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RESEARCH ARTICLE

Neuro PID Speed Controller for Permanent Magnet Synchronous Motor

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Abstract— This paper deals with the designing of neural PID speed controller of Permanent Magnet synchronous Motor (PMSM). The conventional Proportional-Integral-Derivative (PID) controller is largely used in industry because of the robustness this regulator procures. ANN is developed controller in this work, offer inherent advantages over conventional PID controller for PMSM, Reduction of the effects of motor parameter variations, improvement of controller time response and improvement of drive robustness. The permanent magnet synchronous motor is controlled with a neural network tuned PID controller. Neural network is trained to provide the optimum value for various set speed and various load conditions. Simulation results show the designed controller improves the dynamic and steady state performance of the PMSM when compared to the conventional PID controller.

Keywords— ANN, PMSM, PID controller, robustness, PI controller

I. INTRODUCTION

Among the ac drives, permanent magnet synchronous machine (PMSM) drives have been increasingly applied in a wide variety of industrial applications. The reason comes from the advantages of PMSM: high power density and efficiency, high torque to inertia ratio, and high reliability. Recently, the continuous cost reduction of magnetic materials with high energy density and coercitivity (e.g., samarium cobalt and neodymium-boron iron) makes the ac drives based on PMSM more attractive and competitive. In the high performance applications, the PMSM drives are ready to meet sophisticated requirements such as fast dynamic response, high power factor and wide operating speed range. This has opened up new possibilities for large scale application of PMSM. Consequently, a continuous increase in the use of PMSM drives will surely be witnessed in the near future. Due to advent of higher frequency switching devices like MOSFETs, IGBTs and MCTs etc., very accurate position and speed control are possible with PMSM drives. The PMSM replaces field coil, dc power supply and slip rings of Synchronous Machine with a permanent magnet. The PMSM requires sinusoidal current to produce constant torque like Synchronous Motor. To obtain highly desirable control characteristics like separately excited dc motor, vector control of the PMSM is used [3], [4]. Vector control of the PMSM drive can be viewed as a multiple single-input-output feedback control problem.

The conventional proportional integral (PI) and proportional integral derivative (PID) controllers have been widely utilized as speed controllers in PMSM drives. However in order to obtain the best results from the controls, the d-q axis reactance parameters of the PMSM must be known exactly. This is rather difficult and conventional fixed gain PI and PID controllers are very sensitive to step change of command speed, parameter variations and load disturbance [1]. Therefore, a special controller of PMSM is needed to make speed control in high performance drive systems [2]

In order to improve controller performance by reducing torque and flux ripples, many control strategies have been presented since 1990's one of these methods is by using Artificial Intelligent (Artificial Neural network (ANNs), Fuzzy Logic Control (FLC) techniques [6-8].This is mainly due to their ability learning and generalization. For that, we developed an intelligent technique to improve the dynamic performances of the PMSM; this method consists in replacing the PID controller based on the artificial neurons networks in order to lead the flux and the torque.

II. PERMANENT MAGNET SYNCHRONOUS MOTOR DRIVE SYSTEM

The motor drive consists of four main components, the PM motor, inverter, control unit and the position sensor. The components are connected as shown in fig 1

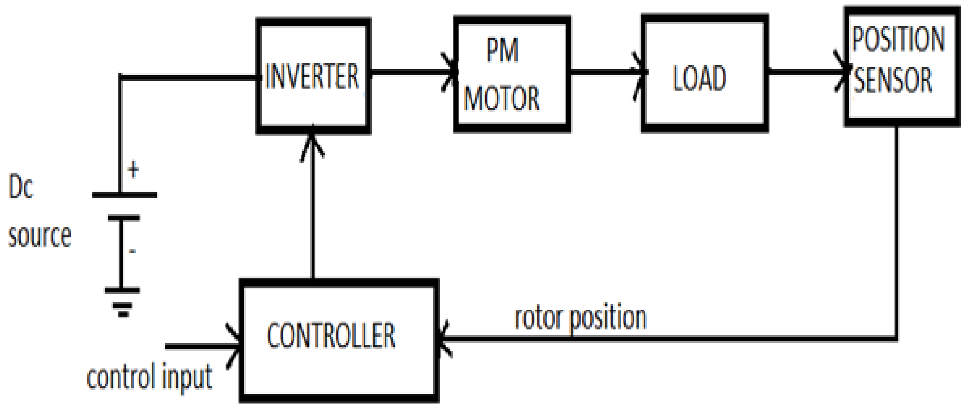

Fig 1 Drive System Schematic

A. *Mathematical Modelling of PMSM*

The two axes PMSM stator windings can be considered to have equal turn per phase. The rotor flux can be assumed to be concentrated along the d axis while there is zero flux along the q axis, an assumption similarly made in the derivation of indirect vector controlled induction motor drives. Also, rotor flux is assumed to be constant at a given operating point.

The model of PMSM without damper winding has been developed on rotor reference frame using the following assumptions:

1) Saturation is neglected although it can be taken into account by parameter changes;

2) The back emf is sinusoidal;

3) Eddy currents and hysteresis losses are negligible.

4) There are no field current dynamic

With these assumptions the stator d, q equations in the rotor reference frame of the PMSM are [6], [7]

$$V_q = R_s i_q + \frac{d}{dt}\Psi_q - \omega_r \Psi_d \tag{1}$$

$$V_d = R_s i_d + \frac{d}{dt}\Psi_d - \omega_r \Psi_q \tag{2}$$

Where R_s= stator resistance and Ψ_d, Ψ_q, Ψ_f are d, q-axis and field flux linkages respectively.

The flux linkages can be written as

$$\Psi_d = L_d i_d + L_m i_f \tag{3}$$

$$\Psi_q = L_q i_q \tag{4}$$

Where L_m is the mutual inductance between the phases. L_d & L_q are d, q-axis inductances. i_d,

i_q & i_f are d, q-axis & field currents respectively. Substituting these flux linkages into the stator voltage equations (1) & (2).

The voltage equations can be represented in Matrix form as

$$\begin{pmatrix} v_d \\ v_q \end{pmatrix} = \begin{pmatrix} R_q + pL_q & \omega_r L_d \\ -\omega_r L_q & R_d + pL_d \end{pmatrix} \begin{pmatrix} i_d \\ i_q \end{pmatrix} + \begin{pmatrix} \omega_r L_m i_f \\ p\Psi_f \end{pmatrix} \tag{5}$$

Where p= differential operator.

The developed electromagnetic torque equation can be given as

$$T_e = \frac{3}{2} P\left(\Psi_d i_q - \Psi_q i_d\right) \tag{6}$$

Substitution of flux linkages in terms of inductances and current yields

$$T_e = \frac{3}{2} P\left(\Psi_d i_q + (L_d - L_q) \mathrm{i}_q i_d\right) \tag{7}$$

The mechanical torque equation can be given as

$$T_m = T_L + J\frac{d\omega_m}{dt} + B\omega_m \tag{8}$$

$$\omega_m = \frac{2}{P}\omega_r \tag{9}$$

III. Controller For PMSM Drive

A. *Conventional PID*

In conventional PID controller, the proportional gain value Kp , integral gain value Ki and derivative gain Kd are kept at optimum value. The optimum value is chosen at which, the Kp, Kd and Ki value provides less speed oscillation for different load and speed conditions. This conventional PID controller produces better results for some speed and load settings only. Figure 3 shows the Speed Vs Time curve for the set speed of 3500 Rpm under 1Nm Load in Conventional PID Controller. Figure 4 shows the Speed Vs Time curve for the set speed of 3500 Rpm under 3Nm Load in Conventional PID Controller. From figure 3 and figure 4 it is clear that the speed response results in oscillation under a fixed Kp, Kd and Ki

B. *Artificial Neural Network(ANN) Controller*

Neural network mathematical model is based on perceptron structure. Each neuron is a Perceptron with input data set, weight for each input data, activation function and output, which usually has binary value. Neural network consists of several layers. Each layer may have definite or indefinite number of neurons. Neural networks give possibility to analyze an object by input parameter set and to detect predefined class of the object on the output. That means, neural network should be trained to detect classes and classes are predefined.

An ANN controller is a sophisticated intelligent controller. The designing of ANN controller requires four steps.

1. Obtaining the inputs and target samples from the reference plant. (Here the reference plant is considered as an Permanent Magnet synchronous Motor)
2. Extracting the network architecture consisting of a minimum of any hidden layer.

3. Training the network with the samples generated.
4. Simulating the network and obtaining the controller.

The architecture of the proposed neural network is a two layer feed forward neural network, consisting of a single hidden layer and an output layer. The hidden layer consists of ten neuron cells with tan sigmoid activation function and is shown in fig.2. The outer layer consists of one neuron cell with linear activation function.

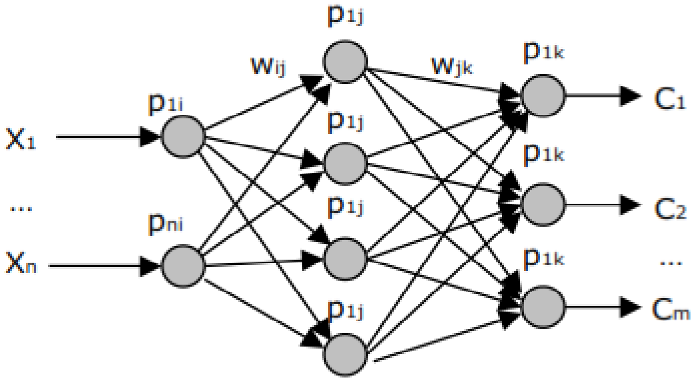

Fig.2 Architecture of the proposed neural network

IV. Neural Network Based PID Controller

The simulink block for closed loop control of PMSM using both PID and ANN controllers is shown in below Fig.3

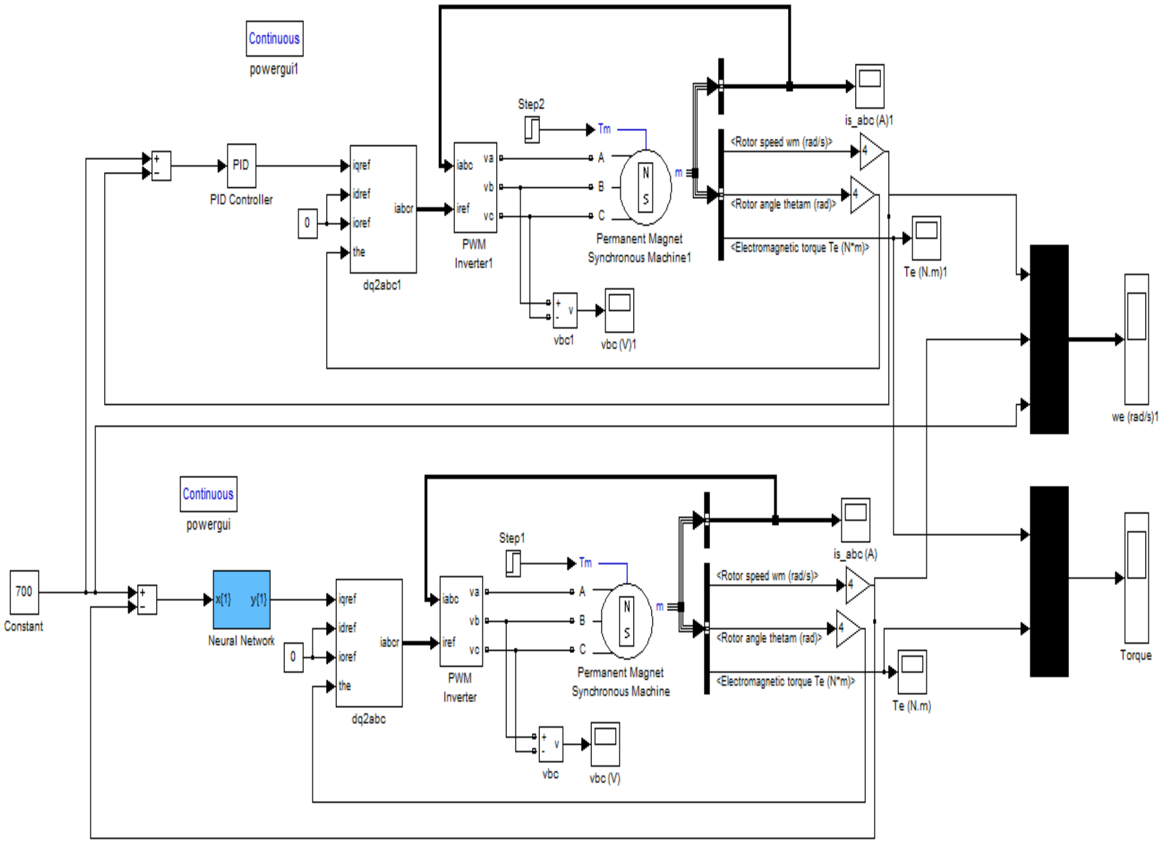

Fig.3 SIMULINK of PID and ANN Controller

In proposed PID controller neural network is used to tune the KP and KI values according to the different load and set speed conditions. The optimum values for different load and speed conditions are calculated from the conventional methods. This optimum values are used to train the neural network. Here inputs for neural network are speed and load torque, the outputs are optimum KP and KI values

A. Case1

No Load T_L=0 N-m, J=1.2e-3 and reference speed =700Rpm and the corresponding speed, Torque and stator currents are obtained as follows:

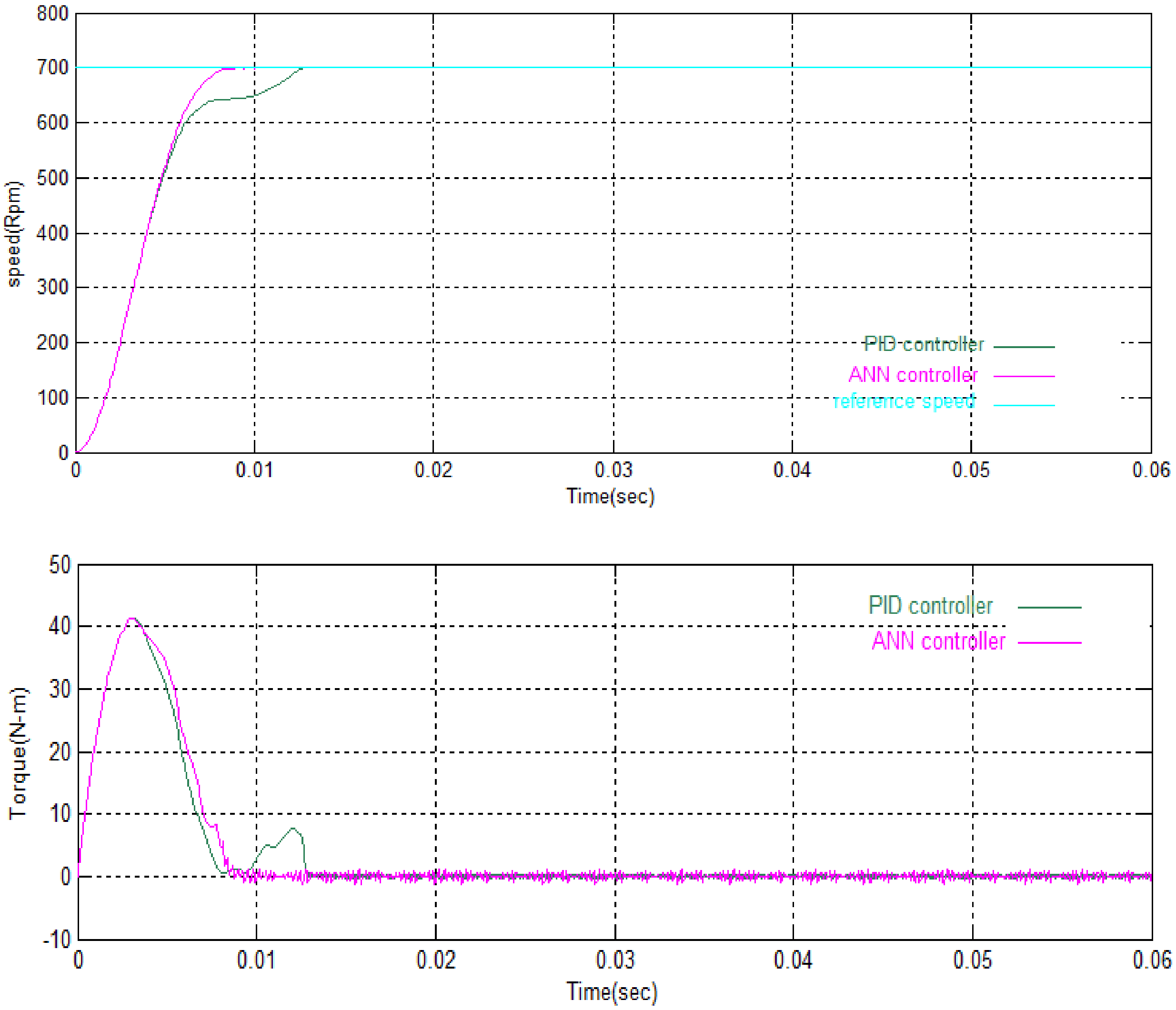

Fig.4 Speed and Torque Characteristics

B. Case 2

T_L=5 N-m applied at t=0.1sec and load is increased to T_L=10 N-m at t=0.3sec ,J=1.2 e-3 and reference speed =700 Rpm and the corresponding speed, Torque and stator currents are obtained as follows:

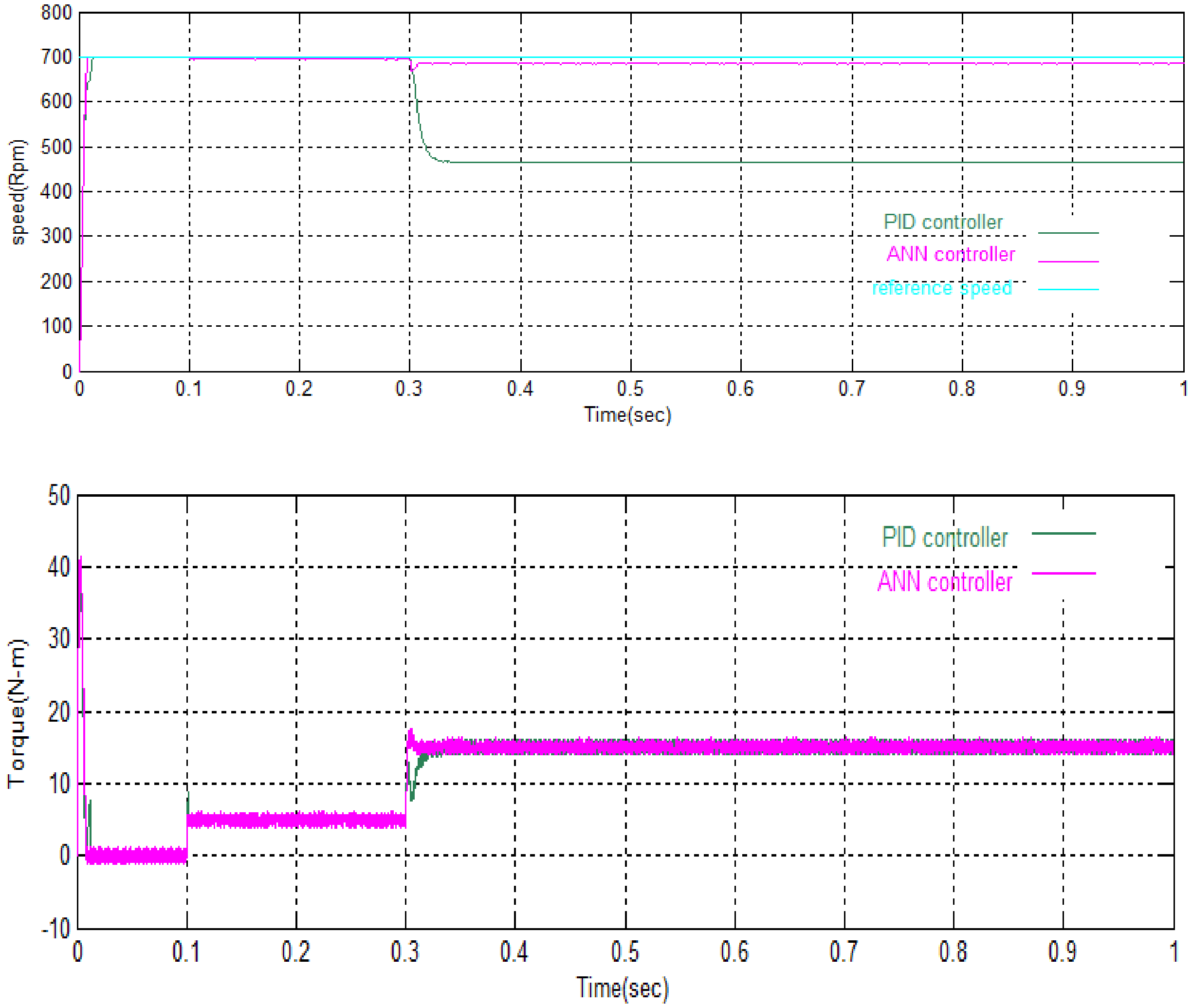

Fig.5 Speed and Torque Characteristics

V. CONCLUSIONS

The project focuses on the permanent magnet machine speed control using neural networks. First a neural network was trained with an appropriate training data set. Next, the neural controller obtained as applied in place of the speed PID regulator. The effectiveness of the proposed control technique has been established in simulation at different operating conditions. The proposed controller provides better performances in terms of speed tracking and load torque disturbance rejection. It also shows good adaptability to variation of parameters. From the comparison of PID controller and ANN controller we conclude that:

1) At no load and loaded condition, ANN has less peak over shoot and smaller settling time.

2) At no load and smaller values of J, PID controller has less peak overshoot and smaller settling time.

3) At no load and larger values of J, ANN has zero peak over shoot and very small settling time.

Hence ANN controller gives better performance compared to PID controller for large parameter variations and load disturbances.

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