REDUCTION OF TORQUE RIPPLES OF INDUCTION MOTOR BY IMPROVED METHOD OF DIRECT TORQUE CONTROL USING FUZZY LOGIC TECHNIQUES.

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ABSTRACT—*In this paper we describe the control of an induction machine (IM) using the principle of direct torque and flux control(DTFC). This method is designed by means of fuzzy logic with three inputs and three outputs and contains 180 rules.For improvement of this method a fuzzy duty ratio controller is added. This controller prepares an optimum voltage vector(output from fuzzy DTFC control). In this control the selected inverter switching state is applied for a portion of the switching period, defined as duty ratio and the zero switching state is applied for the rest of the period. The duty ratio is chosen to give an average voltage vector for a change of torque with decreasing ripples. The control is verified by simulation.*

Keywords— ***induction machine, direct torque and flux control, fuzzy controller, speed control.***

1, INTRODUCTION

In many industrial applications, direct torque control (DTC) of induction motor is well-known control method which provides fast dynamic response compared with other control methods like field oriented control (FOC). The DTC has been proposed for induction motor control in 1985 by Takahashi [1] and similar idea that the name of Direct Self Control developed in 1988 by Depenbrock [2]. Over the past years, the DTC has gained great attention due to its advantages like simple control structure, robustness to parameters variations, fast dynamic response. However, DTC has still some disadvantages and they can be summarized as follows; high current and torque ripples, difficulty to control torque and flux at very low speed, variable switching frequency behavior and high sampling frequency needed for digital implementation. The big interest in DTFC is caused by some advantages in comparison with the conventional vector-controlled drives, like: The control is without using current loops. The drive does not require coordinate transformation between the stationary frame and synchronous frame. A pulse-width modulation (PWM) modulator is not required. Conventional DTFC has also some disadvantages:

• Possible problems during starting and low speed operation.

• High requirements upon flux and torque estimation.

• Variable switching frequency.

These are disadvantages that we want to remove by using and implementing modern resources of artificial intelligence like neural networks, fuzzy logic, genetic algorithms etc. [3]. In the following, we will describe the application of fuzzy logic in DTFC control.

2. PRINCIPLES OF DIRECT TORQUE CONTROL

Direct torque control principles were first introduced by Depenbrock and Takahashi. In this 2.1 Transpose Function method, Stator voltage vectors are selected according to the differences between the reference and actual torque; reference and actual stator flux linkage. The DTC method is characterized by its simple implementation and a fast dynamic response. Furthermore, the inverter is directly controlled by the algorithm, i.e. a modulation technique for the inverter is not needed. The main advantages of DTC are absence of coordinate transformation and current regulator; absence of separate voltage modulation block. Common disadvantages of conventional DTC are high torque ripple and slow transient response to the step changes in torque during start-up.

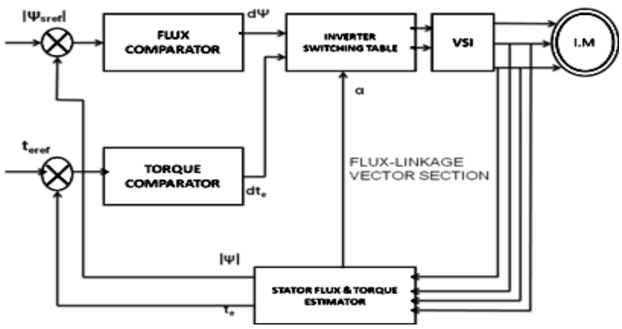

Fig. 1 Block diagram of basic DTC drive

Fig. 1 shows the schematic of the basic functional blocks used to implement the DTC of induction motor drive. A voltage source inverter (VSI) supplies the motor and it is possible to control directly the stator flux and the electromagnetic torque by the selection of optimum inverter switching modes. This control strategy uses two level inverter suggested by Takahashi, to control the stator flux and the electromagnetic torque of the induction motor.

The DTC scheme consists of torque and flux comparator (hysteresis controllers), torque and flux estimator and a switching table. It is much simpler than the vector control system due to the absence of coordinate transformation between stationary frame and synchronous frame and PI regulators. DTC does not need a pulse width modulator and a position encoder, which introduce delays and requires mechanical transducers respectively. DTC based drives are controlled in the manner of a closed loop system without using the current regulation loop. DTC scheme uses a stationary d-q reference frame having its d-axis aligned with the stator q-axis. Torque and flux are controlled by the stator voltage space vector defined in this reference frame [8]. The basic concept of DTC is to control directly both the stator flux linkage and electromagnetic torque of machine simultaneously by the selection of optimum inverter switching modes. The use of a switching table 1 for voltage vector selection provides fast torque response, low inverter switching frequency and low harmonic losses without the complex field orientation by restricting the flux and torque errors within respective flux and torque hysteresis bands with the optimum selection being made. The DTC controller consists of two hysteresis comparator (flux and torque) to select the switching voltage vector in order to maintain flux and torque between upper and lower limit.

DTC explained in this paper is closed loop drive. Here flux and torque measured from the induction motor using proper electrical transducer. Then flux and torque errors are found out by equation (1) and (2) [7].

$$d\Psi=\Psi ref - \Psi \quad \text{……………….} \ (1)$$

$$dte=tref - te \quad \text{…………………...} \ (2)$$

Using flux and torque comparator flux and torque command obtained respectively. From these commands, drive can know flux has to increase or decrease and torque has to increase, make constant or decrease. Then by finding field angle, drive can find sector of flux linkage vector. After acquiring signals from flux comparator ($d\Psi$), torque comparator (dte) and flux-linkage vector section (α), control algorithm of DTC was developed means gate pulse required for inverter is developed using switching table 1 [6]. As shown in fig 2, particular logic level signals developed. Here U0 indicates (000) and U7 indicates (111). Sector can be obtained as per the flux vector angle as shown below [7]:

$$-30° \le \alpha < 30°$$

$$30° \le \alpha < 90°$$

$$90° \le \alpha < 150°$$

$$150° \le \alpha < 210°$$

$$210° \le \alpha < 270°$$

$$270° \le \alpha < 330°$$

dΨ	dt	α1	α2	α3	α4	α5	α6
1	1	U2	U3	U4	U5	U6	U1
1	0	U7	U0	U7	U0	U7	U0
1	-1	U6	U1	U2	U3	U4	U5
0	1	U3	U4	U5	U6	U1	U2
0	0	U0	U7	U0	U7	U0	U7
0	-1	U5	U6	U1	U2	U3	U4

Table 1 :Switching Vector Table

Where, dΨ=1; Increase in flux

=0; Decrease in flux

dt=1; Increase in torque

=0; No change

=-1; Decrease in torque

3. FUZZY LOGIC BASED DTC

To obtain improved performance of the DTFC drive during changes in the reference torque, it is possible to use a fuzzy-logic-based switching vector selection process[1]. For this purpose a Mamdani-type fuzzy logic system will be used. The different output voltage states (active and zero states) are selected by using three inputs: flux e and torque errors and also the position of the stator flux linkage space vector us (Fig.2). Two mamdani type fuzzy logic controllers which contain fuzzifier, inference engine, rule base and defuzzifier replace the two hysteresis comparators in conventional DTC. 4.1. Flux error fuzzification The flux error is obtained from equation (12) $\Delta\Psi = \Psi s^* - \Psi s$ (12) For flux error, there are three linguistic terms negative error, zero error and positive error denoted as N, Z and P. For this purpose it is assumed that the stator flux link-age space vector can be located in any of twelve sectors, each spanning over a 60∘ wide region.

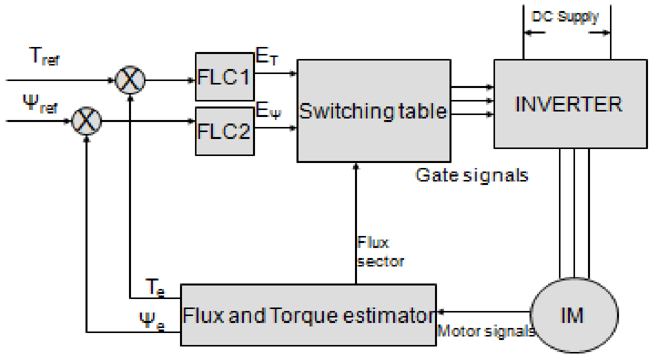

Fig.2 FUZZY LOGIC BASED DTC

For every sector there are 15 rules. The stator flux error has three fuzzy sets: stator error can be positive P, zero ZE, and negative N. For the torque error, there are five fuzzy sets: the torque error em = M∗m fMs can be positive large PL, positive small PS, zero ZE, negative small NS and negative large NL (Fig. 2). Since there are 12 sectors, for each sector 15 rules, the total number of rules is 180.

4.FUZZY DUTY RATIO CONTROLLER

The voltage vectors selected from the fuzzy DTFC are not optimal in some region of stator flux vector positions. These disadvantages are improved by the fuzzy controller called a duty ratio controller [1]. In this control the selected inverter switching state is applied for a portion of the sample period, defined as a duty ratio [3], and the zero switching state is applied for the rest of the period. The duty ratio is chosen to give an average voltage vector, which causes torque change with ripple reduction. Fuzzy controller includes two inputs (torque error and the position of the stator flux linkage us according on sector) and one output (duty ratio). Figure 3 describes membership function inputs and outputs.

5.PROPOSED FUZZY LOGIC CONTROLLER

The fuzzy logic control is one of the controllers in the artificial intelligence techniques. Fig.4 shows the schematic model of Fuzzy based DTC for IMD. In this project, Mamdani type FLC is used and the DTC of IMD using PI controller based SR(speed regulator) are requires the precise mathematical model of the system and appropriate gain values of PI controller to achieve high performance drive. Therefore, unexpected change in load conditions would produce overshoot, oscillation of the IMD speed, long settling time, high torque ripple, and high stator flux ripples. To overcome this problem, a fuzzy control rule look-up table is designed from the performance of torque response of the DTC of IMD. According to the torque error and change in torque error, the proportional gain values are adjusted on-line [8].

The fuzzy controller is characterized as follows:

1) Seven fuzzy sets for each input and output variables,
2) Fuzzification using continuous universe of discourse,
3) Implication using Mamdani's „min" operator,

The membership functions of fuzzy logic controller flux-torque inputs and angle output can be Seen in Figure 3. Table 1. Describes rule table of fuzzy logic controller.

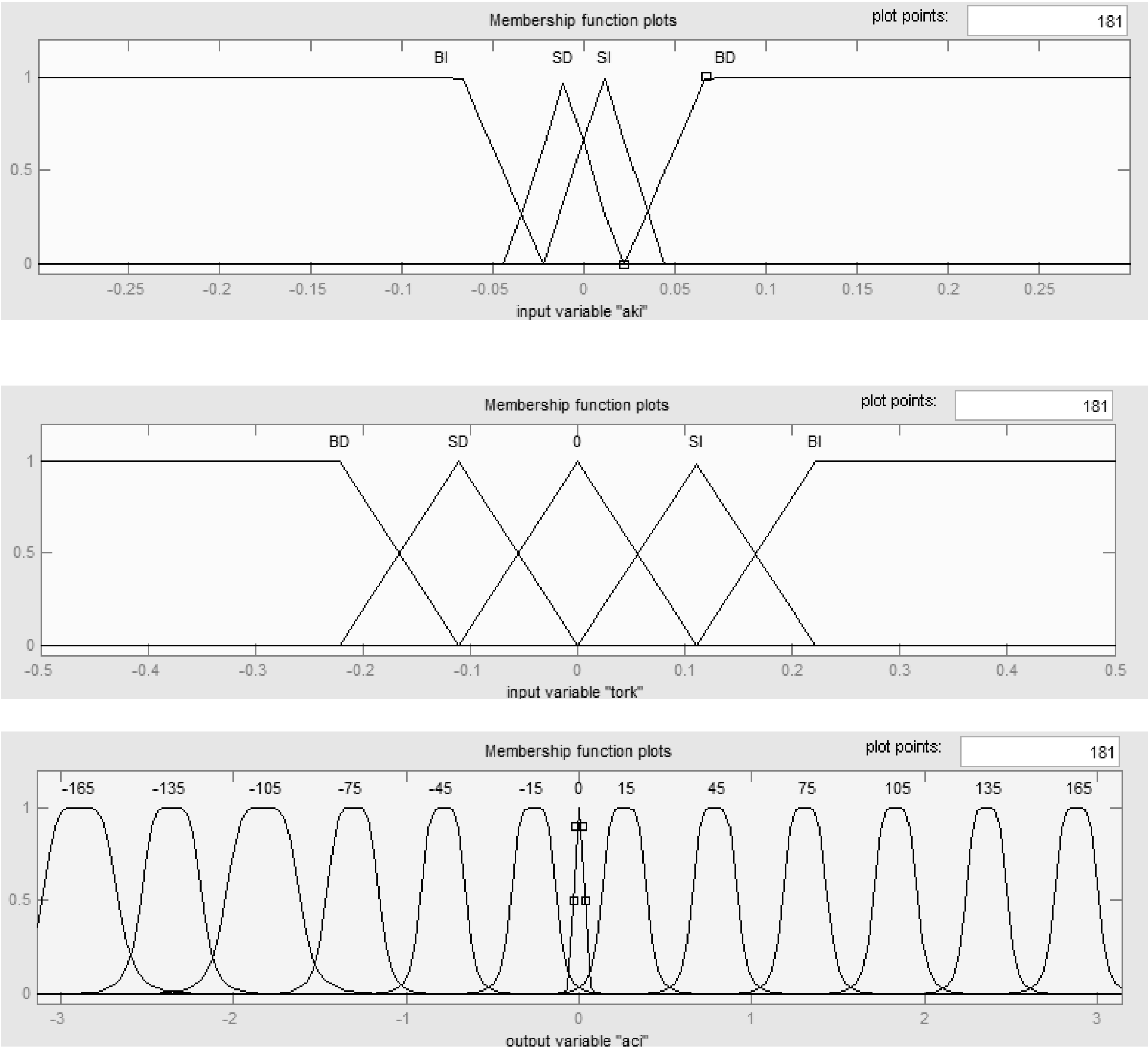

Figure 3. Flux, torque and angle membership functions

6. **EXPERIMENTS**

Simulations in Simulink/Matlab 6.5.1 verify the control. With a speed controller on the torque generator(Fig. 4& Fig5.) we get speed fuzzy DTFC control of the induction machine. For verification of the control we do not need the speed, torque and flux estimators (for sensorless control). These state values are the feedback from the model of the induction machine.

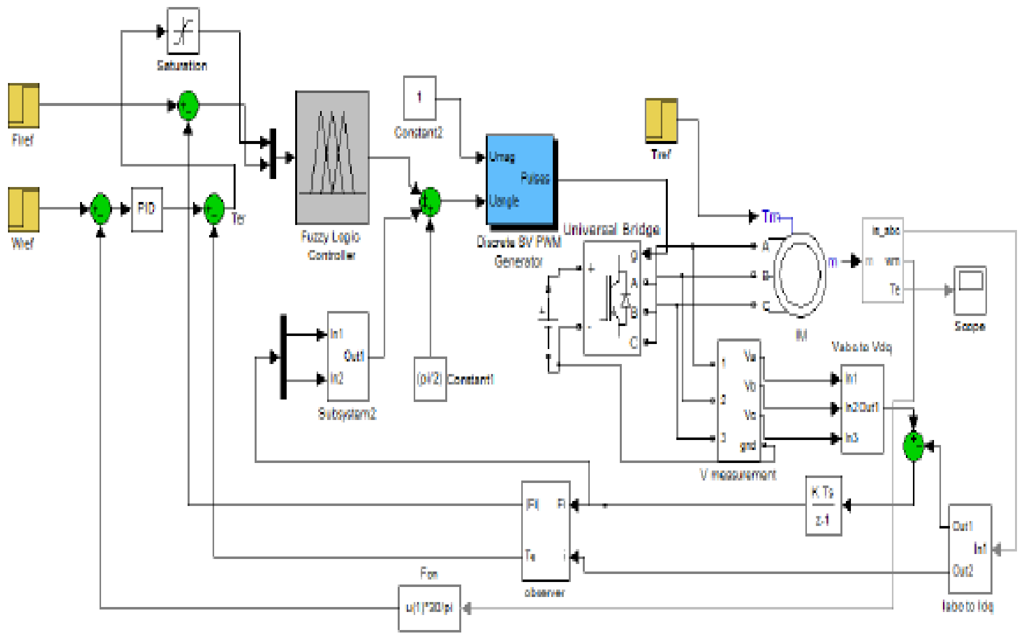

Fig 4.1 MATLAB SIMULINK model of DTC of induction motor using Fuzzy Controller.

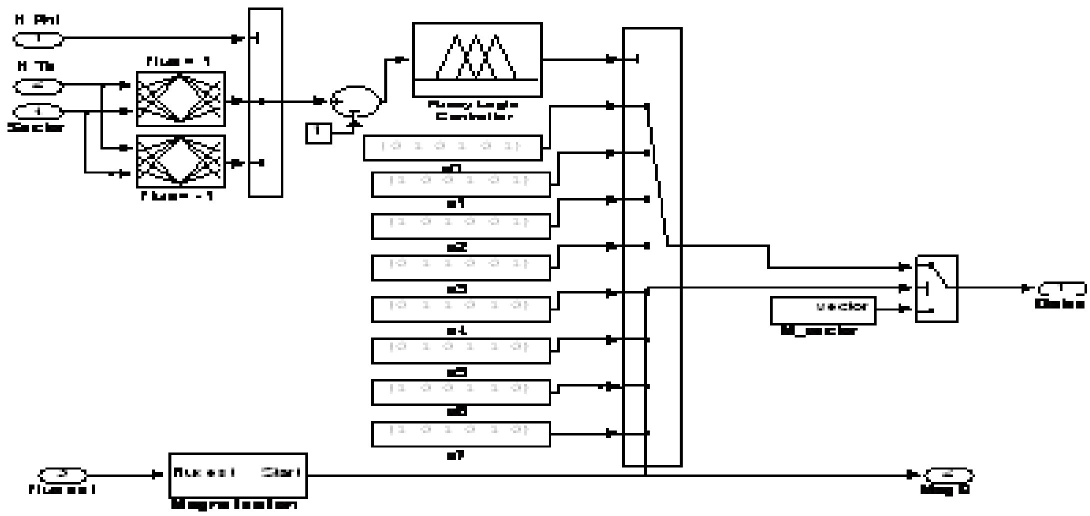

Fig 4.2 SIMULINK model of DTC Switching Table using Fuzzy Controller.

7.SIMULATION RESULTS

To study the performance of the proposed DTC with fuzzy logic controllers, simulation was carried out using MATLAB/SIMULINK simulation package.

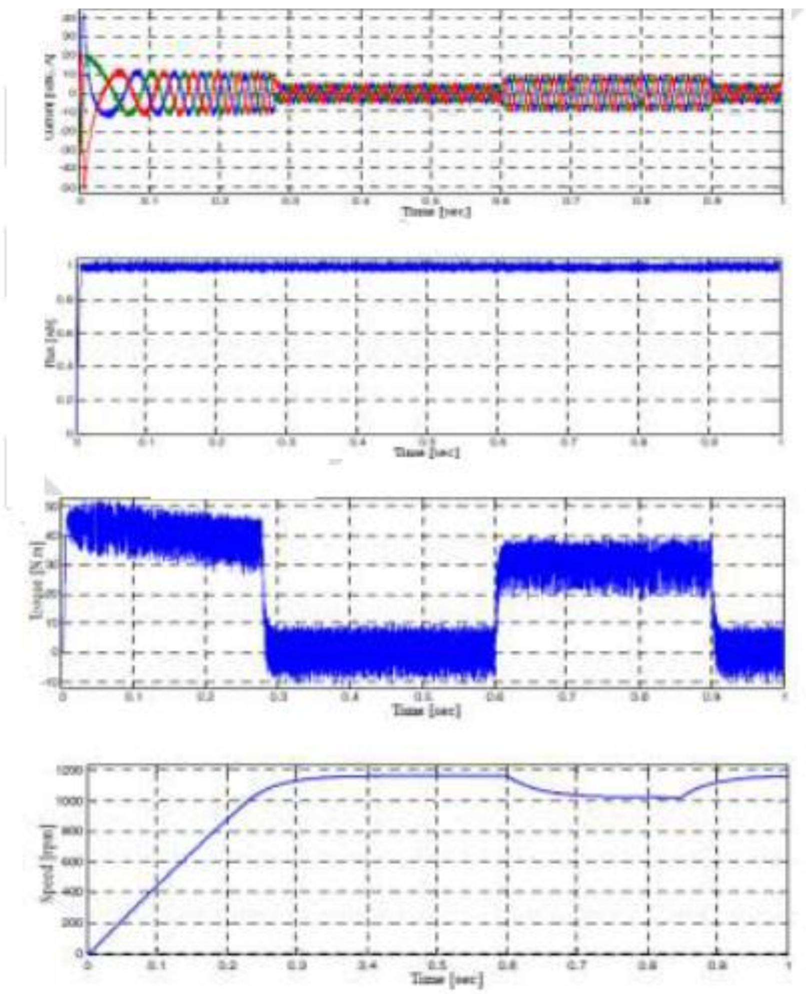

Figure 5. Simulation results of conventional DTC: Stator Currents, Stator flux, Electromagnetic load torque.

8.CONCULSION

By these simulations we have verified the control of zero speed operation, where the control is more sensitive than elsewhere. Figure 7 presents the curves of the switching state, for example only Sa . There is an evident interference of the duty ratio control. Figures 7 and8 present that the new method brings a decrease of the torque and stator flux ripples. So, we conclude that the fuzzy duty ratio controller brings improvements in fuzzy DTFC and in DTFC generally.

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