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Design and Development of Fuzzy Controller model with DTC on induction motor

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Abstract

Fuzzy controller is becoming more popular in soft computing applications for improving torque based control technique in induction motor systems. Direct Torque control (DTC) techniques are based on hexagonal path having rated voltage required at high speed. This paper is based on three phase Induction motor model that used the DTC and Fuzzy logic controller to control the speed and fluctuations in the torque of induction motor .The fuzzy logic controller is used to reduce the flux and torque ripples and improves the performance of DTC method at very low constraint of speed in induction motor. The simulated model is made in Matlab/Simulink software to check the performance of the three phase induction motor model.

Keywords: Three phase Induction Motor model, Direct Torque Control, Voltage Source Inverter, Fuzzy logic controller.

1. INTRODUCTION

The three phase squirrel cage induction motors are almost worldwide extensively utilized in industrial applications [1-2]. There are some difficulties during its torque, flux or speed control. Now a day’s three phase squirrel cage induction motors are becoming more popular because of economical in cost, rugged construction, easy to use, reliable and have small size [3-4]. The three phase squirrel cage induction motors are available from few watts to megawatts as per the requirement to drive load.

In previous systems, the speed, torque and flux control of three phase squirrel cage induction motors are very complicated and difficult. In these techniques to control the above mentioned parameters the supply voltage is to vary by using auto transformer, supply frequency is varied with the help of cyclo converts and numbers of poles of the motor [5]. By utilizing these schemes speed , torque and flux control is available but upto certain limits for precise control these equipments becomes more costly, to overcome these drawbacks the new direct torque control schemes are proposed [6]. The direct torque control scheme was suggested by TAKAHASHI Depenbrock for the speed control of three phase squirrel cage induction motor [7-8]. Direct torque control scheme is popular due to following points [6]:

1. Fast dynamic torque response
2. Robustness with respect to parameter variations
3. Feedback system is not required
4. Simple construction and low cost
5. No need of external excitation

Despite benefits, there are some causes like a highly slower response during start up and during a step change in torque and stator flux.

2. MATERIAL AND METHOD

2.1 Voltage vector model for three phase squirrel cage voltage source inverter output

The voltage source inverter consists of three phase supply with three parallel legs each leg consists of two switches which are able to work as eight possible stator voltage vectors. The torque and flux of three phase induction motor model is controlled by using hysteresis band within limits [1-2].

$$V(t) = \frac{2}{3}[V_a(t) + ZV_b(t) + Z^2V_c(t)] \quad (1)$$

Where

$$Z = e^{i2/3\pi} \quad (2)$$

V_a, V_b and V_c are the per phase instantaneous voltages. The equation (1) and (2) shows that equation (1) has 6 non-zero states and equation (2) has 2 null states. The phasor diagram of equation (1) and (2) shown in Figure 2.1 [9-10].

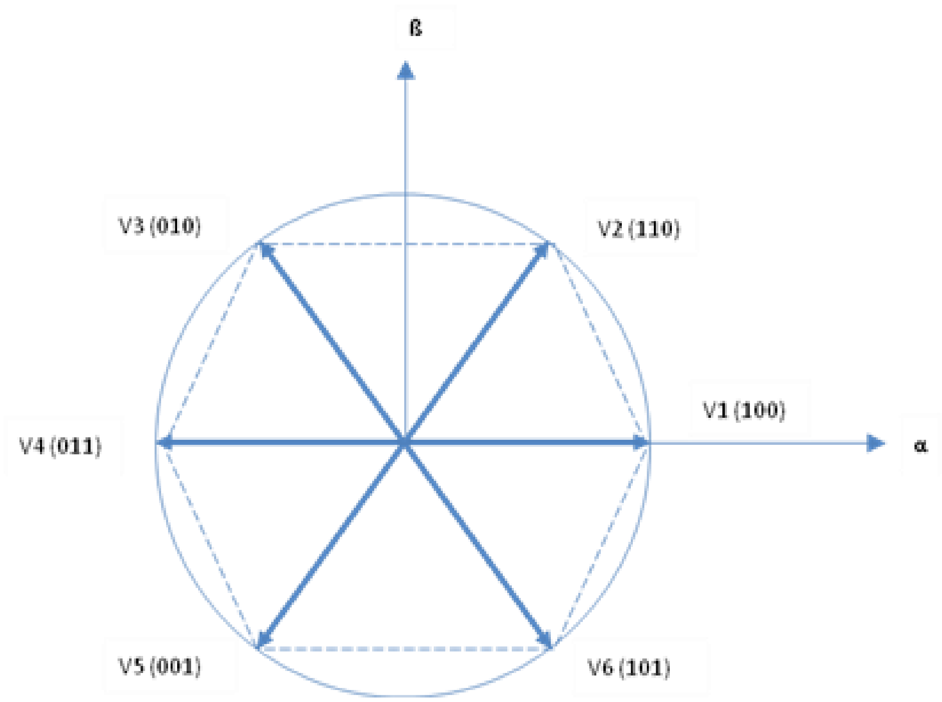

Fig. 2.1: DTC with Space Vector

The voltage space phasor using equation (1) along D-axis is V_d.

$$V(t) = \frac{2}{3} V_d [S_a(t) + ZS_b(t) + Z^2 S_d(t)] \quad (3)$$

2.2 Mathematical model of three phase induction motor model

The mathematical model of three phase induction motor when it is operated in both the states i.e. transient state as well as steady state [11-13] is given below. The equilateral circuit is used to calculate torque flux, stator voltage, stator and rotor current etc. The stator voltage and stator current and flux equation are given as [12]:

Stator voltages equations are:

$$V_{sa}(t) = R_s i_{sa}(t) + \frac{d}{dt}(\Psi_{sa}(t)) \quad (4)$$

$$V_{sc}(t) = R_s i_{sc}(t) + \frac{d}{dt}(\Psi_{sc}(t)) \quad (5)$$

$$Vsc\ (t) = Rs\ isc\ (t) + \frac{d}{dt}(\Psi\ sc\ (t)) \quad (6)$$

Rotor voltages equations are:

$$V_{ra}(t) = R_r i_{ra}(t) + \frac{d}{dt}(\Psi_{ra}(t)) \quad (7)$$

$$V_{rb}(t) = R_r\, i_{rb}(t) + \frac{d}{dt}(\Psi_{rb}(t)) \qquad (8)$$

$$V_{rc}(t) = R_r\, i_{rc}(t) + \frac{d}{dt}(\Psi_{rc}(t)) \qquad (9)$$

Converting to d_q frame: The three-phase supply voltage is converted into two phases by using the given equations. Where V_{sa}, V_{sb} and V_{sc} are the three-phase stator voltages and, V_{sd} is stator voltage direct axis and V_{sq} is stator voltage of quardature axis. i_{sa}, i_{sb}, i_{sc} and i_{ra}, i_{rb}, i_{rc} are three phase stator and rotor currents respectively, while i_{sd}, i_{sq} and ird, irq are two phase stator currents and rotor currents respectively [14].

Flux equations are

$$\Psi_{sd} = [V_{sd} - i_{sd}R_s]\frac{1}{s} \qquad (10)$$

$$\Psi_{sq} = [V_{sq} - i_{sq}R_s]\frac{1}{s} \qquad (11)$$

$$\Psi_{rd} = [\omega\Psi_{rq} - i_{rd}R_r]\frac{1}{s} \qquad (12)$$

$$\Psi_{rq} = [\omega\Psi_{rd} - i_{rd}R_r]\frac{1}{s} \qquad (13)$$

Stator current equations are

$$i_{sd} = \Psi_{sd}\frac{L_r}{L_x} - \Psi_{rd}\frac{L_m}{L_x} \qquad (14)$$

$$i_{sq} = \Psi_{sq}\frac{L_r}{L_x} - \Psi_{rq}\frac{L_m}{L_x} \qquad (15)$$

Rotor Current Equations

$$i_{rd} = \Psi_{rd}\frac{L_s}{L_x} - \Psi_{sd}\frac{L_m}{L_x} \qquad (16)$$

$$i_{rq} = \Psi_{rq}\frac{L_s}{L_x} - \Psi_{sq}\frac{L_m}{L_x} \qquad (17)$$

$$L_x = L_sL_r - Lm^2 \qquad (18)$$

3. RESULTS AND DISCURSION

3.1 Modeling of Three phase induction machine

The three phase induction machine consists of two main parts i.e. stator and rotor. Stator is the stationary part and rotor is the rotating part. The parameters of three phase induction motors are stator resistance, rotor resistance, stator reactance, rotor reactance, mutual and self inductance of the motor [15-16]. The equivalent circuit diagram with rating is shown in Figure 3.1.

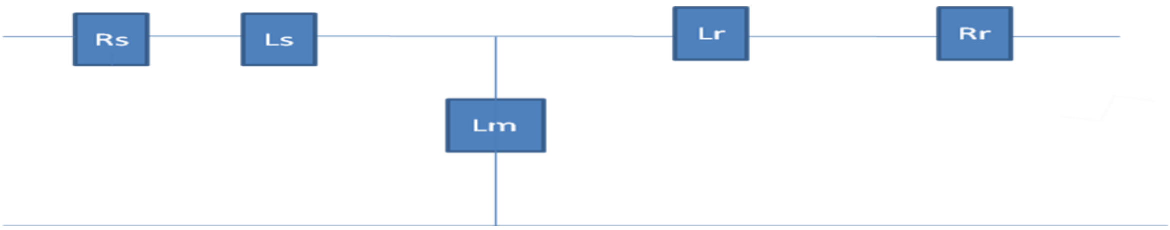

Fig. 3.1: Equivalent circuit diagram of three phase induction motor

3.2 Principle Model of DTC

The DTC scheme consist of Voltage source inverter , six voltage phasors and two zero phasors to keep in sequential order , the stator flux and torque with in limits of hysteresis band near the command is shown in figure 2.1. In fig. 1 the DTC space vector the switching positions of the voltage source inverter are shown out with similar voltage vectors based on the model of voltage source inverter shown in figure 3.2 [17,19].In figure 3.2 the upper switches are shown by 1,3and 5 and the lower switches are shown by 4,6 and 2.

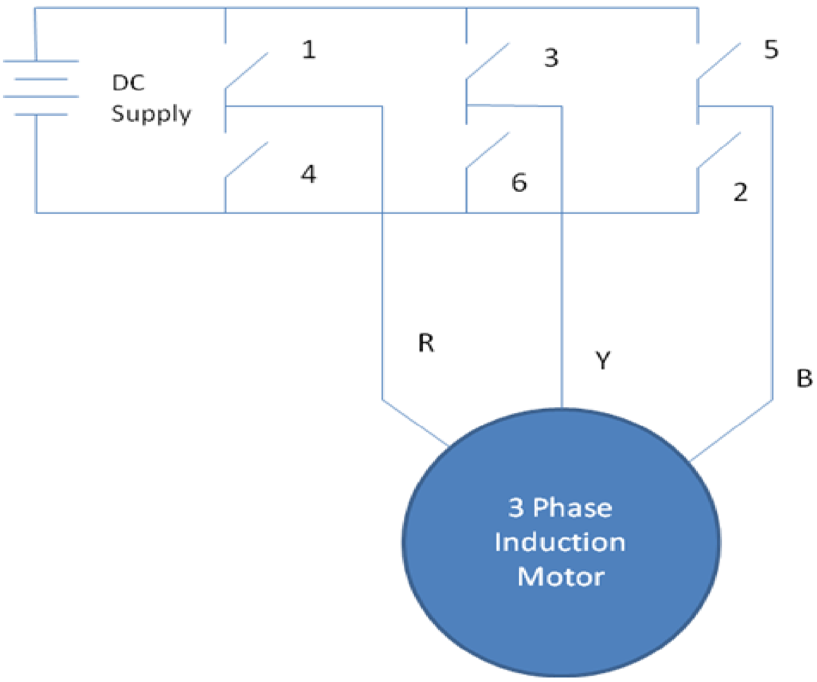

Fig. 3.2: Switching model of voltage source inverter

The basic block diagram of direct torque control scheme consist of supply voltage, voltage source inverter, switching table , hysteresis controller, flux and torque estimator , input flux , input torque and three phase induction motor with feedback arrangement as shown in Figure 3.3[18,20].

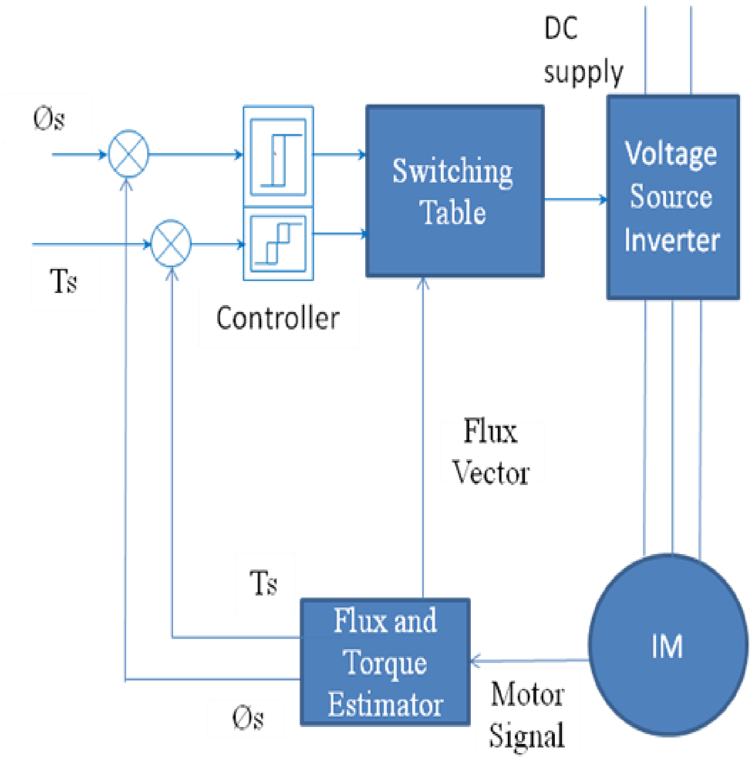

Fig. 3.3: Block diagram of conventional DTC scheme

The block diagram of conventional DTC scheme that reference value of stator flux and stator torque is compared with actual values of three phase induction motor scheme and calculated errors are obtained [21].

3.3 Fuzzy Logic Controller with DTC

Fuzzy logic controller consists of three error input variables such as stator flux, electromagnetic torque, stator flux and one output (known as voltage space vector). Fuzzy logic error is measured that shows the dissimilarity between stator flux with real value of stator flux. Fuzzy logic errors are measured in terms of negative, zero and positive [22, 26].

Electromagnetic torque error is comparison between actual torque and desired torque. Electromagnetic torque error is measured in term of gigantic positive, compact positive, gigantic negative, and compact negative. Flux linkage angle is the flux between stator flux with reference axis [23, 25]. Fuzzy logic controller using with DTC is shown in Figure 3.4[24].

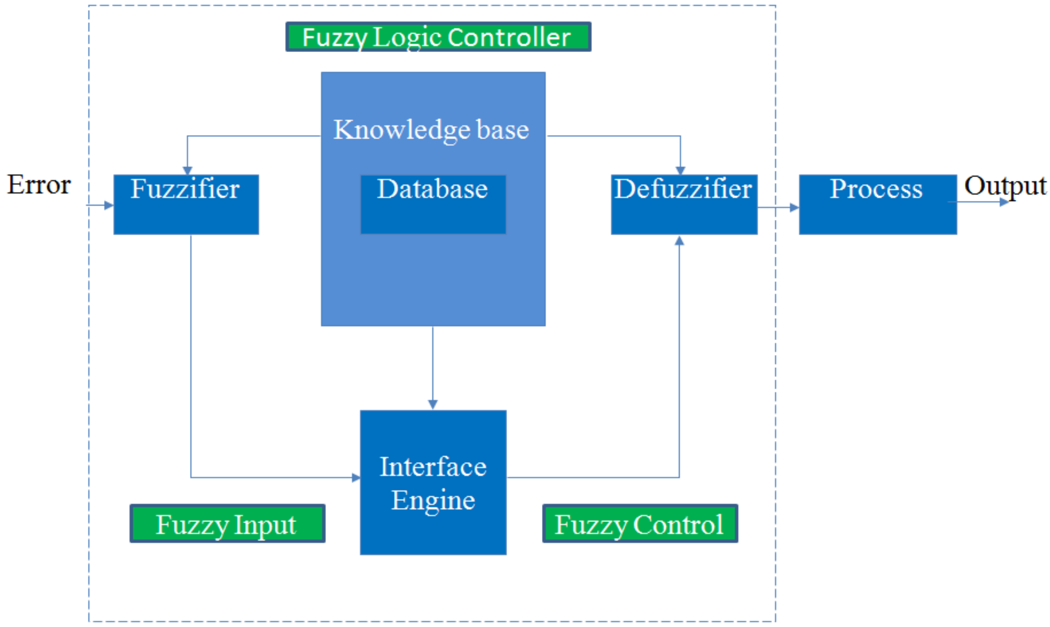

Fig.3.4: Block diagram of fuzzy logic controller with DTC

The DTC using with Fuzzy logic consist of three input variables i.e. flux, electromagnetic torque, stator flux and one output known as voltage space vector. Fuzzy logic errors are measured in terms of negative, zero and positive values. Electromagnetic torque error is the difference between desired torque and real torque. Electromagnetic torque error is measured in term of large positive, small positive and large [27, 28].

3.3.1 Working model of Fuzzy logic Controller with DTC

The fuzzy logic model consists of Fuzzy controller, Parks transformation, Inverter, Induction machine model and wind Turbine. In this model, wind turbine is used as electrical power source to induction motor model, load angle and pitch is used to control the speed of the wind generator [29, 30]. The output of the wind generator is connected to induction motor machine model through gain. The speed and torque of the induction motor model is controlled when we compare the reference speed with actual speed. The fuzzy controller is used is of Mamdani type. It consists of seven membership function. The proposed rules are different from others. To handle these rules I used NVB and PVS system [29-30].

Table 3.1: Fuzzy Rules [32]

ΔE/E	NB	NM	NS	ZE	PS	PM	PB
NB	NB	NB	NB	NB	NM	NS	ZE
NM	NB	NB	NM	NM	ZE	PS	NB
NS	NB	NM	NS	PB	PS	ZE	PM
ZE	NB	NS	ZE	PM	PM	PM	PB
PS	NM	NM	PS	PS	PS	PM	PB
PM	NS	ZE	PM	ZE	PB	PB	PB
PB	ZE	PS	NS	NS	NM	PB	PB
49 Rules a/c = ΔE/Δe							

$$e(k) = \omega_{ref} - \omega_r \quad (19)$$

$$i = \frac{2}{3}\frac{2}{P}\frac{Lr}{Lm}\frac{Te}{3}\frac{1}{\Psi r} \quad (20)$$

$|\Psi r|$= rotor flux

$$\Psi_{s\alpha} = \int (V_{s\alpha} - R_s I_{s\alpha})\,dt \quad (21)$$

$$\Psi_{s\beta} = \int (V_{s\beta} - R_s I_{s\beta})\,dt \quad (22)$$

$$Te = \frac{3}{2}\frac{P}{2}\frac{Lr}{Lm}(\Psi_{s\alpha} I_{s\beta} - \Psi_{s\beta} I_{s\alpha}) \quad (23)$$

$$T = T_e - T_L = \frac{P}{2}\left(J\frac{d\omega r}{dt} + B\omega r\right) \quad (24)$$

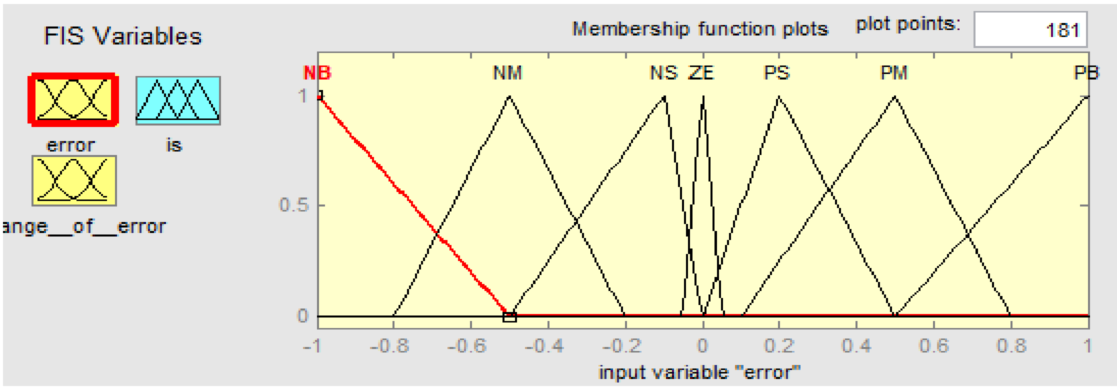

Fig.3.5: Membership functions of inputs variables

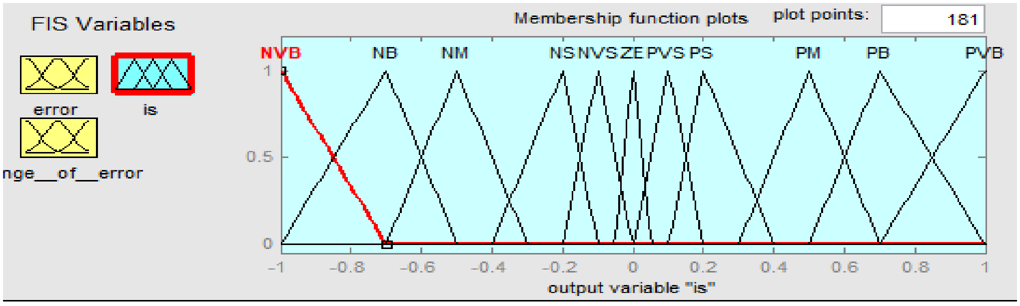

Fig.3.6: Membership functions of output variables

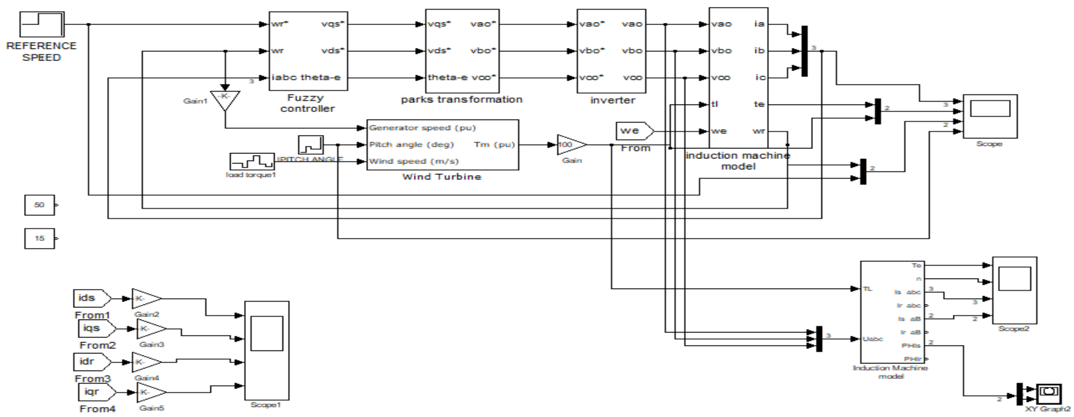

Fig. 3.7: Simulink model of DTC with Fuzzy Logic controller

As proposed model speed, rise time, settling time, transient time and torque ripples has been controlled using Fuzzy logic controller.

4. SIMULATION ANALYSIS

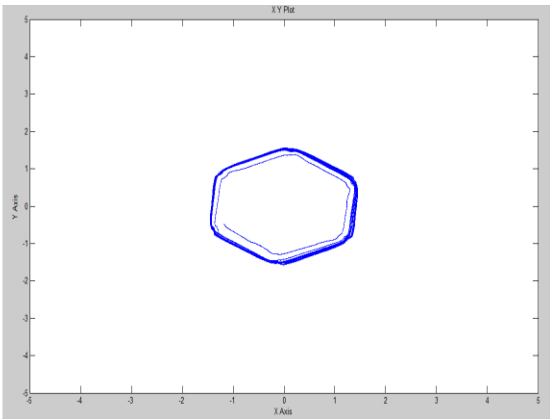

Fig. 4.1: Stator flux trajectory path response DTC with FLC

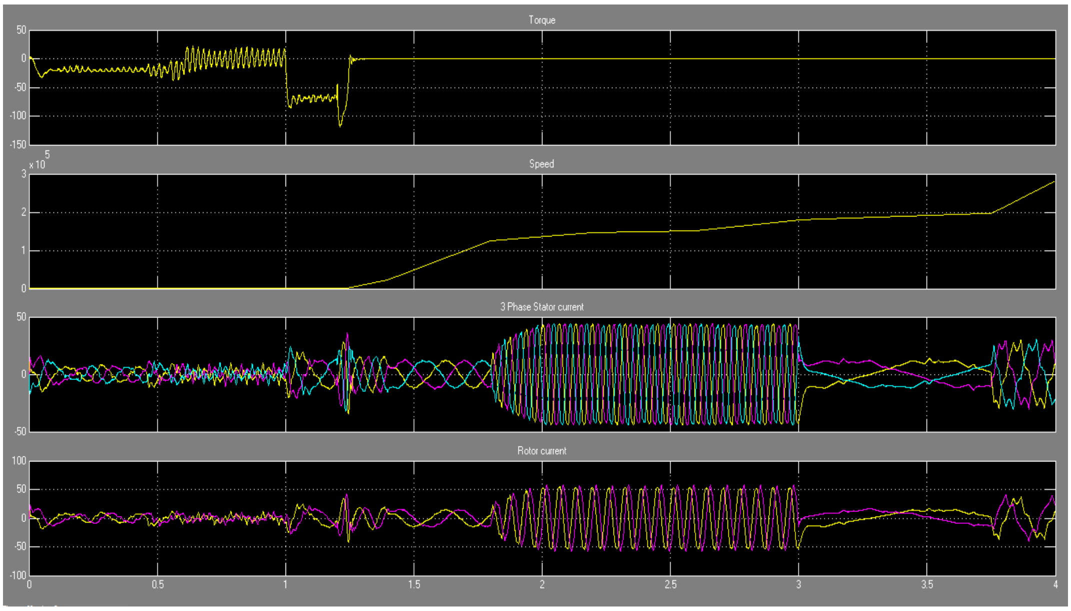

Fig. 4.2: Simulation response of DTC with fuzzy logic controller

The Parameters of three phase induction motor model is - Resistance of Rotor in Ohm is 0.39. Resistance of Stator in Ohm is 0.19.Inductance of Stator in Henry is 0.00021. Inductance of Rotor in Henry is 0.0006. Mutual inductance in Henry is 0.0004. Numbers of Poles = 4. Moment of inertia ($Kgm^{2)}$ = 0.0226. Base speed =1400rpm.

5. CONCLUSION

In this paper propose the DTC technique for the control of speed and fluctuations of an induction motor .we offered the direct torque control technique integration with fuzzy logic controller. Moreover, this technique is used to control the speed and torque fluctuations of induction motor by reducing the torque ripples. Furthermore, the simulation results justify that by using Fuzzy logic controller coordination with DTC the speed, fluctuations are controlled and torque ripples are also reduced. The simulation and experimental results have been verified by using MATLAB software.

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