PMSM Drives Using Artificial Neural Network For Reducing Torque Ripple

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Abstract

This paper describes intelligent direct torque control (DTC) technique for Permanent Magnet Synchronous Motor (PMSM) drive based on Artificial Neural Network (ANN) Systems. The proposed system has proven successful in controlling the instantaneous torque so as not to depend only on the estimation flux, torque and position, but also the estimation of the lookup table and the generation of driver switching table. Experimental results prove the MATLAB simulation results for torque, speed and flux estimations.

1. 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 [1 - 3].

A simplified variation of field orientation known as direct torque control (DTC) was developed by Takahashi and Depenbrock [4]. DTC has a relatively simple control structure yet performs at least as good as the FOC technique. It is also known that DTC drive is less sensitive to parameters de-tuning (only stator resistor is used to estimate the stator flux) and provides a high dynamic performances than the classical vector control (fastest response of torque and flux).

This method allows a decoupled control of flux and torque without using speed or position sensors. This type of command involves nonlinear controller type hysteresis, for both stator flux magnitude and electromagnetic torque, which introduces limitations such as a high and uncontrollable switching frequency [5]. This controller produces a variable switching frequency and consequently large torque and flux ripples and high currents distortion

In order to improve DTC 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 DTC control; this method consists in replacing the hysteresis comparators asynchronous machine DTC by a controller based on the artificial neurons networks in order to lead the flux and the torque towards their reference values during a fixed time period.

2. Direct torque control

2.1. Structure

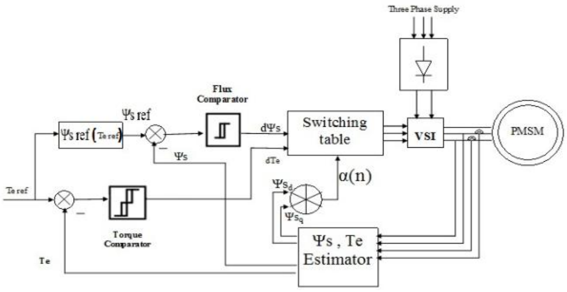

Figure 1. Direct Torque Control structure

A direct-torque-controlled PM synchronous motor supplied by a voltage-source inverter is present and the stator flux linkage and the electromagnetic torque are controlled directly by applying optimum voltage switching vectors of the inverter. It is a principal goal to select those voltage switching vectors which yield the fastest electromagnetic torque response. The six active switching vectors (u_1, u_2, …, u_6) and the control scheme of the DTC PM synchronous motor supplied by a VSI.

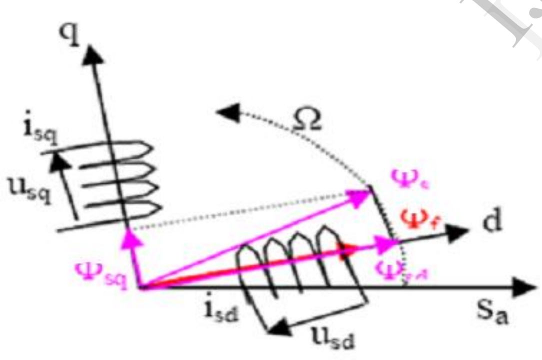

Figure 2. Phasor diagram of the PMSM

In this paper PMSM(Permanent Magnet Synchronous Motor), which consists of three stator windings and a rotor magnet described by the following equation (Voltage, Flux, Torque…),

$$u_{sd} = Rs.i_{sd} + \frac{d\Psi sd}{dt} - \omega.\Psi_{sq} \quad (1)$$

$$u_{sq} = Rs.i_{sq} + \frac{d\Psi sq}{dt} - \omega.\Psi_{sd} \quad (2)$$

Where the direct and quadrate axis flux linkages are,

$$\Psi_{sd} = L_d.i_{sd} + \Psi_f \quad (3)$$

$$\Psi_{sq} = L_q \,.\, i_{sq} \quad (4)$$

The electromagnetic torque of the motor can be evaluated as follows,

$$T_e = \frac{3}{2} P \left[\Psi_f \,.\, i_{sq} + (L_d - L_q) \,.\, i_{sd} \,.\, i_{sq} \right]^{1/2} \quad (5)$$

With:

ω: rotation's speed electric.

P: Number of pairs of poles.

Ψ_f: flux produced by the permanent magnet.

Ψ_{sd}: d axis stator magnetic flux,

Ψ_{sq}: q axis stator magnetic flux,

L_d: d axis stator leakage inductance,

L_q: q axis stator leakage inductance,

R_s: stator winding resistance,

T_e: electromagnetic torque,

2.2. Flux and torque estimator

The stator electric equations of the PMSM, are given by:

$$\Psi_{sd} = \int_0^t V_{sd} - R_s \,.\, i_{sd} \quad (6)$$

$$\Psi_{sq} = \int_0^t V_{sd} - R_s \,.\, i_{sq} \quad (7)$$

$$\Psi_s = \sqrt{\Psi sd^2 + \Psi sq^2} \quad (8)$$

$$\delta = \text{arc tan}\left(\frac{\Psi sq}{\Psi sd}\right) \quad (9)$$

The electromagnetic torque is:

$$T_e = \frac{3}{2} P \left[\Psi_{sd} \,.\, i_{sq} - \Psi_{sq} \,.\, i_{sd} \right]^{1/2} \quad (10)$$

P: Number of pairs of poles

The electromagnetic torque in a PMSM machine can be regulated by controlling the magnitude and angle of the stator flux linkage or load angle δ. This can be performed by applying the proper output voltage vectors of an inverter to the machine

2.3. Control switches of the inverter

The switches of the converter of tension must be controlled so as to maintain the flux and the torque of the machine. The vector of the stator voltage can be written in the form:

$$U_s = \sqrt{\frac{2}{3}} \, . \, U \, . \, (Sa \, + \, Sb \, . \, e^{j\frac{2\pi}{3}} \, + \, Sb \, . \, e^{j\frac{4\pi}{3}}) \quad (11)$$

Where (Sa, Sb, Sc) represent the logical state of the 3 switches: Si = 1 means that the high switch is closed and the low switch is open and Si=0 mean that the high switch is opened and the low switch is closed.

One will thus seek to control flow and the couple via the choice of the vector of voltage which will be done by a configuration of the switches. As we have 3 switches, there are thus 2^3=8 possibilities for the U_i vector. Two vectors correspond to the null vector (U_0, U_7):

$(S_a, S_b, S_c) = (0, 0, 0)$ & $(S_a, S_b, S_c) = (1,1,1)$

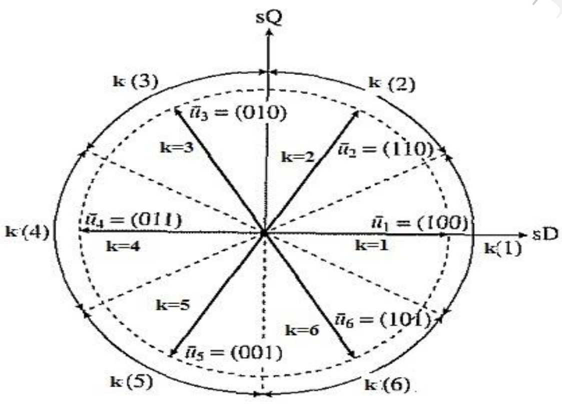

Figure 3. Six active switching vectors

2.4. Switching schemes

When flux is in zone I, the vectors Ui+1or Ui-1are selected to increase the amplitude of flux, and U i+2 or Ui-2 to decrease it. What shows that the choice of the vector tension depends on the sign of the error of flux, independently of its amplitude [4]. This explains why the exit of the corrector of flux can be a Boolean variable. One adds a band of hysteresis around zero to avoid useless commutations when the error of flux is very small,[1] [6]. Indeed, with this type of corrector in spite of his simplicity, one can easily control and maintain the end of the vector flux, in a circular ring. The switching table proposed by Takahashi [4], as given by Table 1.

Table 1. Switching scheme

sector		1	2	3	4	5	6
Flux	Torque						
Ψe=1	Te = 1	U2	U3	U4	U5	U6	U1
	Te = 0	U7	U0	U7	U0	U7	U0
	Te = -1	U6	U1	U2	U3	U4	U5
Ψe=0	Te = 1	U3	U4	U5	U6	U1	U2
	Te = 0	U0	U7	U0	U7	U0	U7
	Te = -1	U5	U6	U1	U2	U3	U4

3. Structure of DTC System Based on ANN

A neural network is a machine like human brain with properties of learning capability and generalization. They require a lot of training to understand the model of the plant. The basic property of this network is that it is capable of approximating complicated nonlinear functions.

It constitutes an approach which gives more opportunities to approach the problems of perception, memory, learning and analysis under new angles. It is also a very promising alternative to avoid certain limitations of the classic numeric methods. Due to its parallel treatment of the information, it infers emergent properties able to resolve problems qualified in the past as complex.

The structure of the direct neuronal torque control of a permanent magnet synchronous machine is illustrated bellow Figure 4.

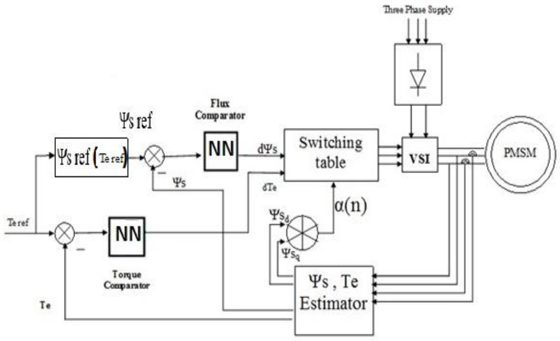

Figure 4. DTC neural networks controller scheme

The Neural Network is based on layers of neurons. Fundamental processing element of a neural network is a neuron. Initially, the network has to be structured for a particular application, then the network can be trained be choosing the initial weights randomly.

In this paper artificial neural network torque are used on torque comparator and flux comparator. The designed ANN controller is a feed forward neural network and it has three layers called input layer, hidden layer and the output layer. The ANN is trained by a learning algorithm in which the weights of the network is adapted iteratively until the error between target vectors and the output of the ANN is less than the error goal. Back propagation algorithm is used for training in this paper. In the back propagation method, the error signal is propagated through the network in backward direction and adjusts the weights of the free parameters and reduces the error. The back propagation training algorithm is shown in the flow chart Figure 5.

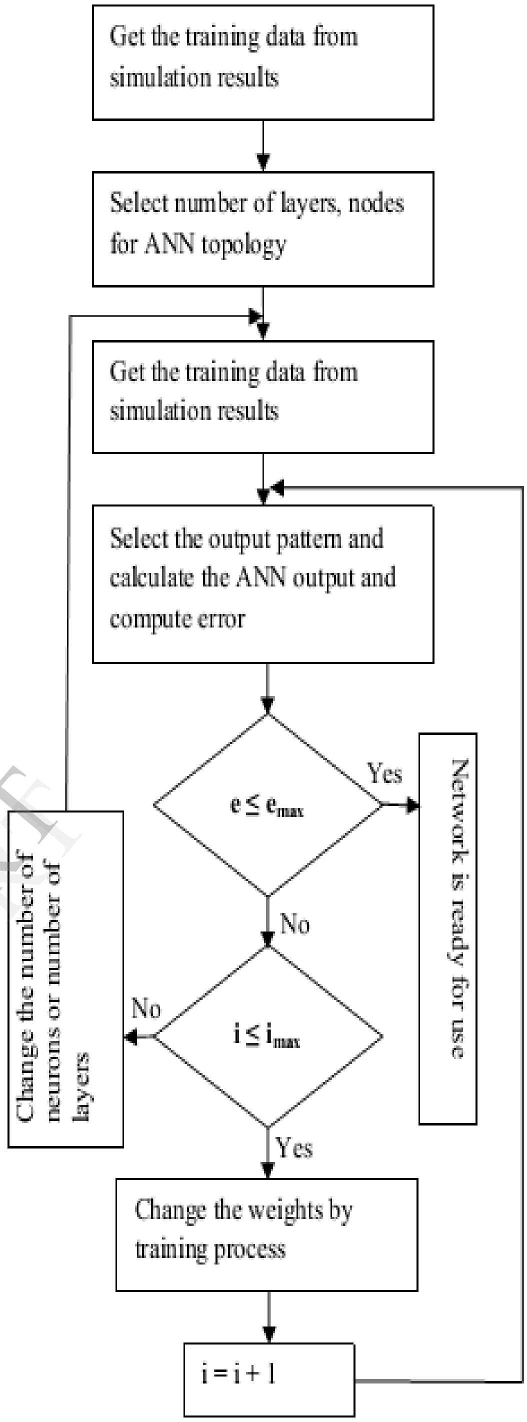

Figure 5. ANN training algorithm

4. MATLAB/SIMULINK models and Results:

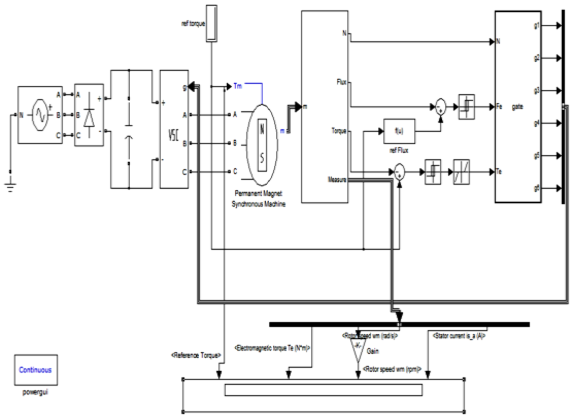

Figure 6. Matlab/Simulink model of PMSM Drive for DTC method

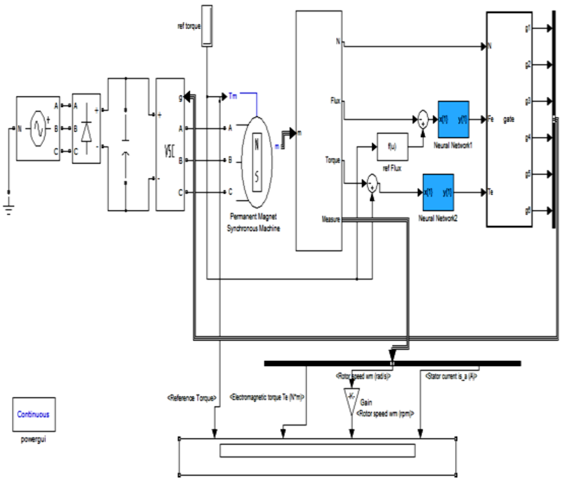

Figure 8. Matlab/Simulink model of PMSM Drive for DTC method using Neural Network

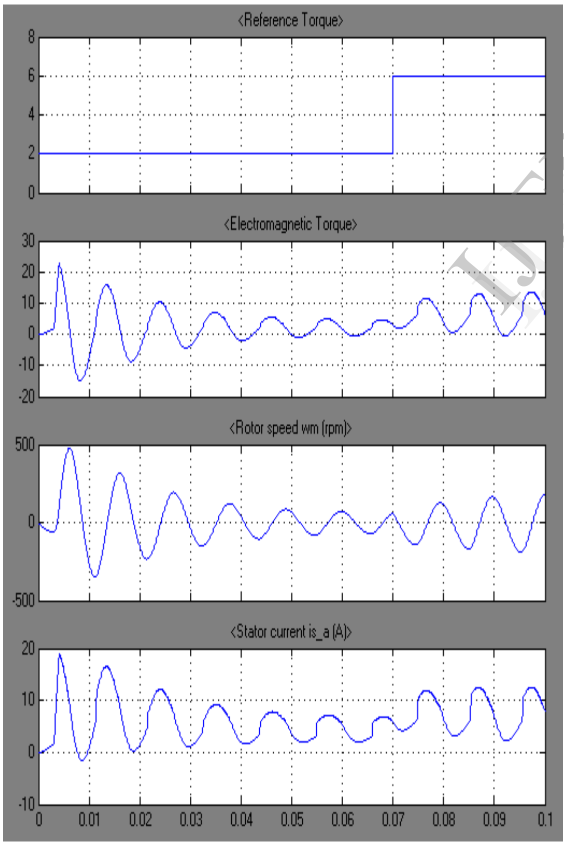

Figure 7. Results of PMSM Drive for DTC method

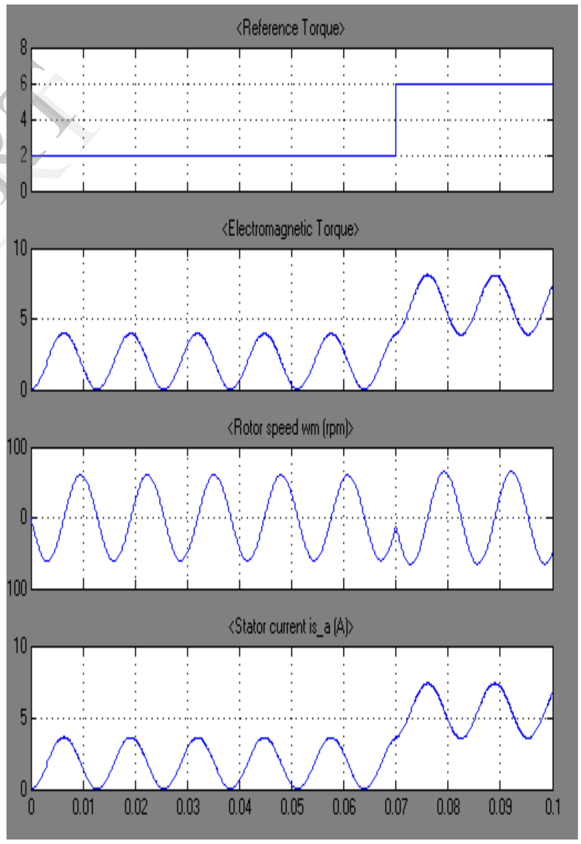

Figure 9. Results of PMSM Drive for DTC method using Neural Network

5. Conclusion

This ANN controller is used successfully in Direct Torque Control system for PMSM. The design of ANN controller and its performance shows that the error is minimized. The overshoot in the speed curve is maintained very less and the ripples in the torque curve are maintained minimum.

6. References

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