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Dynamic Modelling of Induction Motor and Direct Torque Control by Fuzzylogic and ANFIS

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Abstract

This paper studies about the dynamic model of three phase induction motor which is relevant for understanding its dynamic characteristics. We use direct torque control (DTC) method for driving the motor and a detailed study of speed and torque variation is done. Even though DTC control scheme has many advantages, main disadvantage is the presence of ripple in electromagnetic torque output. A controller is designed based on fuzzy logic and is implemented in DTC induction motor drive. The addition of controller helps to reduce the ripples in torque effectively. Then based on adaptive neuro fuzzy inference system (ANFIS) torque ripple is reduced.

Keywords— fuzzy PI controller, induction motor, DTC controller, Adaptive Neuro Fuzzy Inference System (ANFIS)

I. Introduction

Induction motor is a widely used AC machine in variety of industrial applications due to its performance and other factors like reliability, cost. The presence of a drive will help to reduce the cost and reduce the energy consumption.Dynamic modelling is done with the help of MATLAB/SIMULINK on the basis of two-axis theory[1]. Better understanding of the transient and steady state operations is obtained by this dynamic model[2], [3].

Direct torque control of induction motor is done on the basis of deadbeat control of torque as well as flux. The changes in torque and flux is calculated by the estimation of synchronous speed[4].Then the stator voltage is calculated according to this change and both the flux and torque are made equal to the reference values.The switching states of the inverter is defined by space vector pulse width modulation. DTC is easier and less complex than field oriented control because of the absence of frame transformer.

By the addition of fuzzy logic in DTC we can achieve resistance compensation in low speed and better accuracy as compared to classical DTC[6]. Here, fuzzy logic controller is implemented in classical DTC induction motor drive in the Simulink.The development of a new approach that is ANFIS to reduce the torque ripple is also discussed in this paper.

II. *DYNAMIC MODELLING OF INDUCTION MOTOR*

Fig.1 represents the d-q equivalent of arbitrary reference frame which helps to understand the relation between voltages and currents of stator as well as rotor. By d-q transformation 6 x 6 matrix which represents the voltages and currents of stator as well as rotor is reduced to a 4 x 4 matrix.

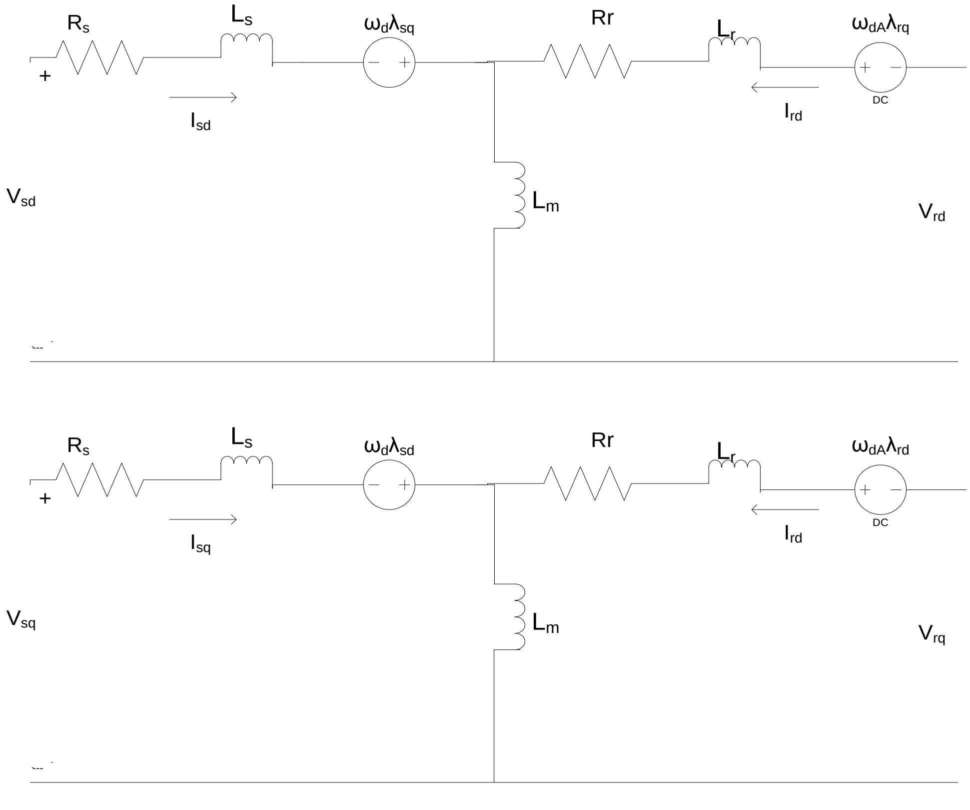

Fig. 1 d-q Equivalent circuit

Basic equations for the modeling of induction motor are given below.
Three phase voltages are converted to d-q frame which is stationary by

$$\begin{bmatrix} Vds \\ Vqs \end{bmatrix} = \begin{bmatrix} \frac{2}{3} & -\frac{1}{2} & -\frac{1}{2} \\ 0 & -\frac{1}{\sqrt{3}} & -\frac{1}{\sqrt{3}} \end{bmatrix} \times \begin{bmatrix} Vas \\ Vbs \\ Vcs \end{bmatrix} \quad (1)$$

The above equation can be implemented using mux and function blocks.

Stationary frame needs to be converted to synchronous frame which rotates in the speed of rotating magnetic field. We use repeating sequence block to represent ‘’ in order to make the frame rotating in synchronous speed ω_s.

$$\begin{aligned} Vqs^e &= Vqs.\cos - Vds.sin \\ Vds^e &= Vqs.sin + Vds.cos \end{aligned} \quad (2)$$

Electromagnetic torque as well as speed equations are expressed in equation (3) and (4) respectively

$$\text{Tem}=\frac{3*P*Lm}{4} \times i_{dr}i_{qs}\text{-}i_{qr}i_{ds} \quad (3)$$

$$\omega_o=\int_{\tau=0}^{t} \frac{T_{em-}T_L-B.\omega}{J}d\tau \quad (4)$$

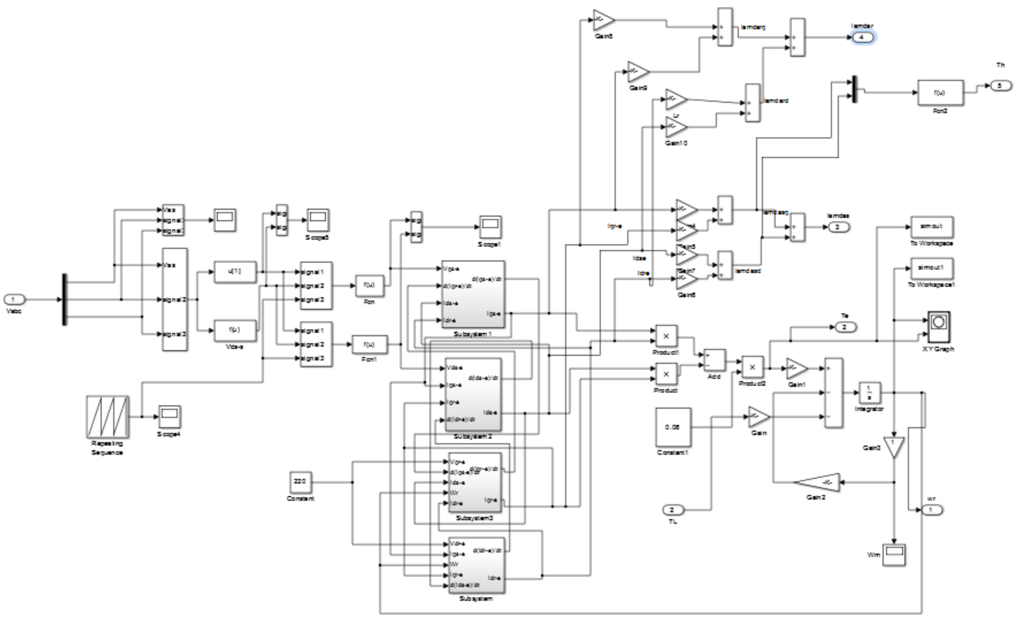

Fig. 2 Complete model of 3-φ induction motor.

Table 1 Motor specifications

Power (VA)	149.2KW
R_s	14.85×10^{-3} ohm
R_r	9.295×10^{-3} ohm
L_s	0.3027×10^{-3}H
L_r	0.3027×10^{-3}H
L_m	10.46×10^{-3}H
M	$3.1Kg.m^2$
No of pole pairs	2

III.DIRECT TORQUE CONTROL

Even though field oriented control is an effective control strategy for three phase induction motor it has a serious drawback that it requires precise knowledge of motor parameters particularly rotor time constant.Torque and flux are controlled by means of hysteresis comparator. The flux comparator gives the error status as 0 or 1. If the estimated flux touches lower band the status will be 1 which means that the actual flux needs to be increased and for that the most appropriate voltage vector is opted. For torque we use a three level hysteresis comparator which takes the value as 1, 0 or -1. Similarly if estimated torque touches the upper band torque need to be decreased and appropriate voltage vector is selected according to binary output created by change of magnetic flux, torque and flux angle.

Table 2- Optimum Switching Table

H_Φ	H_{Te}	S_1	S_2	S_3	S_4	S_5	S_6
-1	-1	V_5	V_6	V_1	V_2	V_3	V_4
	0	V_7	V_0	V_7	V_0	V_7	V_0
	1	V_3	V_4	V_5	V_6	V_1	V_2
1	-1	V_6	V_1	V_2	V_3	V_4	V_5
	0	V_0	V_7	V_0	V_7	V_0	V_7
	1	V_2	V_3	V_4	V_5	V_6	V_1

Induction motor drive given below is made up of 6 main blocks such as three-phase inverter, diode rectifier, induction motor, DTC controller, speed controller and braking chopper.

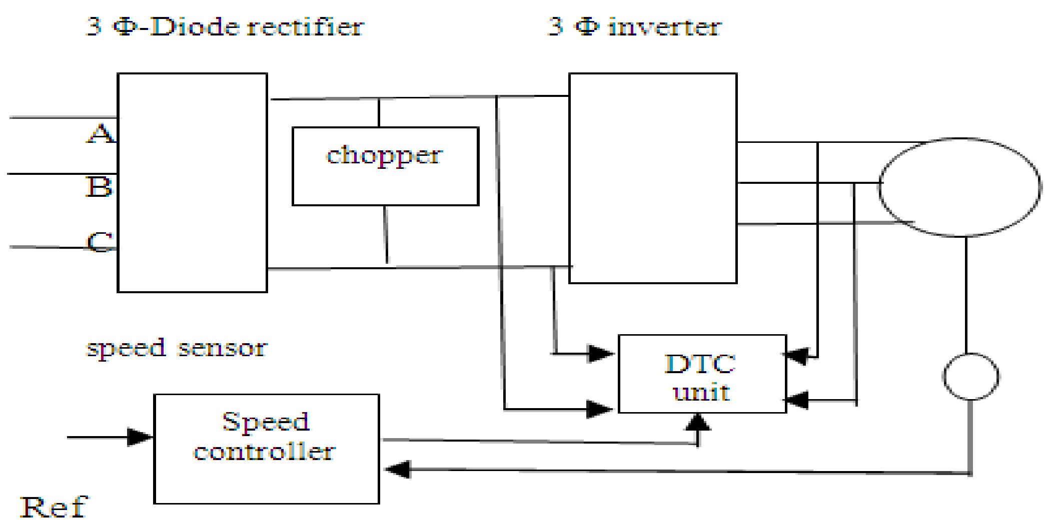

Fig 3. Block Diagram OfDTC Induction Motor Drive.

Complete Simulink model of DTC induction motor drive is shown in the Fig 2

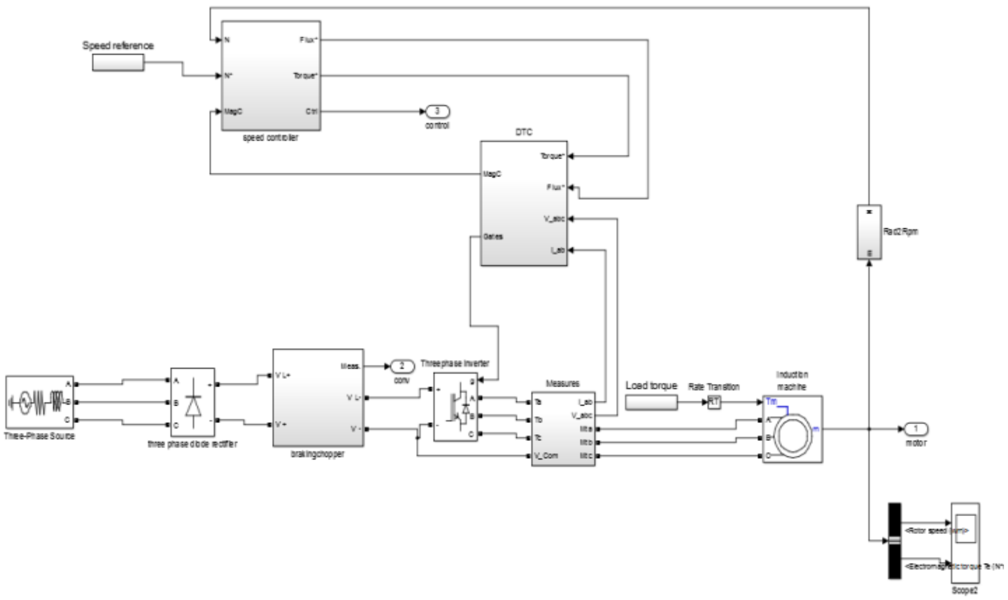

Fig 4.SIMULINK model of DTC drive.

AC4 model which is present in SIMULINK is a 200hp induction motor drive. Under mask of DTC controller there is lookup table, hysteresis comparator of torque and stator flux and estimators. Programming of switching table is done in such a way that appropriate voltage vector is selected according to Table - 1.

IV. FUZZY PI CONTROLLER IN DTC DRIVE

A fuzzy PI controller is implemented inside the torque hysteresis block so that to reduce torque ripple. Reference torque and calculated torque are the input of torque hysteresis. Fuzzy PI is added just before the torque hysteresis. Input to the hysteresis comparator are $T = T_{ref} - T_e$ and $dT = T(t) - T(t-\Delta t)$.

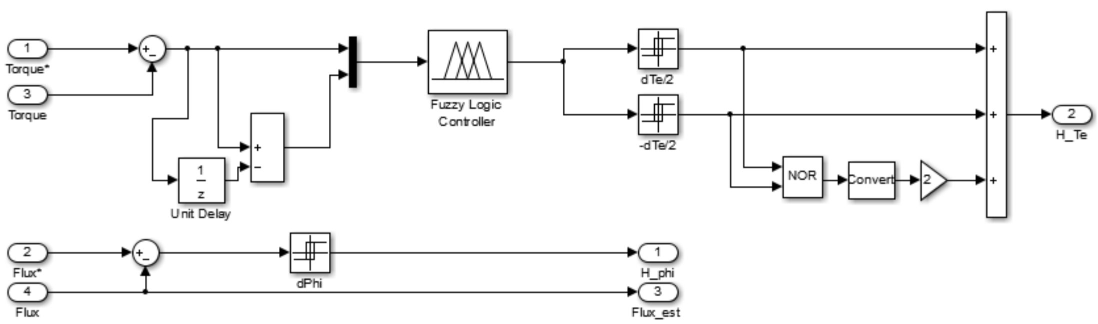

Fig. 5Fuzzy PI controller block

The two gains in the inputs are normalization gains of T as well as dT and output gain is for un-normalization of output. The range of input membership functions are[-4, 4] and output range is [-10, 10]. The inputs and outputs are divided in to seven subsets defined as {-3, -2, -1, 0, 1, 2, 3 } which are denoted as NB, NM, NS, Z, PS, PM, PB. Based on this 49 rules are formulated according to Table-3.

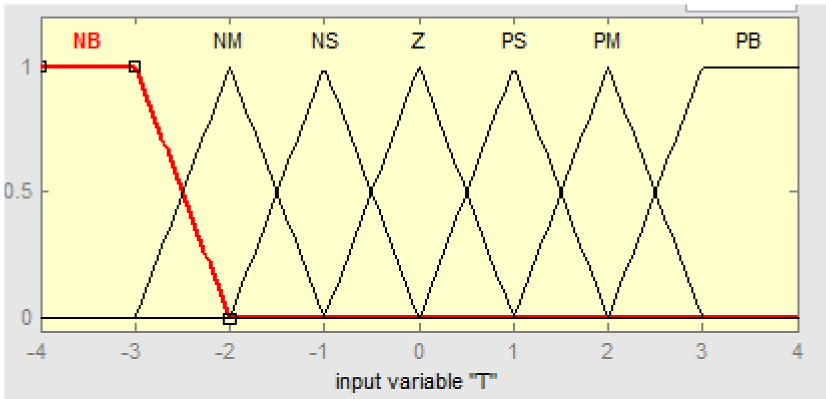

Fig 6.Membership function for input T

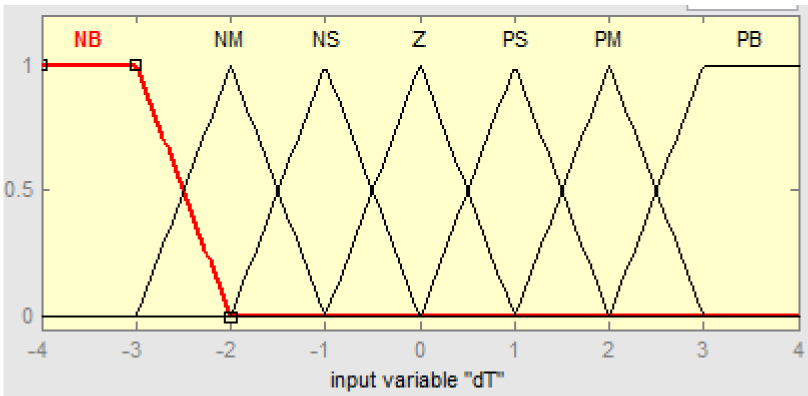

Fig 7.Membership function for input dT

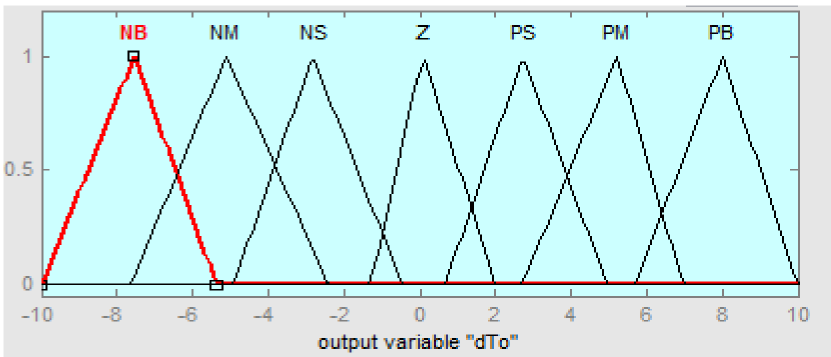

Fig 8.Membership function for output dTo

Table- 3 – Fuzzy Rule Base

T / dT	NB	NM	NS	Z	PS	PM	PB
NB	Z	Z	NB	NB	Z	Z	Z
NM	NB	NM	NB	NS	NM	Z	Z
NS	NM	NM	NB	NB	Z	PS	Z
Z	NM	NS	NB	Z	Z	PS	Z
PS	NS	NS	Z	Z	Z	PM	Z
PM	NS	Z	NB	PS	Z	PM	Z
PB	Z	PS	NB	NB	Z	PB	Z

V. ANFIS BASED DTC INDUCTION MOTOR DRIVE.

Based on the input and output data of torque in fuzzy PI controller we train the ANFIS and the controller obtained can adapt the same characteristics of our designed controller.This scheme uses inputs$T_{=}$ T_{ref} -$T_e$anddT = T (t) - T (t-Δt).The output of ANFIS based DTC induction motor drive is shown in Fig 15. Thus by introducing ANFIS the torque ripple is further reduced.

V. SIMULATION &RESULTS

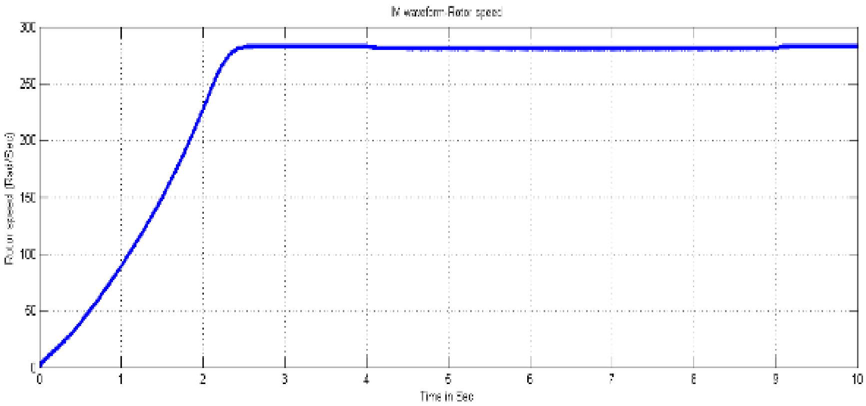

Fig.9Rotor speed of Induction motor

The synchronous speed of the motor is 314 rad/sec. The motor runs with a speed less than synchronous speed, which is attained in almost 2.5 seconds as in Fig. 9

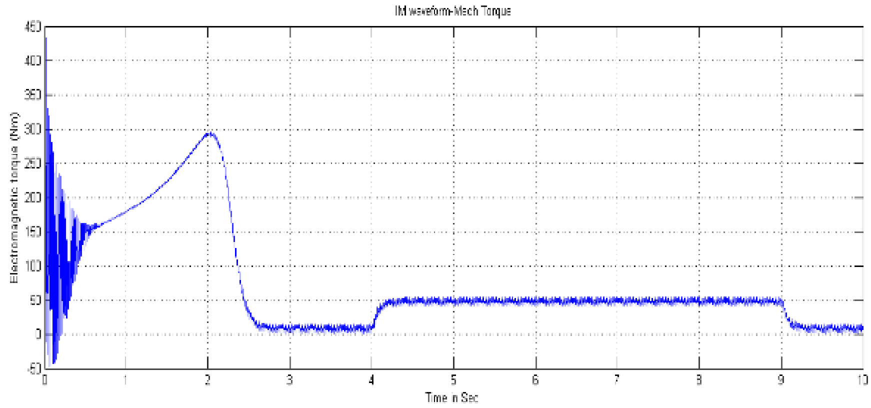

Fig.10 Mechanical Torque Output of Induction motor

Initially there are transients but when motor reaches synchronous speed, the electromagnetic torque will be equal to load torque. Here we applied a pulse of 40N-m amplitude as a load torque and its output is shownin Fig. 10

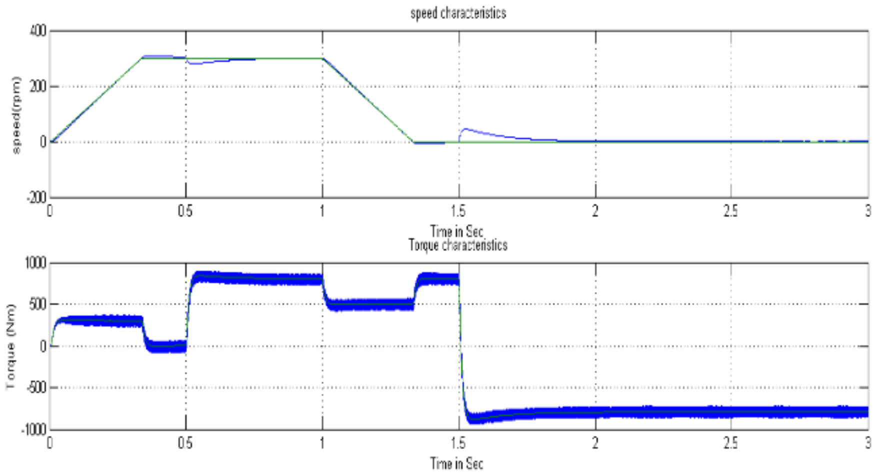

Fig. 11 Speed And Torque Response Of DTC Induction Motor Drive

A speed of 300 rpm is set at t=0sec and output shows accelerating ramp and it reaches synchronous speed and at t=0.5 sec a nominal torque is applied. At t= 1 sec speed is reduced to zero. So speed shows a deceleration ramp and finally at t=1.5sec a negative torque is applied.

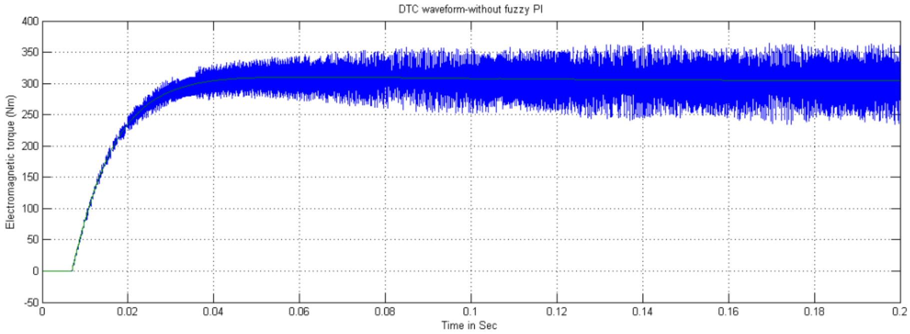

Fig 12.Torque ripple in DTC-IM drive without fuzzy PI

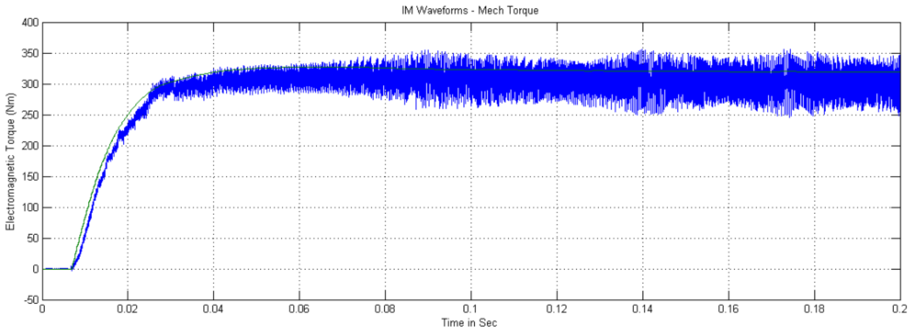

Fig 13. Torque ripple in DTC-IM drive with fuzzy PI

By comparing Fig.12 and Fig. 13 we can see the reduction in torque ripple when fuzzy PI is added to DTC induction motor drive. ThePeak to peak ripple is reduced by 50 Nm.

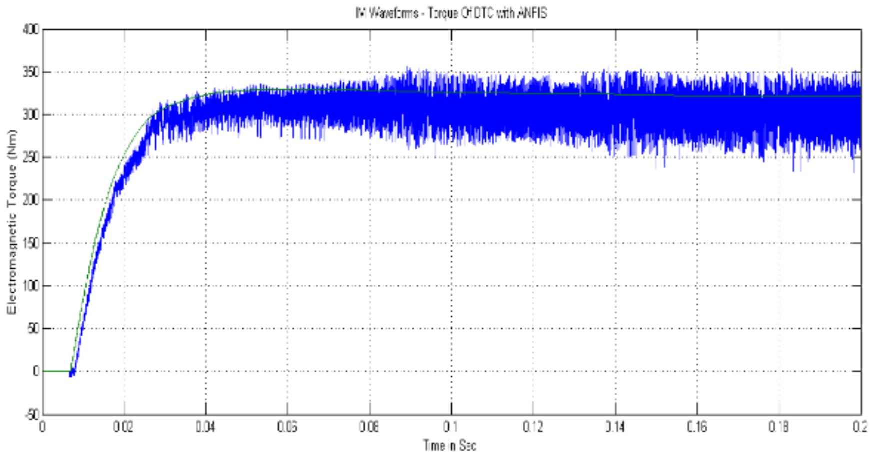

Fig 14. Torque ripple in DTC-IM drive with ANFIS

By comparing figure 13 and 14 the peak to peak ripple is further reduced by 65Nm which shows the validity of ANFIS based DTC induction motor control scheme.

VI CONCLUSION.

Dynamic modelling of induction motor is done and studied the torque and speed characteristics as well as speed vs torque at various loads. Obtained the DTC model of 200 hp three phase induction motor and the speed and torque variation at various speeds and torques are obtained. After the introduction of fuzzy PI controller the peak to peak ripple is reduced. For classical DTC the peak to peak ripple is 140Nm which is reduced to 90 Nm when fuzzy PI is introduced.

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