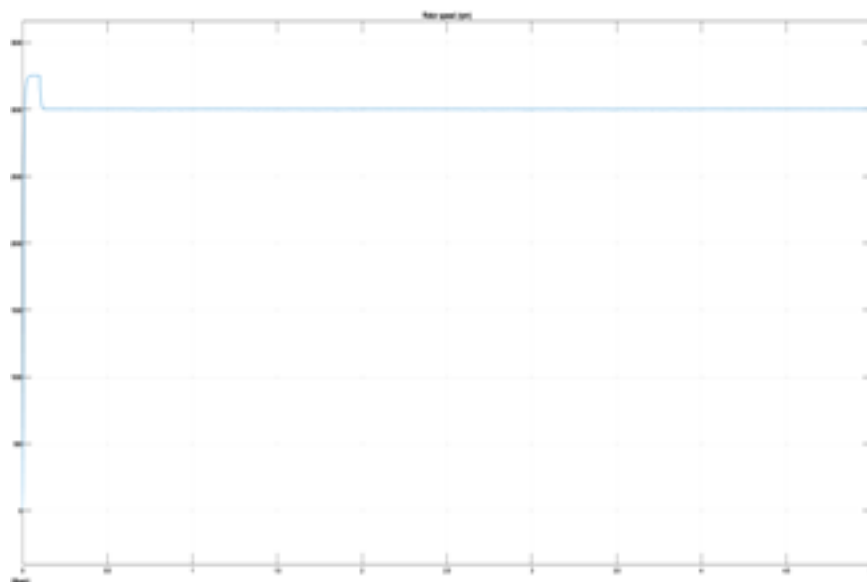**Fig 7.** Stator current and back EMF of Phase A

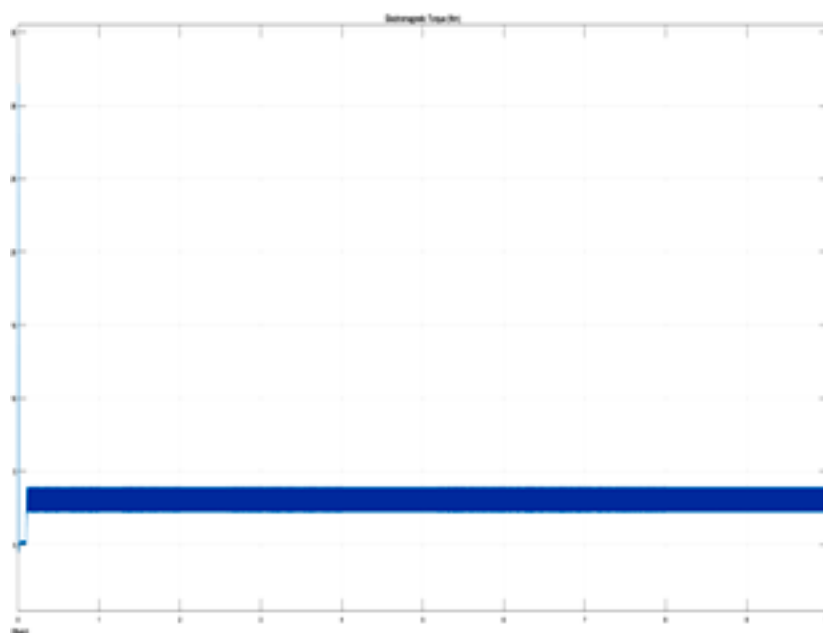**Fig 8.** Speed of BLDC motor with neural controller

Fig 9. Electromagnetic torque of BLDC motor

Figures 7, 8 and 9 shows response curves for stator current and voltage, speed and torque with neural controller respectively. For set speed of 3000 rpm the response values of ANN controller are as shown in Table 2 comparing with PI controller, PID controller and fuzzy logic controller together. Transient responses presented in Table 2 explains the value of rise time and overshoots are found better with neural controller comparing with their reference paper values. It is also found that settling time with ANN controller is also very low and equal to 0.165 sec only. The results obtained and elaborated with the help of figures and tables found the improved performance of BLDC motor with proposed artificial neural network based soft tuning technique.

Table 2. Transient performances comparison with different available controllers

Parameter\Controller	PI Controller	PID Controller	Fuzzy Controller	Proposed Neural Network
Rise Time	14.580 ms	12.288 ms	11.850 ms	5.7 ms
Overshoot (%)	4.737%	No overshoot	0.274%	No overshoot

6 Conclusion

The study outcome provides dynamic execution of proposed controller based on neural network. The study has presented a neural network controller of a BLDC motor drive with closed loop control. The controller efficiency and sensitivity has been checked by MATLAB-Simulink software. Simulation outcomes show that torque ripple and current ripple are decreased which increase the drive performance. It is concluded that applying the load torque to the motor with neural network controller, motor speed will not be decreased. Speed control is done by using soft control technique ANN. Results obtained in this paper are justifying the selection of techniques for motor control as with step load motor speed is not decreased with the use of proposed neural controller. The proposed controller's results are validated with the reference results obtained mathematically for the system. For ANN learning process, multilayer feed forward back-propagation with gradient descent method is used. The main philosophy of this paper is to investigate the parameters such as rise time, settling time and overshoot. With step load motor speed is not decreased. In conclusion, already mention that Simulation outcomes show that torque ripple and current ripple are decreased which increase the drive performance. With neural controller, BLDC motor has no steady state error. Neural network controller response offers high efficiency. The results give satisfactory outcomes of the dynamic execution of the BLDC motor under different load situations.

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