Investigation of Artificial Neural Network Based Direct Torque Control for PMSM by Numerical Simulations

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ABSTRACT

This paper investigates solution for the chronically and the biggest problem of direct torque control scheme: high torque ripple. Otherwise, another main problem faced in direct torque control method is difficulties due to complex algorithm to get high performance control for industrial motors. The purpose of this paper is to simplify the control structure by using artificial neural networks learning abilities and to investigate the affects of this structure on torque performance of motor. For this purpose, two different artificial neural networks have been suggested replacing the optimal switching vector selection and flux sector determination process of conventional direct torque control method. Matlab/Simulink based numerical simulations have been carried out to compare motor performances with conventional control structure and proposed artificial neural network based structure. It has been observed that the dynamic response of motor is faster and torque ripple and the controller complexity of the conventional control system has been reduced with the proposed technique.

KEYWORDS

Artificial neural networks, Direct torque control, PMSM control, Vector control

1. INTRODUCTION

Permanent Magnet Synchronous Motors (PMSM's) are gaining interest in many high torque needed industiral applications such as industrial robots and machine tools due to its well known advantages like high power density, high efficiency, lightweight, small inertia, small volume, etc[1].

Vector controlled drives which named as Field Oriented Control (FOC) and Direct Torque Control (DTC) were initially proposed for induction motor drives but recently they have also been investigated in other motor types like PMSM. When the FOC first introduced by Blasckhe[2] in 1971, it opened a new era on control of induction motors for high performance industrial applications. Because the FOC controlled induction motors have fast torque response and applicable in a lot of kind of industrial applications instead of dc motors. It controlls induction motors by decoupling the stator current two independently components like a dc motor.

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However, the FOC uses rotor flux as basic control variable and it easly changes by parameter variations of motor. So, performance of the FOC directly depends on accurate parameter identification. Otherwise, the FOC has complex control structure due to coordinate transformation and current regulators[3].

In middle of 1980's, a new control method called DTC, has been developed for induction motor control by Takahashi [4] and similar idea that the name of Direct Self Control devoloped by Depenbrock [5]. Unlike the FOC, the DTC does not require complex coordinate transformation and any current regulator. However, the DTC has some disadvantages too such as difficulty to control torque and flux at very low speed, high current and torque ripples, variable switching frequency behavior, high noise level at low speed [6]. Many researchers have been researching to avoid these difficulties for the DTC drives.

Some group of these researches about different switching techniques and inverter topologies [7-8]. In many research, researchers worked about artificial intelligence techniquies on different sections of system [9-10] and the other group of researchers worked about different observer models [11-12].

In this paper, we have presented a new artificial neural network DTC (ANN-DTC) scheme for the PMSMs to improve motor torque performance. In the proposed scheme two different ANN model used to determine flux sector and switching states of inverter. The first model of artificial neural network has been created to determine switching states. The second ANN uses as inputs two phaze components of line currents to determine of stator flux sector. The numerical simulations have been carried out with Mablab/Simulink software and the results of the methods are discussed and compared with the conventional DTC (C-DTC).

2. DTC STRUCTURE

The basic idea of the DTC is to choose the best vector of the voltage which makes the flux rotate and produce the desired torque. During this rotation, the amplitude of the flux remains inside a pre-defined band[13].

Stator flux vector can be calculated using the measured current and voltage vectors as given in (4-6).

$$\lambda_\alpha = \int (V_\alpha - R_s i_\alpha) dt \qquad (4)$$

$$\lambda_\beta = \int (V_\beta - R_s i_\beta) dt \qquad (5)$$

$$\lambda = \sqrt{\lambda_\alpha^2 + \lambda_\beta^2} \qquad (6)$$

Where λ is stator flux space vector, v_{ds} and v_{qs} stator voltage, i_{ds} and i_{qs} line currents in α-β reference frame and R_s stator resistance. The electromagnetic torque of an induction machine is usually estimated as given in (7).

$$T_e = \frac{3}{2} p(\lambda_\alpha i_\beta - \lambda_\beta i_\alpha) \qquad (7)$$

Where p is the number of pole pairs. An important control parameter on DTC is stator flux vector sector. Stator flux rotate trajectory devided six sector and calculation of stator flux vector sector as given in (8).

$$\theta_\lambda = \tan^{-1}(\frac{\lambda_\beta}{\lambda_\alpha}) \qquad (8)$$

Two different hysterezis comparator generates other control parameters on DTC scheme. Flux hysterezis comparator is two level type while torque comparator is tree level type. This comparators use flux and torque instantaneous error values as input and generates control signals as output.

Switching selector unit generates inverter switching states with use of hysterezis comparator outputs and stator flux vector sector. Inverter voltage vectors and determining stator flux sector depending on the stator flux's angle are shown in Fig. 1[14].

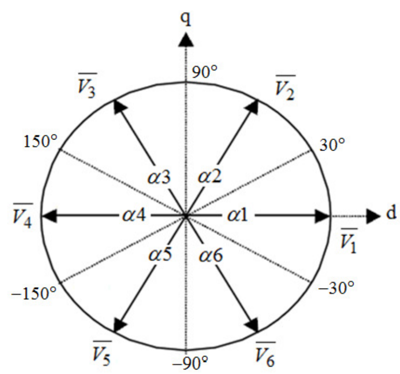

Figure 1. Inverter voltage vectors and sectors

3. ARTIFICIAL NEURAL NETWORK BASED DTC

In proposed ANN-DTC scheme two different feed forward ANN have been used to select switching states and determine stator flux sector. The training method used was the Levenberg-Marquardt back-propagation method.

Both of proposed ANNs, a hidden layer with six neurons which decide by off-line training have been chosen. Stator flux sector determining ANN uses as input the ‘d-axis stator flux’ and ‘q-axis stator flux’. Three layers of neuron are used as shown in Fig. 2.

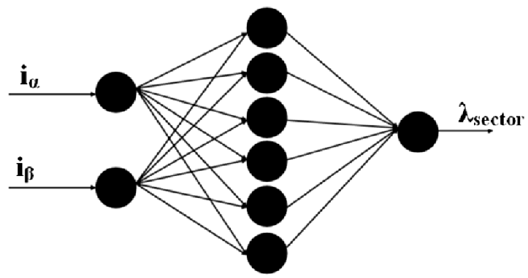

Figure 2. Stator flux sector determining ANN structure

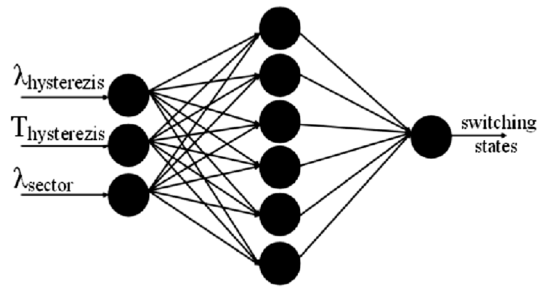

Figure 3. Switching states selection ANN structure

The second ANN is for the selection of switching states as given in Fig.3, which is based on three inputs that flux and torque hysteresis comparators outputs and flux sector data which taken from the sector determining ANN output. Using of ANNs in proposed direct torque control scheme are given in Fig. 4.

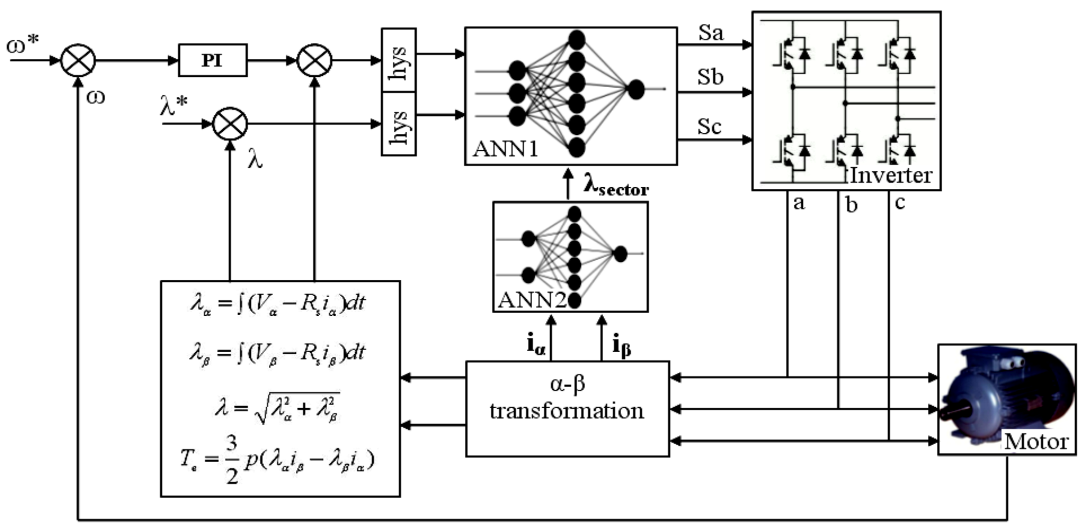

Figure 4. Proposed ANN based DTC scheme

4. NUMERICAL SIMULATIONS

Numerical simulations have been carried out to investigate the effects the proposed ANN based DTC scheme. Its devoloped using Matlab/Simulink®. The results of numerical simulation studies obtained in this work are for the PMSM and parameters of motor and simulations as given below. The machine model is implemented for C-DTC scheme and proposed ANN-DTC scheme using Matlab/Simulink. To compare performances with C-DTC and proposed ANN-DTC for PMSM rated speed applied to the motor under no load and then switch to loaded (10-Nm) condition at 0,5. sec. The parameters of the PMSM and simulations, in SI units: U=300 V, T=10Nm, n= 2300 rpm, Rs =0.4578 Ω, Sampling Time=50µs.

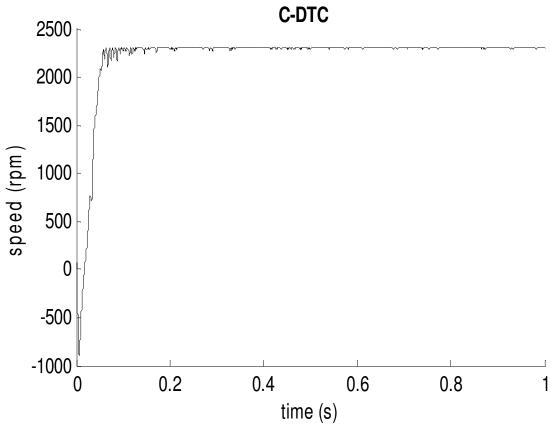

Figure 5. C-DTC speed response

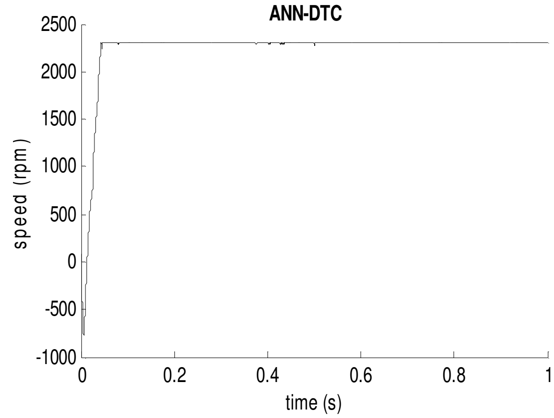

Figure 6. ANN-DTC speed response

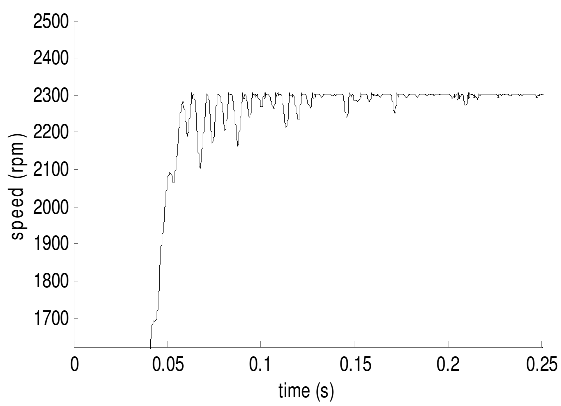

Figure 7. C-DTC speed response at startup

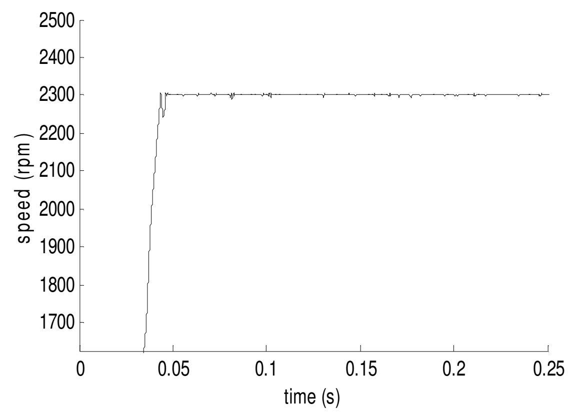

Figure 8. ANN-DTC speed response at startup

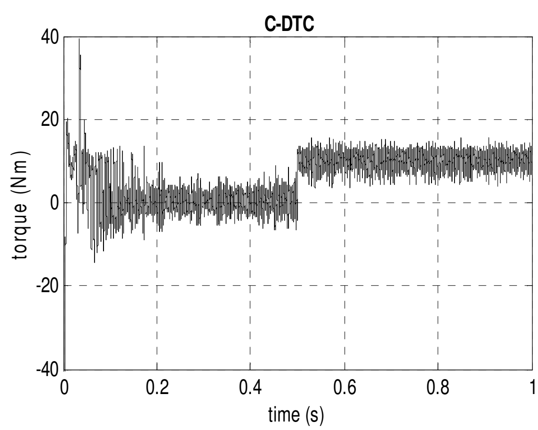

Figure 9. C-DTC torque response

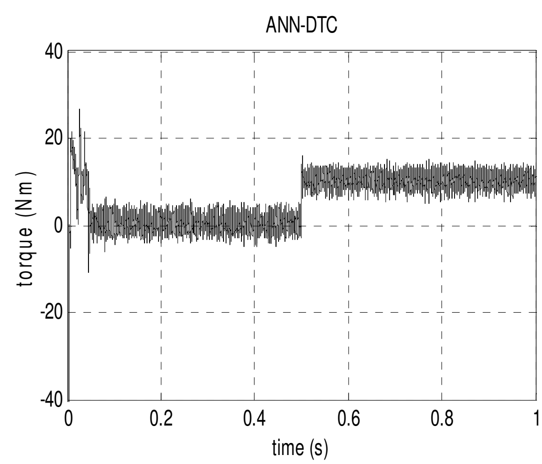

Figure 10. ANN-DTC torque response

Fig. 5 and Fig. 6 shows speed curves of motor with C-DTC and ANN-DTC working conditions. It can be seen that ANN-DTC controlled motor speed ripples are lesser with loaded and unloaded conditions when compared C-DTC controlled. On the other hand, ANN-DTC controlled motor dynamic response is faster and this situation can be seen clearly in Fig. 7 and Fig. 8. The torque response of the C-DTC and ANN-DTC is show in Fig. 9 and Fig. 10. It can be seen that the motor ripple in torque reduced with ANN-DTC for loaded and unloaded conditions.

5. CONCLUSION

In this paper, two different ANN's have been proposed for flux sector determining and the switching voltage vector selection on the DTC scheme and this new scheme investigated for the PMSM motor drive. The proposed ANN-DTC scheme performance is compared with the conventional DTC scheme at rated speed and different load conditions. The ANN-DTC scheme performance has been tested by numerical simulations. The ANN-DTC technique which is shown as dynamic responses are the faster in transient state and the torque ripple in steady state are reduced remarkably when compared with the conventional DTC for loaded and unloaded conditions at rated speed. Besides, complex mathematical structure of C-DTC has been simplified with learning abilities of ANN’s. The simulation results support that the proposed ANN based DTC scheme is a good alternative for the conventional DTC controlled PMSM drives.

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