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Design and Comparison of Direct Torque Control of Induction Motor for Reduced Torque Ripples Minimization by Using Fuzzy Technique

[1]*K. Vijayakumar and* [2]*A. Sivasubramanian*

[1]Department of EEE, SCSVMV University, Kanchipuram, TN, India
[2]Mount Zion College of Engineering, Pathanamthitta, Kerala, India

Abstract: In This paper presents a direct flux and torque control (DTC) of three phase induction motor drive (IMD) using fuzzy logic controllers (FLC) technique for reduced torque ripples. The DTC is one of the most excellent direct control strategies of stator flux and torque ripples of IMD. Classical DTC has inherent the disadvantages such as high stator flux and torque ripples of IMD. To overcome this problem to developed by the proposed new conventional DTC system. This conventional DTC system using FLC to increases the number of voltage vectors beyond the available eight discrete voltage vectors tables. Look-up Table based on-line tuning fuzzy controller is proposed for outer speed control loop to achieve swift response. This conventional control method is based on DTC a novel approach is seen where fuzzy logic controller is adapted which overcomes high torque ripples and improves the system performance. Simulation results are carried out to conventional DTC techniques using MATLAB/SIMULINK.

Key words: Direct Torque Control (DTC) · Fuzzy Logic Control (FLC) · Induction Motor Drive (IMD)

INTRODUCTION

Nowadays around 70% of electric power is consumed by electric drives. This electric drives are mainly classified into AC and DC drives. During last four decades AC drives are become more and more popular; especially induction motor drives (IMD), Because of robustness, high efficiency, high performance and rugged structure, ease of maintenance so widely used in industrial Application, such as paper mills, robotics, steel mills, servos, transportation system, elevators and machines tools etc. Commonly used techniques for speed control of induction motor drive are V/F ratio control, Direct Torque Control (DTC) and Vector Control. Particularly direct torque control is a well-known strategy for ac motor control method which yields fast torque response as it employs instantaneous torque which was developed by Japanese and German researchers more than a decade ago [1].

The Direct Torque Control (DTC) method is characterized its simple implementation and a fast dynamic response. Further more, the inverter is directly controlled by the algorithm, i.e. a modulation technique for the inverter is not needed. However if the control is implemented on a digital system (which can be considered as a standard nowadays); the actual values of flux and torque could cross their boundaries too far [2, 3], which is based on an independent Hysteresis control of flux and torque. 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. These are disadvantages that we want to remove by using and implementing modern simulation by using SIMULINK.

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Corresponding Author: K. Vijayakumar, Department of EEE, SCSVMV University, Kanchipuram, TN, India.

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. These are disadvantages that we want to remove by using and implementing modern simulation by using SIMULINK.

In a DTC drive, flux linkage and electromagnetic torque are controlled independently by the selection of optimum inverter switching modes. The selection is made to restrict the flux linkages and electromagnetic torque errors within the respective flux and torque hysteresis bands, to obtain fast torque response, low inverter switching frequency and low harmonic losses. The basic Functional block diagram of classical DTC scheme is shown in Figure 1. The instantaneous values of the stator flux and torque are calculated from stator variable by using a closed loop estimator. Stator flux and torque can be controlled directly and independently by properly selecting the inverter switching configuration.

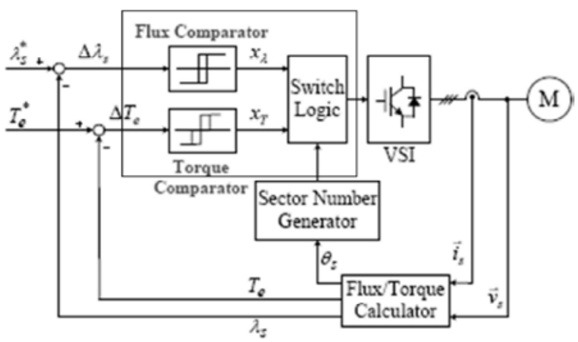

Fig. 1: Block diagram of basic DTC drive

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).

$$d\Psi = \Psi ref - \Psi \quad (1)$$

$$dte = tref - te \quad (2)$$

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.

The switching table blocks to choose appropriate voltage vector. The switching table implemented is According to Table I. A high hysteresis state increases the corresponding quantity and vice-versa. The selected voltage vector is synthesized and then sent to the VSI.

Table 1: Switching Vector Table

ϕ	τ	$\theta_n(D_2D_1D_0)$					
		θ_1(001)	θ_2(010)	θ_3(011)	θ_4(100)	θ_5(101)	θ_6(110)
ϕ=1	τ=1	V_2(110)	V_3(010)	V_4(011)	V_5(001)	V_6(101)	V_1(100)
	τ=0	V_6(101)	V_1(100)	V_2(110)	V_3(010)	V_4(011)	V_5(001)
ϕ=0	τ=1	V_3(010)	V_4(011)	V_5(001)	V_6(101)	V_1(100)	V_2(110)
	τ=0	V_5(001)	V_6(101)	V_1(100)	V_2(110)	V_3(010)	V_4(011)

Fuzzy Logic Controller 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 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. Flux error fuzzification the flux error is obtained from equation

$$\Delta\Psi = \Psi s^* - \Psi s \quad (3)$$

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.

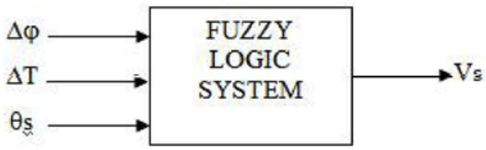

Fig. 2: Fuzzy Logic Based DTC

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 sector15 rules, the total number of rules is 180.

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 online [4-8].

The fuzzy controller is characterized as follows:

- Seven fuzzy sets for each input and output variables,
- Fuzzification using continuous universe of discourse,
- Implication using Mamdani's,, in□ operator,

The membership functions of fuzzy logic controller flux-torque inputs and angle output can be seen in Figure 3. Table 2 Describes rule table of fuzzy logic controller.

Table 2: FIG Fuzzy rules for fuzzy set

$e/\Delta e$	PL	PS	ZE	NS	NL
PL	PL	PL	PL	PS	ZE
PS	PL	PL	PS	ZE	NS
ZE	PL	PS	ZE	NS	NL
NS	PS	ZE	NS	NL	NL
NL	ZE	NS	NL	NL	NL

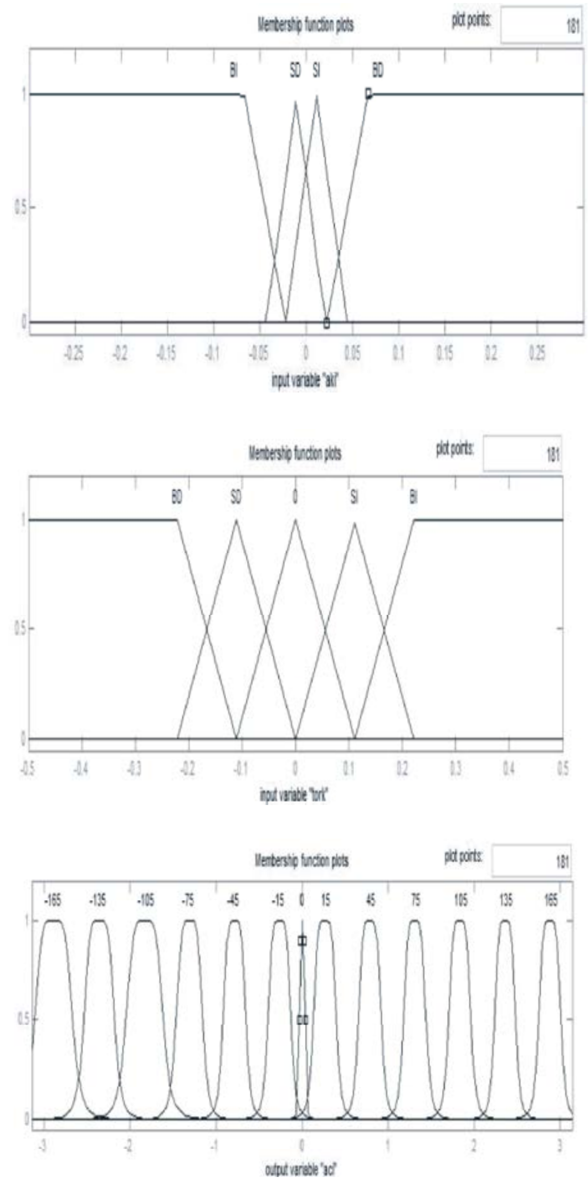

Fig. 3: Membership functions

Experiments of Simulink Model of DTC: MATLAB/ SIMULINK have been a very powerful tool to model the electrical and the mechanical systems because of its simplicity. The dynamic simulation of induction motor is first performed employing the MATLAB/ SIMULINK. Vector control methods and Direct Torque Control method on induction motors follows. A comparison between those DTC with out used FLC DTC with used FLC on the speed response, torque response and others detailed has been discussed. The DTC with and with out FLC models are show in Fig. 4 and Fig. 5 respectively [9-15].

MATLAB/ SIMULINK Model of Classical DTC:

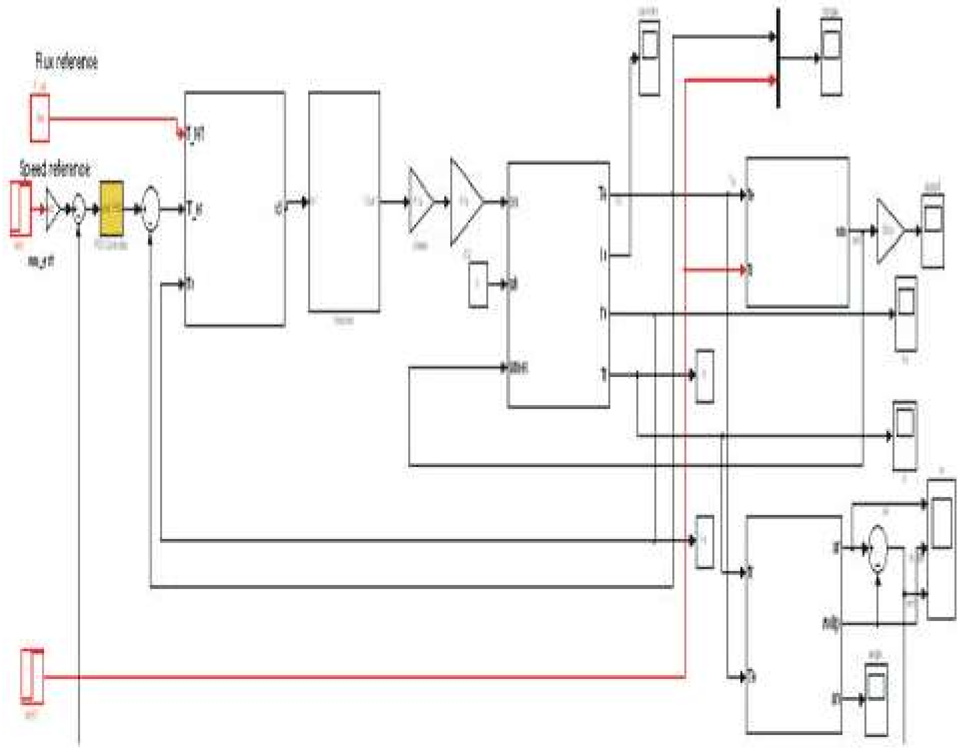

Fig. 4: Simulated Model of DTC with out FLC

SIMULINK Model of conventional DTC with FLC:

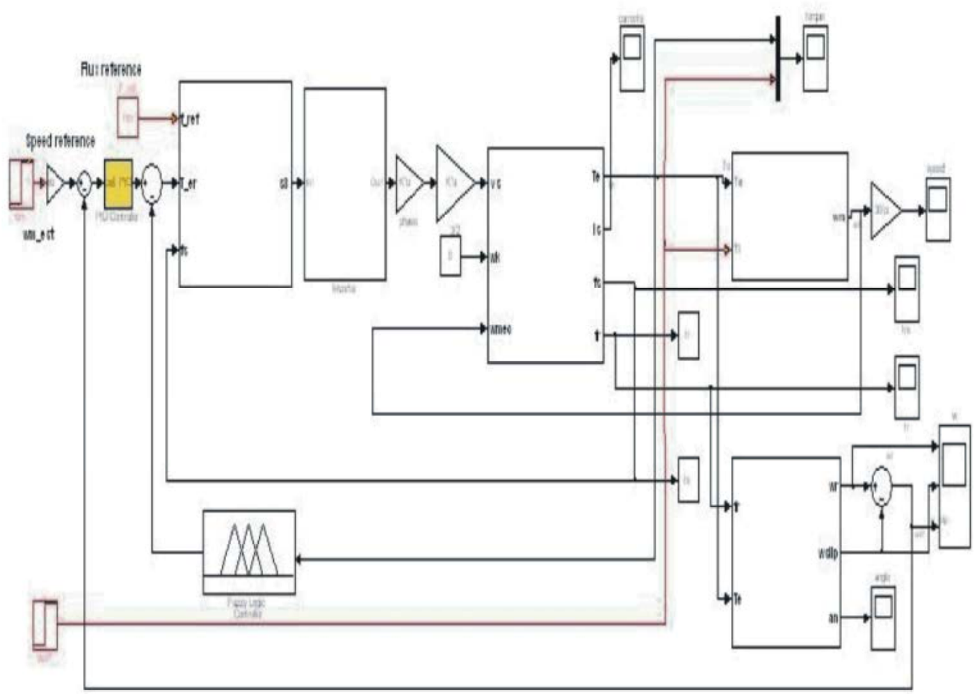

Fig. 5: Simulated Model of DTC with FLC

Simulation Results: The results which are presented and compared are the torque, speed and the three phase current of the stator. In this section, speed, electromagnetic torque and the Three phases current are going to be compared. After the simulation is done, the following results are extracted.

Speed Comparison: From Fig 6 and Fig7, we can notice that the deviation of the speed due to the load is so small in Field Classical DTC and the speed returns to the desired speed in 0.3 second and the deviation of the speed as shown in fig 5(a). From below fig 5(b), the speed decreases and returns to the desired speed after 0.4 sec. That shows the speed response of Classical and conventional DTC.

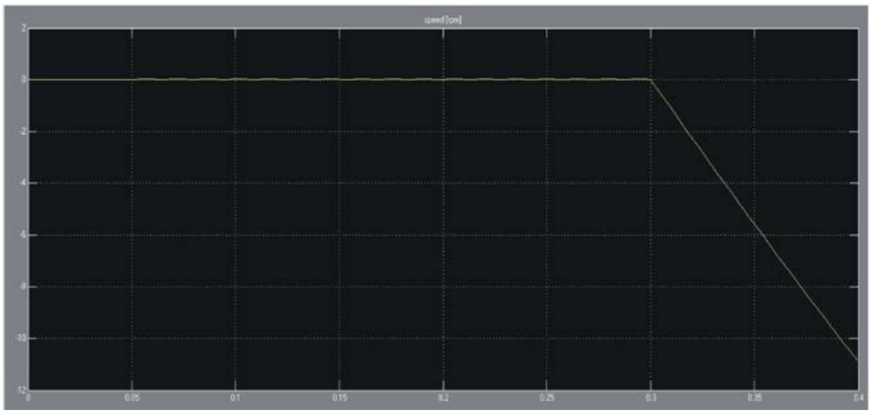

Fig. 5(a): Motor speed response of DTC

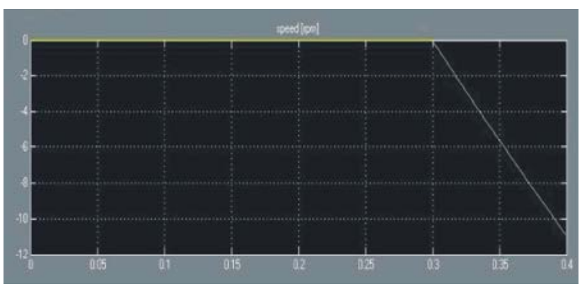

Fig. 5(b): Speed response of DTC with FLC

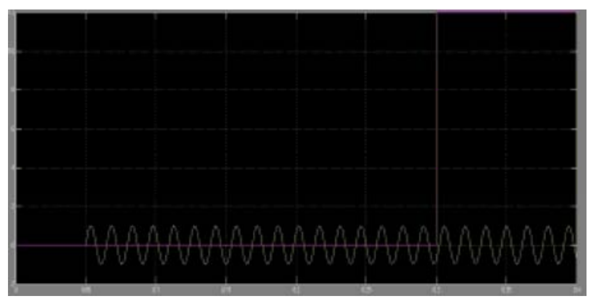

Fig. 6(b): Torque response of DTC with FLC

Torque Comparison: We can say that the torque in below fig 6(a), which is Classical DTC model has less transient ripples and shown by yellow color. The torque in fig 6(b), which is the conventional DTC model, is smoothly following the load torque and it reaches the desired torque slower.

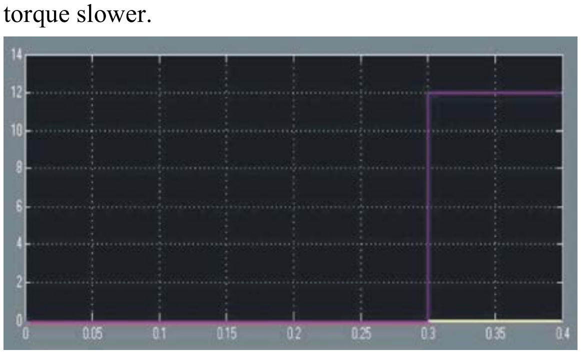

Fig. 6(a): Torque response of DTC

Three phase current Comparison: The three phase current analysis in Classical and conventional DTC models are shown in Fig 7(a) and (b) respectively. We have seen that Fig 7(b) has a higher transient current, but when the motor is loaded, the current is reaching the nominal current smoothly.

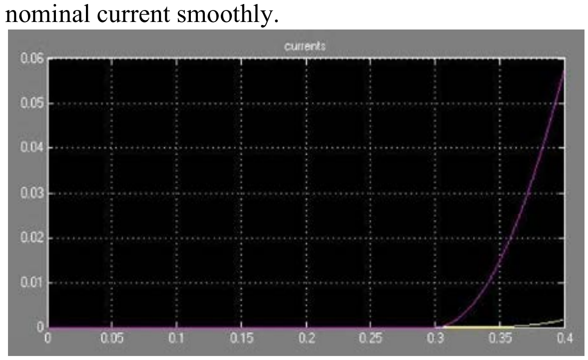

Fig. 7(a): Motor current response of DTC

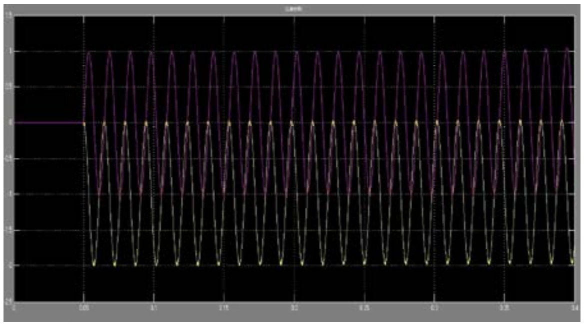

Fig. 7(b): Motor current response of DTC

Flux space vector Comparison: We can say that the torque in below Fig 8(a), which is Classical DTC model has less Flux vector Trajectory and shown by red color. The Flux in fig 8(b), which is the conventional DTC model is smooth.

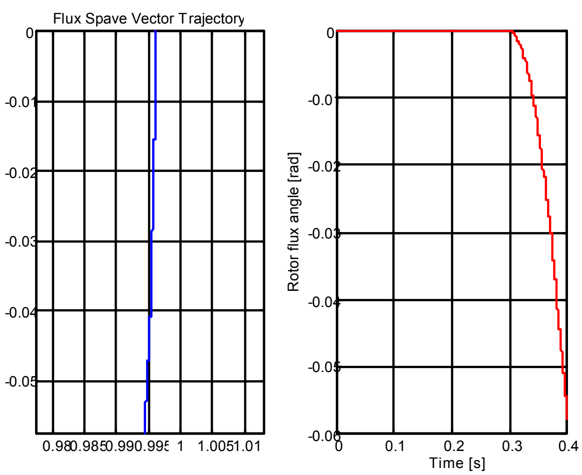

Fig. 8(a): Flux response of DTC

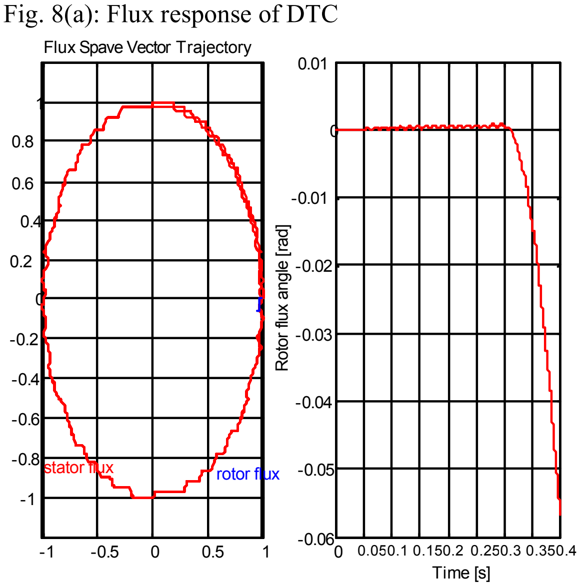

Fig. 8(b): Flux response of DTC with FLC

CONCLUSION

In this paper, two induction motor drive techniques (Classical and conventional DTC) are first studied theoretically by using MATLAB/SIMULINK. Those methods are compared by using MATLAB/SIMULINK models of Classical and conventional DTC. In the comparative study of Classical and conventional DTC.

In this paper a novel fuzzy logic controller is proposed with adaptive flux observer to reduce the torque ripples of Conventional DTC system. Present system improves the system performance as the fuzzy logic controller determinate the desired speed and torque ripple response. Hence even at low speed it provides minimum switching loss and noise.

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