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Torque Ripple Minimization in Permanent Magnet Synchronous Motor Using Neural Networks

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ABSTRACT: This paper proposes the simulation of permanent magnet synchronous motor (PMSM) drive using Artificial Neural Network (ANN) controller. The artificial neural network has self-learning and self-regulatory property helps to control PMSM drive efficiently. In this paper, traditional PI-controller based speed control method is compared with the neural network based speed control method and the results are obtained. The simulation result shows that ANN controller reduces the torque ripples much better than PI-controller. The design, analysis, and simulation of ANN based controller method is simulated using MATLAB SIMULINK.

KEYWORDS: Artificial neural network (ANN), PI-controller, Permanent Magnet Synchronous Motor (PMSM).

I. INTRODUCTION

PMSM has been widely used in the low and medium power system due to its characteristics of high efficiency, high reliability, high torque to inertia ratio, smooth torque and fast dynamic response. In general, a sensor like optical encoder is necessary for the PMSM control system in order to obtain the rotor position and speed. Normally the controlling of the torque of PMSM usually follows either the most popular Direct Torque Control (DTC) or Field Oriented Control (FOC). In this paper the field oriented control based In-direct vector control method is used to control the torque. In this method the pulse production to the inverter is been generated by using the space vector pulse width modulation (SVPWM).

The switching of the power inverter constitutes the harmonics in PMSM and leads to variable switching frequency and high current ripples. The harmonics generated by power inverter which will leads to high torque pulsation and load disturbance. However, the traditional controlling methods are very sensitive to parameter variations, and load disturbance. Therefore, intelligent controllers such as fuzzy and neural network systems are normally needed to deal with such situations.[10]

The inverter and motor is treated as one part in space vector pulse width modulation (SVPWM), and the algorithm has been extensively used, since it has superior features such as low pulsating torque, low current harmonic distortion and high voltage efficiency. However a disadvantage of SVPWM is that it requires complex online computation which limits the switching frequency of the permanent magnet synchronous motor (PMSM) drive and brings high pulsating torque and current harmonic distortion [1].

Artificial Neural Network “ANN” has been applied to a wide range of dynamic system applications in recent years. Advantages of ANN controllers over the conventional ones presented in robustness, parallel distributed structure, and ability to learn as well as capability of handle nonlinear situations. These advantages support the ANN in playing a major role in solving uncertainty problems in motor drive systems, like stator resistance variation and dc voltage measuring operations in existence of high switching surges, leads to uncertainty in torque and flux estimation which

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in turn leads to torque ripple and in worst case it may lead to generation of breaking torque. In the field of ANN controllers many research efforts have been achieved to deal with PMSM control algorithms [2-9].
In this study, an application of ANN based controller for PMSM in the in-direct vector controller to minimize the torque ripples is presented. In this system the speed reference is compared with the actual speed and the output is given to speed controller. Here this speed controller is replaced by ANN controller and the output by this controller will be the torque reference. From the stator currents i_a, i_b, i_c applied to the Clarke transformation and park transformation the output will the synchronous current i_{ds}, i_{qs} .by using these values actual torque is calculated and compared with the reference torque. The output is given to the park inverse transformation and the output is given to the SVPWM generator to produce the pulse to the inverter .By proper switching of the inverter switches harmonics will be reduced in PMSM drives, which will further reduces the torque ripples in the PMSM drive.

II.MODELLING OF PMSM

To design artificial neural network based speed controller and observer for PMSM motor drive, the modeling of PMSM is essential. The vector control of PMSM drive has been chosen in this work. The vector control technique emulates a separately excited fully compensated DC motor into the control structure of the PMSM motor. The dynamic model of PMSM motor in vector control mode is represented in the form of mathematical equations as [12]

$$p_{id} = \left(V_d - R_{id} + \omega_r L_q i_q\right) / L_d \qquad (1)$$

$$p_{iq} = \left(V_q - R_{iq} - \omega_r L_d i_d - \omega_r \lambda_f\right) / L_q \qquad (2)$$

$$p\omega_r = \left(T_e - T_l - B\omega_r\right) / J \qquad (3)$$

$$p\theta_r = \omega_r \qquad (4)$$

where v_d, v_q, i_d and i_q are the voltages and current in d-q reference frame, θ_r and ω_r are the rotor angular position and speed. The electromagnetic torque (Te) is expressed as:

$$T_e = \left(\frac{3}{2}\right)\left(\frac{p}{2}\right)\left[\lambda_f i_q + \left(L_d - L_q\right) i_d i_q\right] \qquad (5)$$

The model of the PMSM is developed using SIMULINK and is utilized to compute the stator currents. [12]

II. EXISTING SYSTEM

Field oriented control (In-direct vector control) principle for PMSM:

The basic principle of vector control is to get a high-performance system through controlling flux and torque independently after getting the motor decoupling model through coordinate transformation. The torque command is generated as a function of the speed error signal, generally processed through a PI controller. The flux command for a simple drive strategy is made to be a function of speed. The flux is kept at rated value up to rated speed; above that, the flux is weakened to maintain the power output at a constant.

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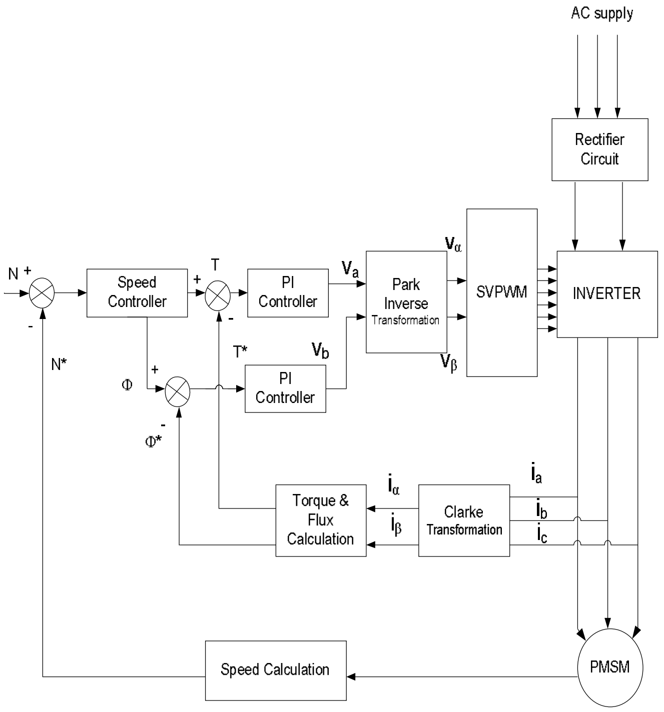

Fig.1 Block diagram of existing indirect-vector control

The speed from the motor is actual speed is compared with the reference speed and produce speed error. The speed error, with the help of a PI controller, is converted into a torque controlling current component i_{qs}* of the stator current. Assuming that i_a, i_b, and i_c are the instantaneous currents in the stator phases, then the complex stator current vector $\vec{i}_s$ defined by:

$$\vec{i}_s = i_a + \alpha i_b + \alpha^2 i_c \qquad (6)$$

Where $\alpha = e^{j\frac{2\pi}{3}}$

and $\alpha^2 = e^{j\frac{4\pi}{3}}$ represent the spatial operators.

The stator current complex space vector system is shown in fig.2:

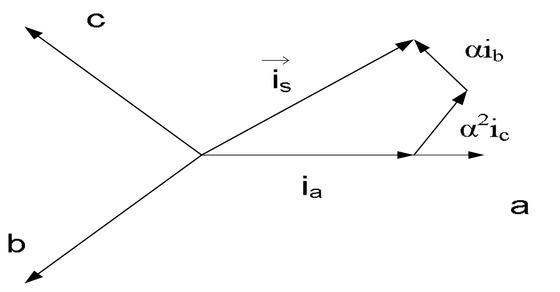

Fig.2 Stator current space vector and its component in (a,b,c)

where (a,b,c) are the three phase system axes. Then stator current space vector depicts the three phase sinusoidal system. It still needs to be transformed into a two time invariant co-ordinate system. This transformation can be split

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into two steps:
(a,b,c)=>(d_s,□q_s) (the Clarke transformation) which outputs a two co-ordinate time variant system.
(d_s,□q_s)=>(d_s*,q_s*) (the Park transformation) which outputs a two co-ordinate time invariant system.

The (a,b,c) to (d_s,□q_s) projection (Clarke transformation):
The vector can be reported in another reference frame with only two orthogonal axis called (d_s,□q_s) Assuming that the axis a and the axis d_s □□are in the same direction we have the following vector diagram.

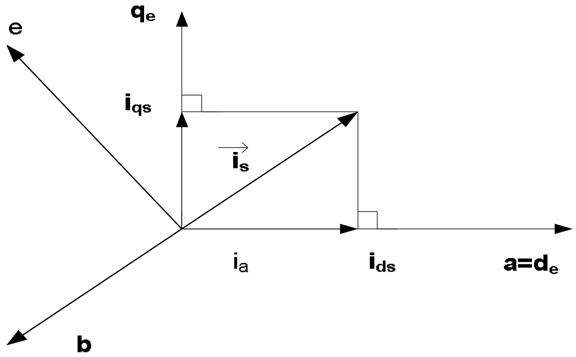

Fig.3 Stator current vector and its components in (a,b)

The projection that modifies the three phase system into the (d_s,q_s) two dimension orthogonal system is presented below.

$$i_{ds} = i_a \quad (7)$$

$$i_{qs} = \frac{1}{\sqrt{3}} i_a + \frac{2}{\sqrt{3}} i_b \quad (8)$$

We obtain a two co-ordinate system $\begin{pmatrix} i_{ds} \\ i_{qs} \end{pmatrix}$ that still depends on time and speed.

The (d_s,q_s) to (d_s*,q_s*) projection (Park transformation):
This is the most important transformation in the FOC. In fact, this projection modifies a two phase orthogonal system (d_s, q_s) in the d,q rotating reference frame. Consider the d axis aligned with the rotor flux, the next diagram shows, for the current vector, the relationship from the two reference frame,

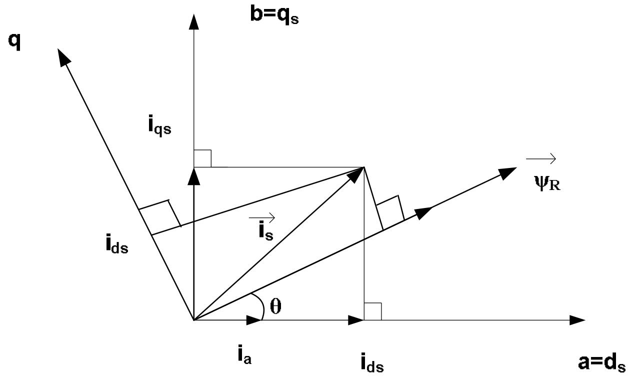

Fig.4 Stator current space vector and its component in (a,b) and in the d_s*,q_s* rotating reference frame.

where $\vec{\psi}_R$ □is the rotor flux position. The flux and torque components of the current vector are determined by the

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following equations:

$$i_{ds}^* = i_{ds}\cos\theta + i_{qs}\sin\theta \qquad (9)$$

$$i_{qs}^* = -i_{ds}\sin\theta + i_{qs}\cos\theta \qquad (10)$$

These components depend on the current vector (d_s,q_s) components and on the rotor flux position; The right rotor flux position is known then, by this projection, the d_s*,q_s* component becomes a constant. Then the obtain a two co-ordinate system $\begin{pmatrix} i_{ds}^* \\ i_{qs}^* \end{pmatrix}$ with the following characteristics: two co-ordinate time invariant system with i_{ds}(flux component) and i_{qs} (torque component) the direct torque control is possible and easy.

PI-controller:

The classic PI (Proportional and Integral) regulator is well suited to regulating the torque and flux feedback to the desired values as it is able to reach constant references, by correctly setting both the P term (K_{pi}) and the I term (K_i) which are respectively responsible for the error sensibility and for the steady state error.

The control equation which the PI controller involves is given as:

$$i_{qs}^* = K_p\Delta\omega_r + K_i\int\Delta\omega_r dt \qquad (11)$$

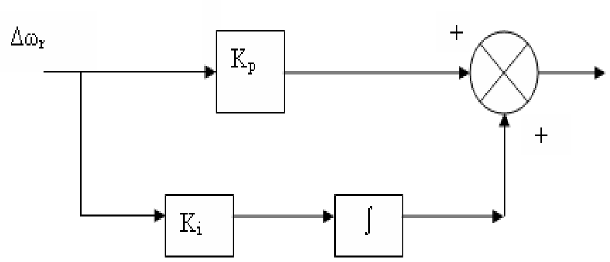

Fig. 5 Classical PI Regulator Structure

III. PROPOSED SYSTEM WITH NEURAL NETWORK CONTROLLER

Traditional PI controller will produce satisfactory results for fixed parameter system but it cannot achieve for the high precision PMSM drive. Artificial neural network has the ability of self-learning and self-regulatory. One of the important aspects of applying an ANN to any particular problem is to formulate the inputs and outputs of the ANN structure under study. The tuning effort of an AI based system is less than that of a conventional PI system. Such a system leads to reduced development time.

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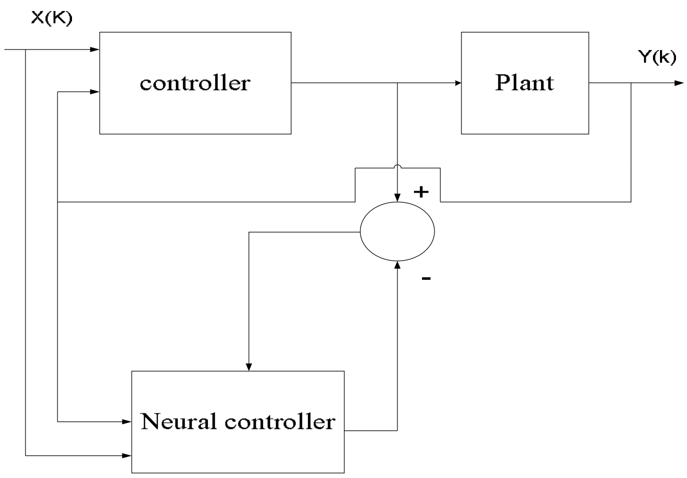

Fig. 6 Training of neural network controller to emulate neural network controller

The proposed ANN controller contains three layers such as input layer, hidden layer and output layer. In this simulation the inputs of the proposed ANN are the speed error of the motor. The corresponding output target is the torque. After the inputs and output are formulated, the next step is to incorporate the hidden layers. Number of hidden layers and number of neurons in the hidden layer are chosen by trial and error, keeping in mind that the smaller the numbers are, the better it is in terms of both memory and time requirement to implement the ANN in the motor control. The input and output of the ANN controller can be determined from the knowledge of conventional PI (Proportional-Integral) controller

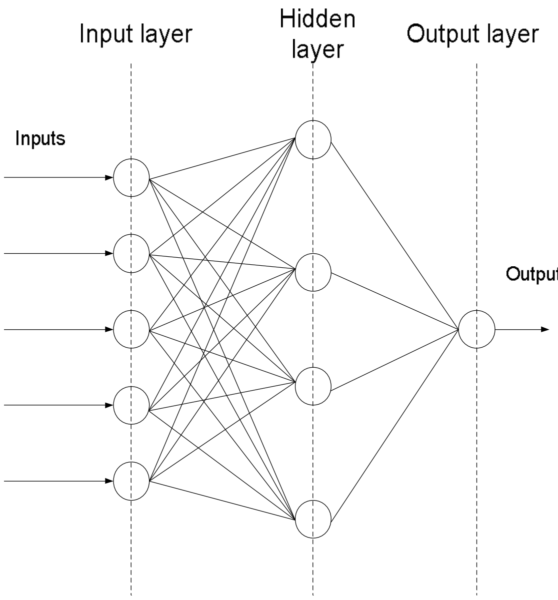

Fig. 7 Multilayer feed-forward artificial neural network with one hidden layer.

For this present paper, the structure of one hidden layer having six neurons gives satisfactory results. Once a design of the ANN structure is done, the next step is to train the network, here normal feed forward network is used because it is simple and easy to implement.
To train the parameters and to find out the desired mean square error the MATLAB commands used are:
net.trainparam.show=100;
This is used to show the status of training of the network after the interval of 100 epochs and

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net.trainparam.goal=.00001;

sets the goal to reach the error up to 10e-5. Following command is used to train the network

[net,tr,y]=train (net,p,t);

where 'p' is the input data and 't' is the output data. To plot the linear regression analysis graph between the desired rotor position and the obtained rotor position the following command is used.

a=sim(net,p);

where 'a' is the trained network .To generate neural network block in Simulink which replaces the controller and an observer in the control system the command used is as:

gensim(net,-1);

The SIMULINK block of proposed ANN controller as shown in Fig.8 is generated as a result of command gensim,

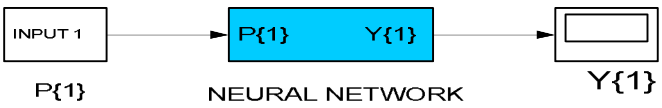

Fig.8 Generated ANN controller in simulink block

The block diagram shown above will replace the speed controller in the general block diagram. Thus the PI controller in the speed controller will be replaced by this block. The block diagram for ANN controller based indirect vector controller is shown below.

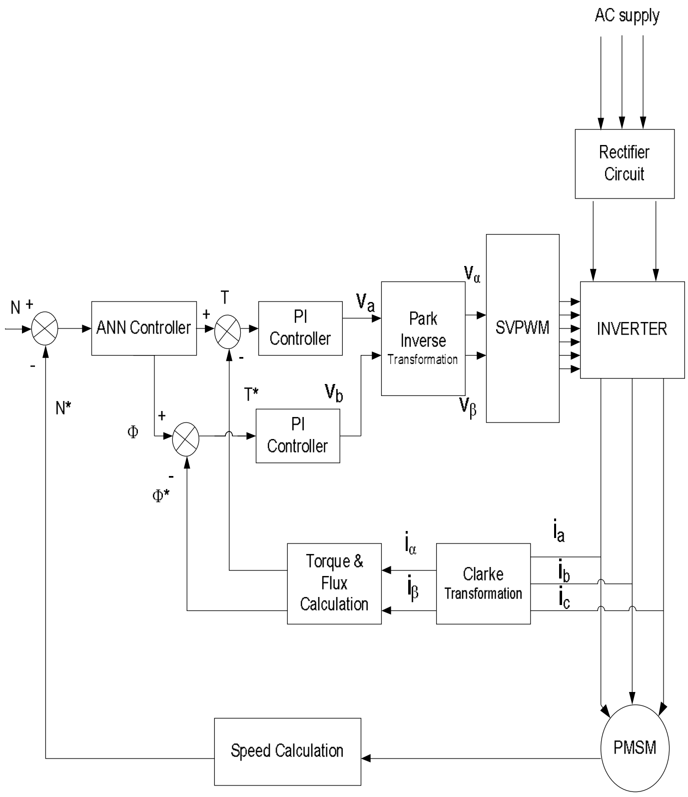

Fig.9 Block diagram of proposed ANN based indirect vector controller.

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V. RESULT AND DISCUSSION

The training diagram for the neural network created network is allowed to use as a speed controller for the PMSM drive for 149 epochs is shown in fig.10, The error has been reduced approximately up to $10^{-}5$.

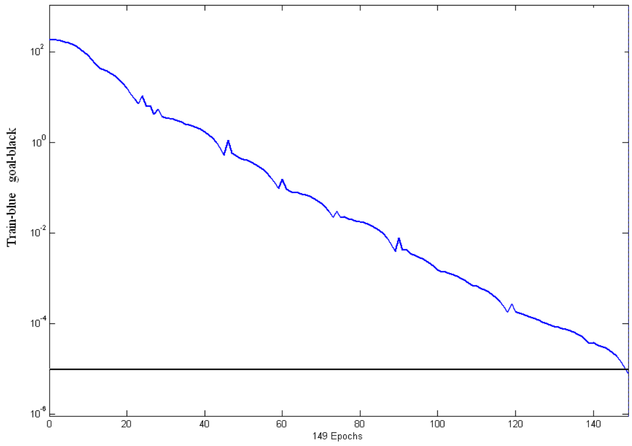

Fig. 10. Training graph of speed control ANN.

By using MAT Lab's built-in neural network functions. The output of the neural network is torque. Fig. 11 shows the perfect linearization of the linear regression analysis graph between the desired output and the obtained output.

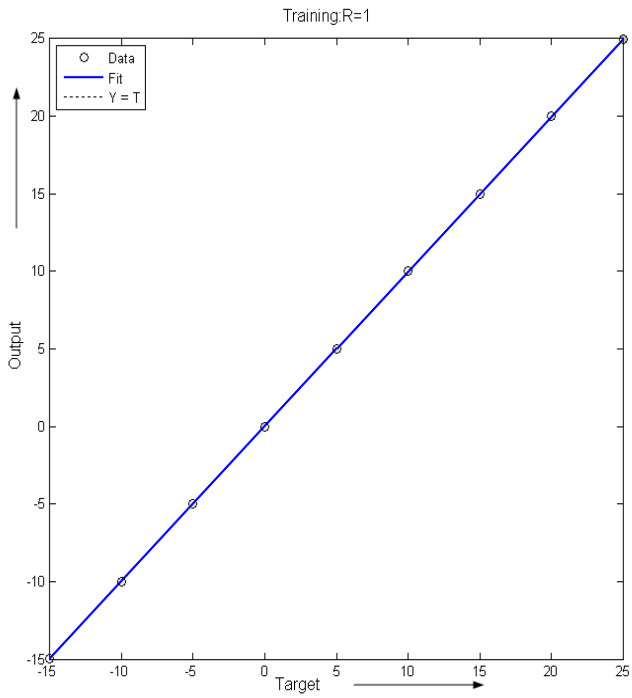

Fig 11. Regression graph obtained from ANN speed controller block.

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The results of PI based controller and the results of ANN based speed controllers speed and torque waveforms are shown in the fig 12,13,14,15. During starting the current and torque rise is observed till the time the motor achieves the set speed. The load of 8 Nm is applied to the motor. The set speed for motor is applied as 50 rad/sec.

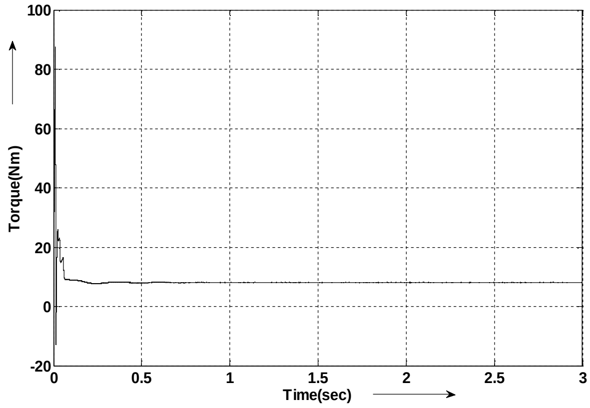

Fig 12. Torque waveform for PI based controller.

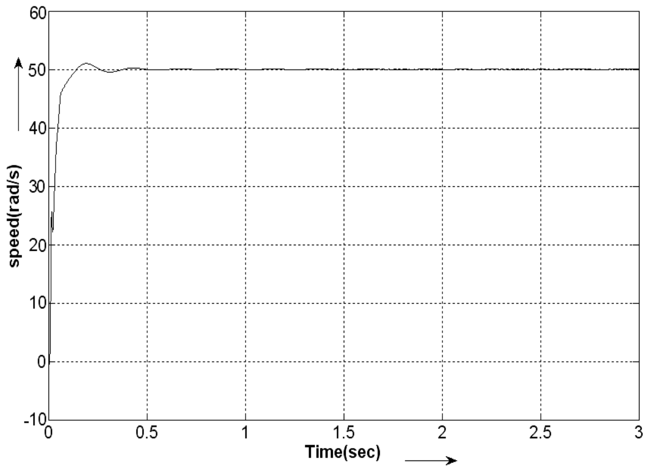

Fig 13. Speed waveform for PI based controller.

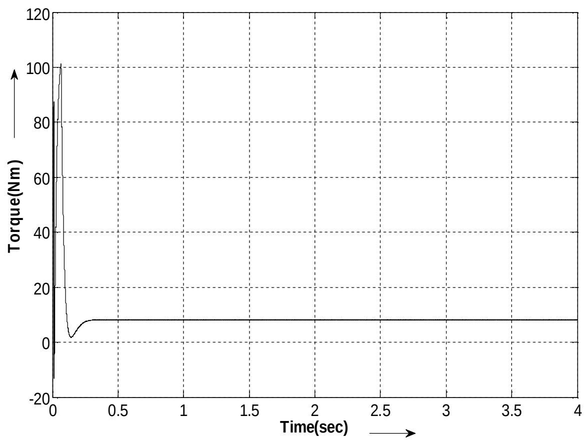

Fig 14. Torque waveform for ANN based controller.

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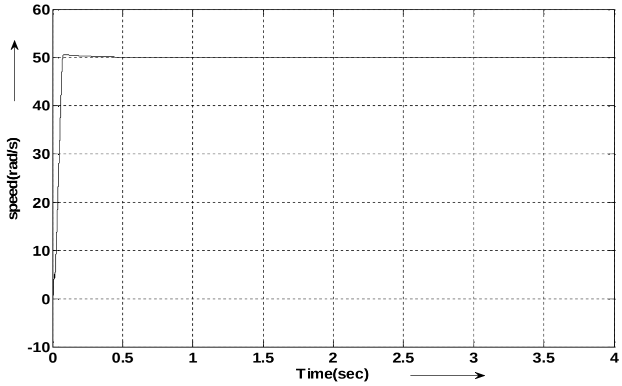

Fig 15. Speed waveform for ANN based controller.

The dynamic torque response both the PI based controller and the ANN based controller is compared and the results are shown in the fig 16,17.

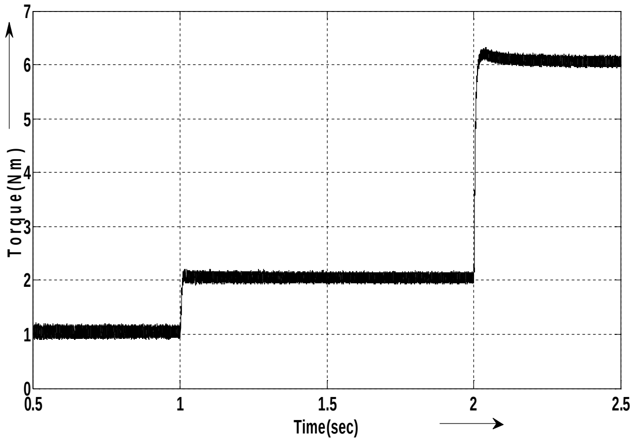

Fig. 16 Dynamic response of torque using PI controller

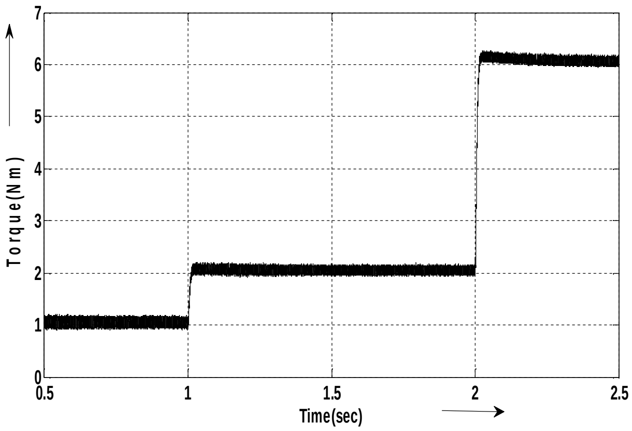

Fig. 17 Dynamic response of torque using ANN controller

The stator currents i_a, i_b, and i_c, waveforms of the ANN based controller is shown in fig.18

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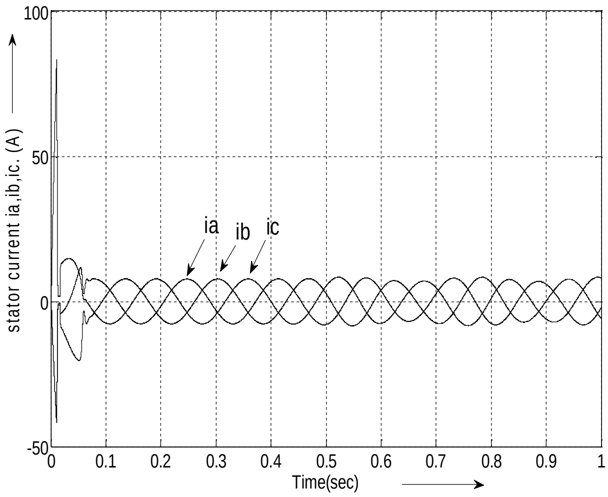

Fig. 18: Stator current waveform of ANN based controller.

The enlarged toque waveforms of the PI based speed controller and ANN waveforms are shown in fig. 19 ,20.

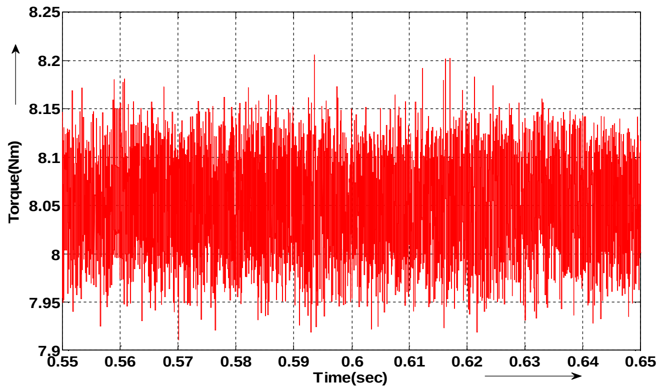

Fig 19. Torque ripples in PI based controller.

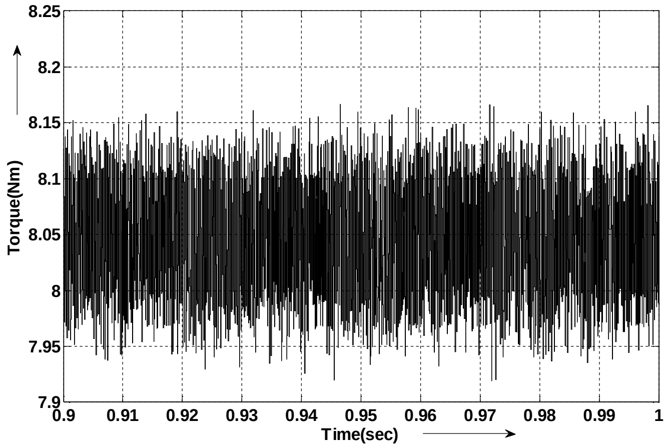

Fig 20. Torque ripples in ANN based controller

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Torque pulsations are less in case of neural network controller. It is clear that a neural network based speed controller achieves the minimum torque ripple than PI based speed controller and hence it is preferred over PI based controller. Moreover neural network controller has better current and torque characteristics over a PI based speed controller designed for the same drive system.
The percentage of ripples obtained by each case are shown and compared, by PI controller it is 3.8% of ripple, and by ANN based controller the ripple is 3.3%. Thus by ANN based controller ripples is reduced by 0.5%.

VI. CONCLUSION

ANN based speed controller model of PMSM motor drive have been modeled and simulated using MATLAB and the results have been presented to demonstrate the proposed Al based control. The simulated results of neural network speed controller have shown the improved performance over the PI speed controller and hence it can be effectively used in place of PI speed controller. The results obtained from ANN based speed and torque demonstrate fast and satisfactory response with satisfactory load perturbation, hence, may replace the resolver and the cost of the drive with the sensor less ANN observer may be reduced considerably.

VII. APPENDIX

MOTOR PARAMETERS

Type	PMSM
Rated speed	75(rad/sec)
Number of phases	3
Number of poles (P)	8
Base current	8 A
Rated voltage	300 V
Stator resistance per phase(R)	0.9585 ohm
q-axis inductance(Lq)	0.00525 H
d-axis inductance (Ld)	0.00525 H
Stator flux linkages per phase due to rotor magnet (A f)	0. 1827V/ (rad/s)
Moment of inertia (J)	0.0006329Kg/m^2
Friction Factor (F)	0.0003035(N.m.s)

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BIOGRAPHY

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