Induction Motor Drive Based Neural Network Direct Torque Control

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Abstract A neural network based direct torque control of an induction motor was presented in this paper. The paper trained a neural network for speed controller of the machine to use in the feed-back loop of the control system. The description of the control system, training procedure of the neural network is given in this paper. The complete neural network based direct torque control scheme of induction motor drive is simulated using MATLAB. The acquired results compared with the conventional direct torque control reveal the effectiveness of the neural network based direct torque control schemes of induction motor drives. The proposed scheme improved the performance of transient response by reduces the overshoot. The validity of the proposed method is verified by the simulation results.

Keywords Induction motor drive · Direct torque control · Neural network control

1 Introduction

Formerly, d.c. motors were used extensively in areas where variable-speed operation was required, since their flux and torque are inherent decoupled and could be controlled easily by the field and armature current, even thought d.c. motors have several disadvantages, due to the existence of the commutator and the brushes, such as they required periodic maintenance, limited commutator capability under high-speed and they cannot be used in explosive or corrosive environment. These

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problems can be solved by the applicant of a.c. motors, which have simple and rugged structure, high maintainability and economy. The main drawback that makes a.c. motors retreat from the industry was the inherent coupling between torque and flux. However, this disadvantage was amend by the exits of vector control credit to the latter development in power electronic device that expand the use of AC electric machines instead of DC electric machines [1] and [2].

Vector control ensure dynamically decouples fast flux and torque control and belongs to high-performance control implemented in a closed-loop fashion [1], [3], [4], and [5]. The vector control can be implemented in many different ways but only several basic schemes that are offered in the market. The most popular strategies among are Field Oriented Control (FOC), Direct Torque Control (DTC) and Direct Torque Control-Space vector Modulation (DTC-SVM).

Due to the merit over the IM compare with other motor drives and the characteristic of fast torque response and high efficiency variable speed drives make it the best choice for electric vehicle driving motor since the EV drive system must have the following feature [6–8]. DTC provides a very quick and precise torque response excluding the complex field-oriented block and inner current regulation loop [4], in contrast to vector control. The Direct Torque Control was first introduced by Takahashi and has found great success with the notion to reduce the dependence on parameters of induction motor and increase the precision and the dynamic of flux and torque response [5].

In Sect.2, the Direct Torque Control system is described. Development of the proposed neural network DTC-SVM will be explained in Sect.3. Simulation result is given in Sect. 4. The last section will be a discussion and conclusion.

2 DTC System Control Description

The generic DTC-SVM scheme consists of two hysteresis controller namely the stator flux controller and torque. On the other hand, the DTC-SVM uses two errors to produce stator reference voltage vectors, and then modulated by the SVM algorithm [9] as illustrated in Fig. 1.

The induction model in the stator-fixed d-q reference frame is described by [10].

$$V_s = R_s i_s + \frac{d}{dt}(\Psi_s) \ . \tag{1}$$

$$V_r = 0 = R_r i_r + \frac{d}{dt}(\Psi_r) - j\omega_r \Psi_r \ . \tag{2}$$

$$\Psi_s = L_s i_s + L_m i_r \ . \tag{3}$$

$$\Psi_s = L_m i_s + L_r i_r \ . \tag{4}$$

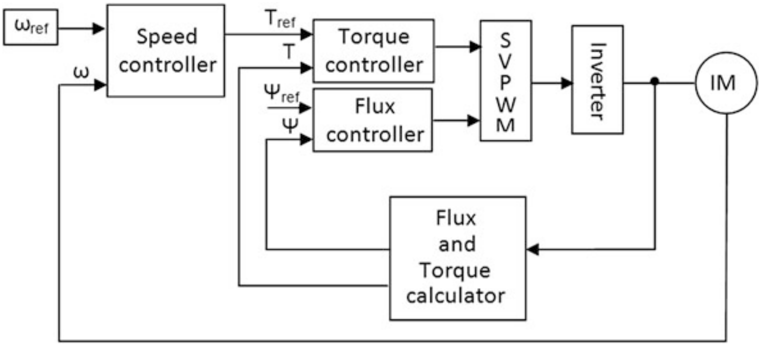

Fig. 1 DTC-SVM induction motor drive

Whereas the mechanical equation is given as below. The induction motor stator flux and torque are calculated in the flux and torque calculator as follows:

$$\Psi_{d_s} = \int (V_{ds} - R_s i_{ds}) dt\cdot \tag{5}$$

$$\Psi_{q_s} = \int \left(V_{qs} - R_s i_{qs}\right) dt\cdot \tag{6}$$

$$|\Psi_s| = \sqrt{\Psi_{ds}^2 + \Psi_{qs}^2}\ . \tag{7}$$

$$\theta_{\Psi s} = \tan^{-1}\left(\frac{\Psi_{qs}}{\Psi_{ds}}\right)\cdot \tag{8}$$

Then, the electromagnetic torque is estimated as:

$$T_e = \frac{3}{2}\frac{p}{2}\left(\Psi_{ds} i_{qs} - \Psi_{qs} i_{ds}\right)\ . \tag{9}$$

3 Neural Network DTC-SVM

Inspired by the successful function of the human brains, the artificial neural network (ANN) was developed for solving many large scale and complex problems. Based on ability to process some information and also to analyze the input and output simultaneously, it makes ANN suitable for dynamic and nonlinear system. The development of the structure and learning algorithm of the Neural Network Direct Torque Control (NNDTC) is explained as follows [11].

3.1 Proposed NN Speed Controller

This paper proposed a NN control method of DTC based on SVM to reduce the overshoot and torque ripple. The NN control is added to the speed controller to produce the torque reference. The block diagram of the proposed NN DTC-SVM of induction motor drive is shown in Fig. 2.

3.2 Structure of NNDTC

To design the neural network control some information about the plant is required. Basically, the numbers of input and output neuron at each layer are equal to the number of input and output signals of the system respectively. Based on the type of the task to be performed, the structure of the proposed NNDTC is as shown in Fig. 3.

The controller consists of input layer, hidden layer and output layer. Based on number of the neuron in the layers, the NNDTC is defined as a 1-3-1 network structure. The first neuron of the output layer is used as a torque reference signal $\left(a_1^2 = m_f\right)$. The connections weight parameter between $j$thand $i$thneuron at $m$thlayer is given by w_{ij}^m, while bias parameter of this layer at $i$thneuron is given by b_i^m. Transfer function of the network at $i$thneuron in $m$thlayer is defined by:

$$n_i^m = \sum_{j=1}^{S^{m\,1}} w_{ij}^m a_j^{m\,1} + b_i^m \ . \tag{10}$$

The output function of neuron at $m$thlayer is given by:

$$a_i^m = f^m\left(n_i^m\right) \ . \tag{11}$$

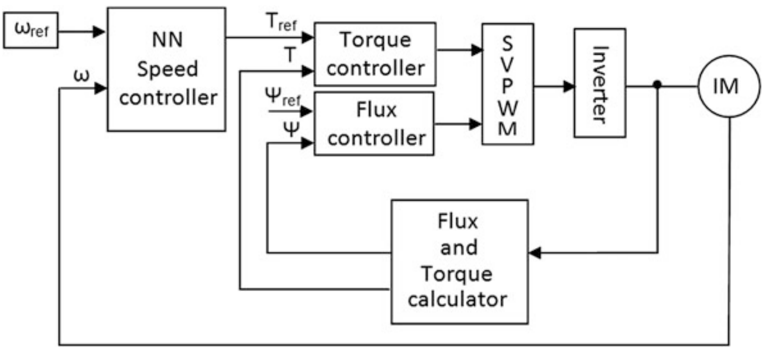

Fig. 2 Complete block diagram of proposed NN DTC-SVM

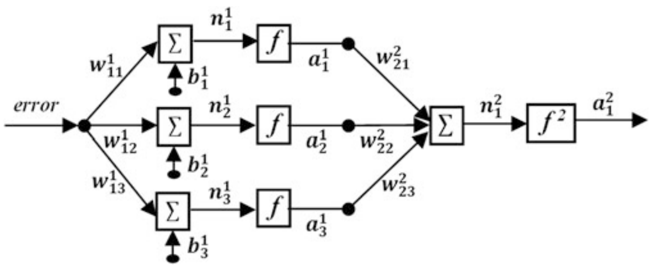

Fig. 3 Diagram block of neural network speed control for DTC induction motor drive

where f is activation function of the neuron. In this design the activation function of the output layer is unity and for the hidden layer is a tangent hyperbolic function given by:

$$f^m\left(n_i^m\right) = \frac{2}{1 + e^{-2n_i^m}} - 1\ . \tag{12}$$

Updating of the connection weight and bias parameters are given by:

$$w_{ij}^m(k+1) = w_{ij}^m(k) - \alpha \frac{\partial F(k)}{\partial w_{ij}^m}\ . \tag{13}$$

$$b_i^m(k+1) = b_i^m(k) - \alpha \frac{\partial F(k)}{\partial b_i^m}\ . \tag{14}$$

where $\boldsymbol{k}$ is sampling time, $\boldsymbol{\alpha}$ is learning rate, and $\boldsymbol{F}$ performance index function of the network.

4 Simulation and Results

Simulation was carried out to investigate the performance of the NNDTC. In this section the dynamic model of a three-phase induction motor, space vector PWM and neural network control model have been developed. The simulation is developed using Borland C++, and then embedded as S-function in Simulink-Matlab. The parameters for the motor are given by:

- Frequency, $f = 50$ Hz.
- Pole, $p = 4$.
- Stator and rotor resistances, $R_s = 0.5\Omega$ and $R_r = 0.25\Omega$.
- Stator and rotor self inductances, $L_s = 0.0415$H and $L_r = 0.0412$H
- Mutual inductance, $L_m = 0.0403$H.
- Combined of inertia, $J = 0.1\,\text{kg} - \text{m2}$.

To verify performance of the proposed NNDTC, the simulation results for a conventional DTC-SVM and the neural network (NN) DTC-SVM proposed controller are compared. With the same speed and load torque reference, the simulations of both methods are run simultaneously. The simulation is start at the speed on 80 rad/s with a constant load of 20 Nm applied. The startup response of both system is shown in Fig. 4, the improvement of the startup response by great reduce in overshoot as well as the settling time is observed.

Referring to Fig. 4, it shows that NN-controller have a start up response improved from the conventional PID controller. It is clearly explain that the startup response has a great improve by removed the overshoot from 94 rad/s. Besides that, the settling time also can be reduced.

The simulation testing is carry on by vary the speed reference from 80 to 120 rad/s. The performance of two system is observed. The speed trajectory of the motor when speed vary at the time of 1.5 s is shown in Fig. 5.

As illustrated in Fig. 5, with the constant load applied, the step up response of the speed trajectory again show the vast reduce in overshoot as well as the settling time. The overshoot is removed from 135 rad/s.

The simulation testing is continuing by step down the speed from 120 to 100 rad/s at the time of 3 s. The performance of two systems is observed. The speed trajectory of the motor when load is applied to the system at the time of 3 s is shown in Fig. 6.

As illustrated in Fig. 6, the overshoot of transient response is removed from 87 rad/s by apply of the proposed neural technique.

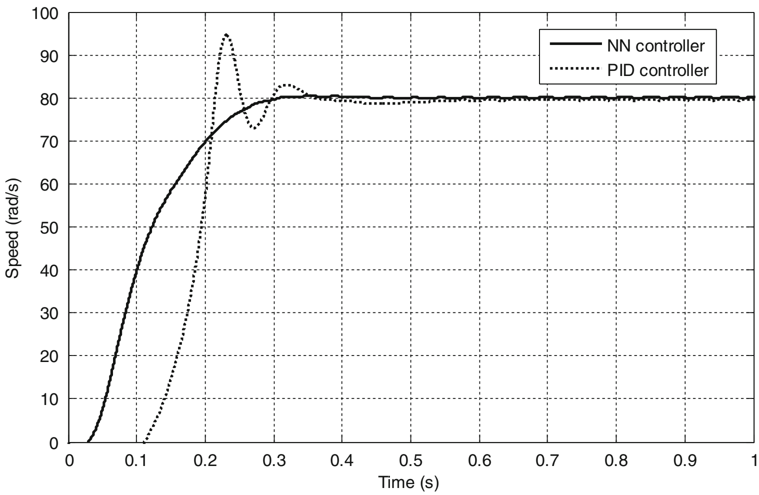

Fig. 4 Start up speed response comparison between conventional PID-DTC and NN-DTC controller

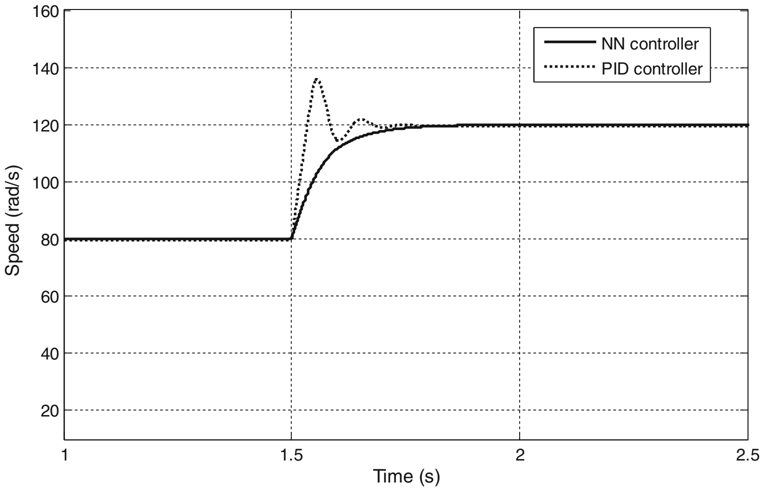

Fig. 5 Step up speed response comparison between conventional PID SVM and NN-SVM controller when the speed reference is varied from 80 to 120 rad/s

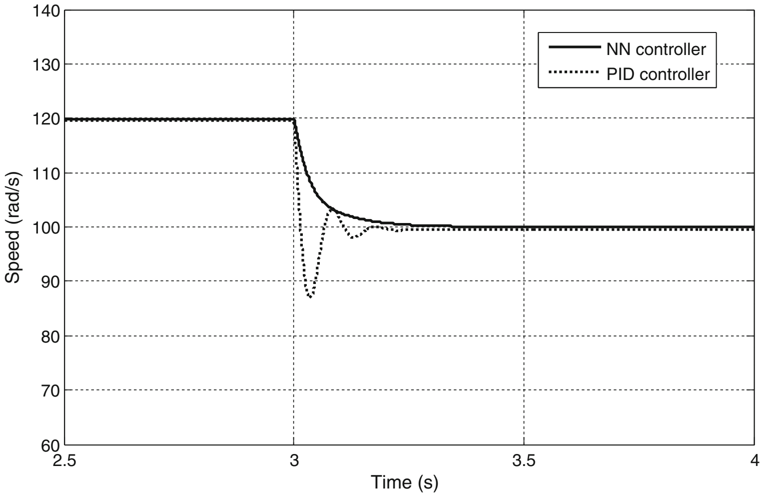

Fig. 6 Step down speed response comparison between conventional PID-DTC and NN-DTC controller when the speed reference is varied from 120 to 100 rad/s

5 Conclusion

The neural network controller for DTC-SVM speed controller induction motor drive system has been presented in this paper. The proposed method employs a single hidden layer neural network algorithm to generate the torque references.

The proposed controller is a nonlinear controller which can be employed without required any motor parameter data. Two control methods have been tested and compared: a conventional PID controlled DTC IM drive, and a NN controlled DTC IM drive. Proposed scheme shows good simulated result that improved the system performance. The improper transient response with high overshoot problem of the conventional PID-DTC can be solved. In addition, the results shows that the performance of transient response is improved by reduce the settling time.

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