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Simulation Study on Direct Torque Control of Induction Motor using Neural Network

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Abstract

DC motors were used in adjustable speed drives system in most of the industrial applications, due to the various disadvantages of DC motor drives system, AC motor drives has been replaced from last four decades, after the existence and availability of fast acting semiconductor devices. The methods used to control the torque using induction motor were found to be not as better as that of DC motor; However lot of research work is in progress to develop good response of torque in AC motor drives. In this paper the high performance implementation of induction motor control called as direct torque control (DTC) using neural network has been used to reduce torque ripple. Simulation work is carried using MATLAB/SIMULINK software based on PI controller and compared with the results obtained with neural network control.

Keywords: DTC, training of NN, torque ripple reduction, NN based DTC scheme, PI control technique for comparison.

1. INTRODUCTION

Induction motors are one of the important machine used in industries as it has most advantages like low cost , easy maintenance, simple construction, rough machine, this machine was used earlier for constant speed applications, after the existence of power electronics components it was made easy to control induction motor by varying its supply frequency, the research proceed with the control of induction motor with the vector control analysis by making a three phase induction motor to behave like a DC motor. The improvement in vector control deals with the Direct Torque Control (DTC) technique, this method in simplest form has been explained in [1]. A DTC scheme consists of a controller, torque and flux calculator and a voltage source inverter (VSI). This method of control is very simple as it is less dependent on parameters; the only disadvantage is its large torque ripple. This paper describes the implementation of neural network to reduce torque ripple comparing with the PI method of DTC drive system.

2. PRINCIPLE OF DTC

When a three phase induction motor is connected to a three phase VSI then eight possible switching states are achieved with two zero vectors resulting in eight possible input voltage vectors to control the stator flux and torque to follow the reference value as shown in Fig 1. The three phase voltage space vectors are given as:

$$\bar{v}_s(t) = \tfrac{2}{3}\left(v_{sA}(t) + a v_{sB}(t) + a^2 v_{sC}(t)\right), \quad \text{where } a = e^{j\frac{2}{3}\pi} \qquad (1)$$

VsA, VsB and VsC are the instantaneous phase voltages. The voltage space vector switching with VSI of the DC link voltage Vd, is given as:

$$\bar{v}_s(t) = \tfrac{2}{3} V_d \left(S_a(t) + S_b(t)a + S_c(t)a^2\right), \quad \text{where } a = e^{j\frac{2}{3}\pi} \qquad (2)$$

Sa(t), Sb(t) and Sc(t) are the switching functions of each leg of the VSI, such that,

$$S_i = \begin{cases} 1 & \text{when upper switch is on} \\ 0 & \text{when lower switch is on} \end{cases} \qquad i = a,b,c \qquad (3)$$

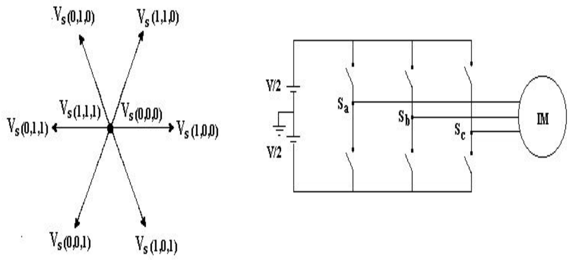

Fig 1 Voltage Vectors For 3-Phase VSI

2.1.Direct Torque & Flux Control

Figure 2 shown represents the basic block diagram of a DTC scheme of control of an induction motor, the reference flux and torque values are □e* & Te* respectively and are compared with the calculated values, based on the error obtained an equivalent gate signal is generated to turn ON or OFF the switches.[2] [3]

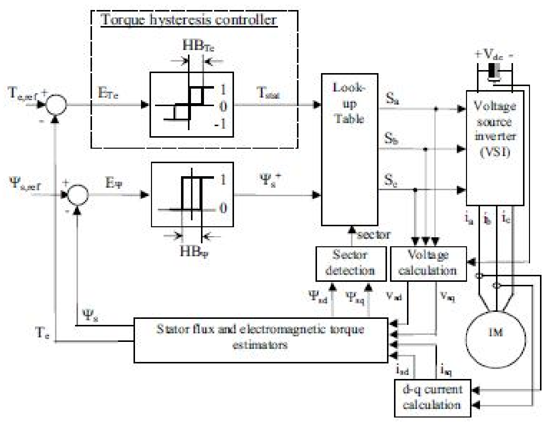

Figure 2. Block diagram of DTC

The voltage equation of an induction motor is given by:

$$\bar{v}_s = R_s \bar{i}_s + \frac{d\bar{\psi}_s}{dt} \quad (4)$$

Where $\bar{v}_s$, $\bar{i}_s$ and $\bar{\psi}_s$ are the stator voltage, current and flux space vectors respectively. According to equation (4), if the stator resistance value is neglected, then the change in stator flux $\Delta\bar{\psi}_S$ will follow the stator voltage, as

$$\Delta\bar{\psi}_S = \bar{v}_S \Delta t \quad (5)$$

From the above equation it is clear that the flux of the stator will track the product of stator voltage vector and the change in time. The flux will oscillate in the hysteresis band based on switching lookup table. If the stator flux space vector plane is divided into six sectors as shown in Fig 3, a set of table or rules of which voltage vector should be chosen in a particular sector either to increase stator flux or to reduce stator flux and either to increase torque or to reduce torque can be constructed; such table is given by Table 1.

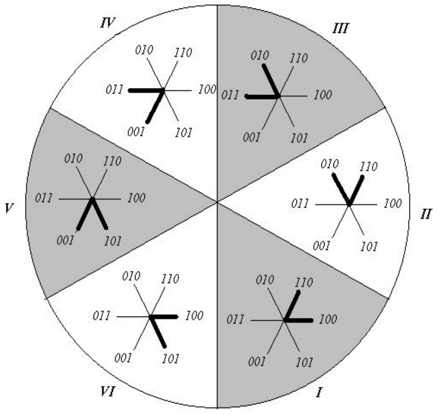

Fig 3 Six Sectors of Stator Flux Plane

Table 1 Voltage Vectors Table

Counterclockwise		Sec I	Sec II	Sec III	Sec IV	Sec V	Sec VI
Inc Flux (0)	*Inc T*(01)	100	110	010	011	001	101
	Dec T(00)	000	111	000	111	000	111
Dec Flux (1)	*Inc T*(01)	110	010	011	001	101	100
	Dec T(00)	111	000	111	000	111	000

Clockwise		Sec I	Sec II	Sec III	Sec IV	Sec V	Sec VI
Inc Flux (0)	*Inc T*(10)	001	101	100	110	010	011
	Dec T(00)	000	111	000	111	000	111
Dec Flux (1)	*Inc T*(10)	011	001	101	100	110	010
	Dec T(00)	111	000	111	000	111	000

3. MATHAMATICAL MODELLING

3.1. Equivalent circuit of an induction motor

Considering an induction motor having IS & Ir are stator & rotor currents, Io the no load current Iw & Im Active & magnetizing Currents, RS & Rr are Stator & Rotor Resistances per phase XS & Xr are Stator & Rotor Reactance's per phase, Rm & Xm are Resistance & Magnetizing Reactance, S as the Slip, an equivalent diagram can be obtained and is as shown in fig 4

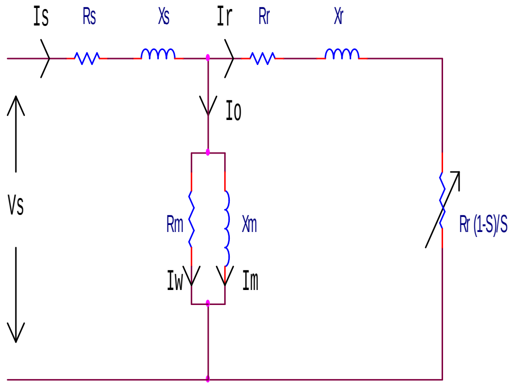

Fig.4 Per phase equivalent circuit

The stator and rotor voltage differential equations in a reference frame is given as

$$V_{sd} = R_s i_{sd} + \frac{d}{dt}\psi_{sd} - \omega_s \psi_{sd} \quad (6)$$

$$V_{sq} = R_s i_{sq} + \frac{d}{dt}\psi_{sq} - \omega_s \psi_{sq} \quad (7)$$

$$V_{rd} = 0 = R_r i_{rd} + \frac{d}{dt}\psi_{rd} - (\omega_s - \omega)\psi_{rq} \quad (8)$$

$$V_{rq} = 0 = R_r i_{rq} + \frac{d}{dt}\psi_{rq} - (\omega_s - \omega)\psi_{rd} \quad (9)$$

Where

Vsd, Vsq, Vrd & Vrq are the direct axis and quadrature axis stator & rotor Voltages

isd, isq, ird & irq are the direct axis and quadreture axis stator & rotor Currents

ψsd, ψsq, ψrd & ψrq are the direct axis and quadreture axis stator & rotor fluxes

3.2. Flux and Torque estimation

To ensure a proper voltage vector selection by the DTC controller, the estimation of stator flux & torque must be accurate. Stator flux and torque estimations are based on the IM dynamic equations in the stationary stator reference frame. Most of the stator flux calculation is based on voltage model, current model or the combination of both models. Voltage model-based estimator on the other hand only requires the knowledge of stator resistance to perform the estimation. The voltage model is used for the stator flux estimation.

The voltage model-based stator flux is calculated using equation (10).

$$\bar{\Psi}_s = \int (\bar{v} - \bar{i}_s R_s) dt \quad (10)$$

The torque is calculated In terms of d and q components, can be written as (11).

$$T_e = \frac{3}{2} P_p (\psi_{sd} i_{sq} - \psi_{sq} i_{sd}) \quad (11)$$

Where

T_e Electromagnetic torque

$$\psi_{ds} = \int (v_d - i_{ds} R_s) dt$$

$$\psi_{qs} = \int (v_{dq} - i_{qs}R_s)dt$$

4. TRAINING OF NEURAL NETWORK

4.1. Principles of Neural Networks

Neural networks use a complicated interconnection of computing nodes to approximate nonlinear functions .Each node constitutes a neuron and performs the multiplication of its input signals by constant weights, sums up the results and maps the sum to a nonlinear activation function; the result is then transferred to its output. A feed forward NN is organized in layers: an input layer, one or more hidden layers and an output layer as shown in figure 5.

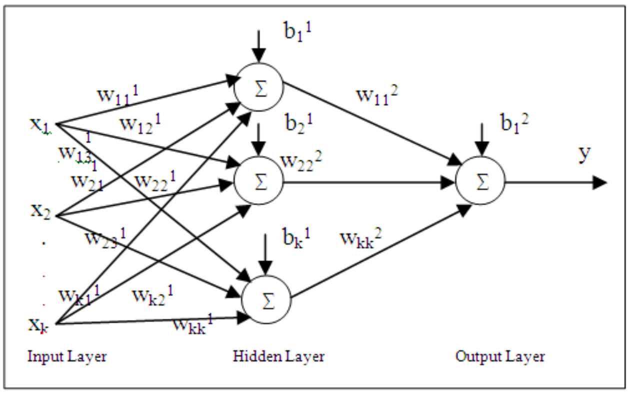

Fig 5. Structure of neural network

The inputs xk, k = 1...K to the neuron are multiplied by weights wki and summed up together with the constant bias term bi. The resulting i is the input to the activation function..The basic mathematical model of a neuron is given by:

$$y_i = \sum_{i=1}^{nc}\sum_{j=1}^{nc}(w_{ij}x_i + b_i) \quad (12)$$

After a neural network has been created, it needs to be configured with the weights and biases need to be initialized and then be tuned, so that the network performance is optimized. This tuning process is referred to as training the network, the internal diagram of trained NNis as shown in fig6 & fig 7 represents the simulink model of the proposed scheme.

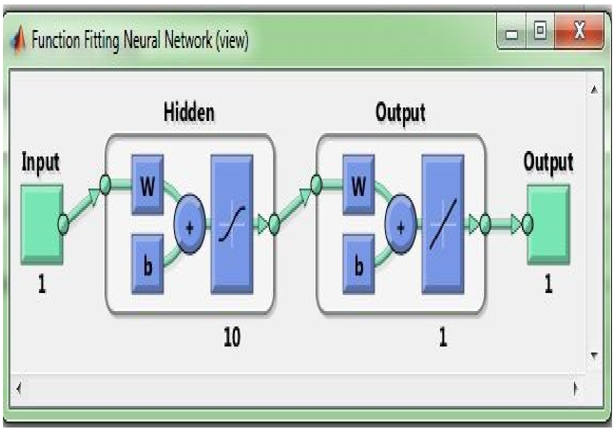

Fig. 6 Internal Diagram of Trained Neural Network

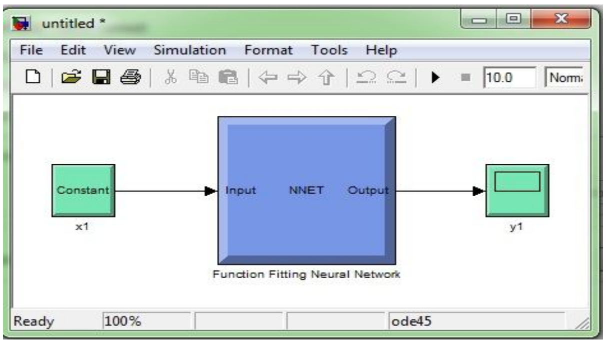

Fig. 7 Simulink Diagram

5. RESULT COMPARISION AND DISCUSSION

To study the performance of the neural network control with direct torque control strategy, the simulation of the system was conducted by using MATLAB /SIMULINK and neural network toolbox. The results will be compared with DTC of induction machine using PI controller.

5.1. PI control strategy

In this section a study on the performance of IM with Proportional Integral (PI) control technique has been made.It is a generic control loop feedback mechanism widely used in systems. A PI controller calculates an "error" value as the difference between a measured process variable and a desired set point. The controller attempts to minimize the error by adjusting the process control inputs as shown in Fig. 8 is the PI control with induction machine circuit for this is also shown in Fig.9.

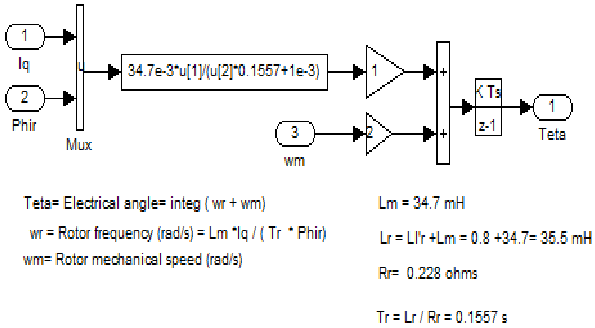

Fig.8 Internal Circuit Diagram of PI Controller

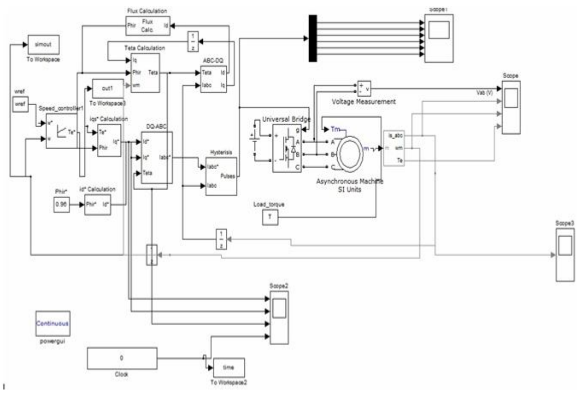

Fig.9 PI Control Circuit for IM

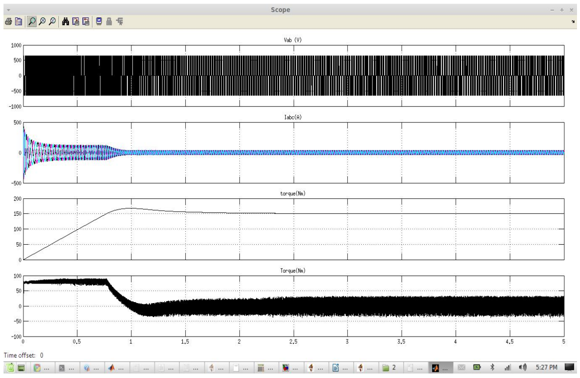

Fig.10 Simulation results with PI Control Technique

The torque performance extracted from this circuit is shown in Fig.10.It can be easily recognize from obtained results that torque distortions (ripple) are more. The effects of torque ripple are particularly undesirable in some demanding motion control and machine tool applications such as induction motor. They lead to speed oscillations which cause deterioration in the performance.

5.2. Simulation Model and Structure of DTC Neural network control technique

In order to evaluate and validate the effectiveness of proposed control scheme, a simulation model has been developed by using Matlab/ Simulink, & Fig. 11 shows the simulink model the entire motor drive system.

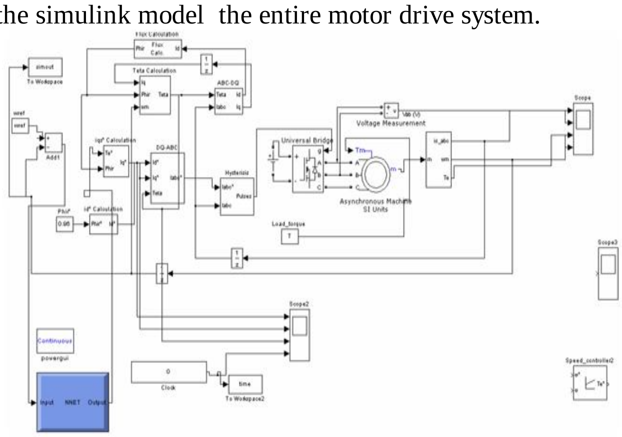

Fig.11 Direct Torque Control of Induction Motor using Neural Network

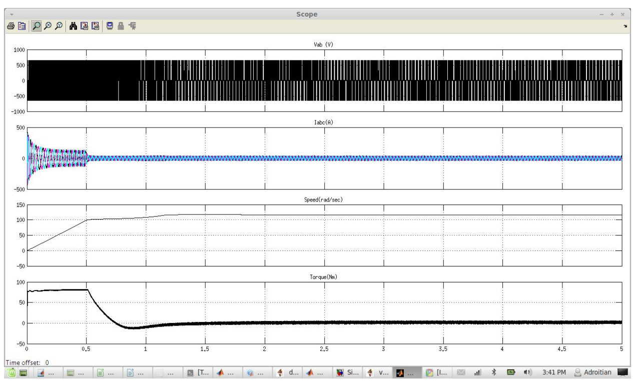

Fig.12 Performance Results of Neural Network Control

The comparative results obtained by simulation for an IM are given in Fig 12. The torque pulsations in the case of neural network control strategy are smaller than in the case of PI control strategy as shown in Fig.10. The results of simulation obtained shows that performances of the combined neural network direct torque control of the induction motor gives fast torque response and good establishment time. In the case of neural network strategy as we can see from Fig.12 the torque ripples are reduced. The simulation results show a good tracking of electromagnetic torque and prove that this technique allows a good dynamic performance similar to the basic DTC schemes.

6. Conclusions

In this study, it is concluded that by using the neural network technique it is observed that the torque ripple has been reduced to a minimum value. The performance has been tested by simulations. The results show a reasonable improvement by reducing torque ripple.

Acknowledgment

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