IMPROVED DIRECT TORQUE CONTROL OF INDUCTION MOTOR USING FUZZY LOGIC BASED DUTY RATIO CONTROLLER

Sudheer H[1], Kodad S.F[2]and Sarvesh B[3]
[1]Research Scholar JNTU Anantapur, Hyderabad, India.
[2]Principal, Krishna Murthy Inst. of Tech.and Engg., Hyderabad, India.
[3]HoD, Electrical and Electronics Dept. JNTU, Anantapur, India

ABSTRACT

Classical DTC has inherent disadvantages such as: problems during starting resulting from the null states, the compulsory requirement of torque and flux estimators, and torque ripple. In this paper the improved response of the DTC is achieved by varying the duty ratio of the selected voltage vector during each switching period according to the magnitude of the torque error and position of the stator flux using Fuzzy logic. A duty ratio control scheme for an inverter-fed induction machine using DTC method is presented in this paper. Fuzzy logic control is used to implement the duty ratio controller. The effectiveness of the duty ratio method was verified by simulation using Matlab SIMULINK.

KEYWORDS: *DTC, Fuzzy Logic, Duty Ratio controller, Membership function (MF), Fuzzy controller, switching table.*

I. INTRODUCTION

In recent years much research has been developed in order to find simpler control schemes of induction motors that meet the requirements like low torque ripple, low harmonic distortion and quick response [1]. The IM offers several features, which make it attractive for use in electric drive systems. Among various proposals Direct Torque control (DTC) found wide acceptance. In the 1980s, Takahashi proposed a direct torque control for an induction machine drive [2-3]. Furthermore, DTC provides very quick response with simple control structure and hence, this technique is gaining popularity in industries In DTC it is possible to control directly the stator flux and the torque by selecting the appropriate inverter state [2-4].

The main advantages of DTC are absence of coordinate transformation, current regulator and separate voltage modulation block. However common disadvantages of conventional DTC are high torque and stator flux ripple, requirement of torque and flux estimators, implying the consequent parameters identification and sluggish speed response during start up and abrupt change in Torque command. Many methods have been proposed to reduce the torque ripple like multi level inverters [19], and matrix converters. Many solutions are proposed to reduce the torque ripple as mention in literature like (a) hysteresis band with variable amplitude based on fuzzy logic [20]. (b) AN optimal switching instant during one switching cycle is calculated for torque ripple minimization [21]. (c) Using duty ratio control by increasing the number of voltage vectors beyond the available eight discrete ones, without any increase in the number of semiconductor switches in the inverter [23]. (d) Fuzzy logic control has been used to implement the duty ratio during each switching cycle using the torque and flux errors as input [25]. (e) Space vector based hybrid pulse width modulation (HPWM) method for direct torque controlled induction motor drive to reduce the steady state ripples [26]. In order to overcome these disadvantages we can employ new Artificial Intelligent techniques like neural networks, Fuzzy logic.

Based upon literature the duty ratio control of DTC is the promising method minimizes torque and flux ripple. In the classical DTC, a voltage vector is applied for the entire switching period, and this causes the stator current and electromagnetic torque to increase over the whole switching period. Thus for small errors, the electromagnetic torque exceeds its reference value early during the switching period, and continues to increase, causing a high torque ripple. The duty ratio technique based on applying to the inverter the selected active states just enough time to achieve the torque and flux references values. The rest of the switching period a null state is selected which won't almost change both the torque and the flux [14].

This paper deals with the development of an improved Fuzzy logic based Duty ratio controllers for DTC of induction motor. The main improvement is torque ripple reduction. The suggested technique is based on applying switching state to the inverter and the selected active state just enough time to achieve the torque and flux reference values. Therefore, a duty ratio (δ) has to be determined each switching time. By means of varying the duty ratio between its extreme values (0 up to 1), it is to apply any voltage to the motor [16-17]. The Elements of space phasor notation are introduced and used to develop a compact notation. All simulations are obtained using MATLAB\ SIMULINK.

The paper is organized as follows. Section 2 gives the theoretical and mathematical analysis of conventional Direct Torque control of induction motor, its basic block diagram and the switching table. The need for duty ratio controller to overcome the conventional DTC draw backs are discussed at the end of the section 2. Section 3 gives design of fuzzy logic based duty ratio controller. In this section the procedure to develop the fuzzy logic controller using the membership function and fuzzy rules are specified. In section 4 the results of conventional DTC and proposed model results presented. Finally based upon results it is concluded in section 5.

II. DIRECT TORQUE CONTROL

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.

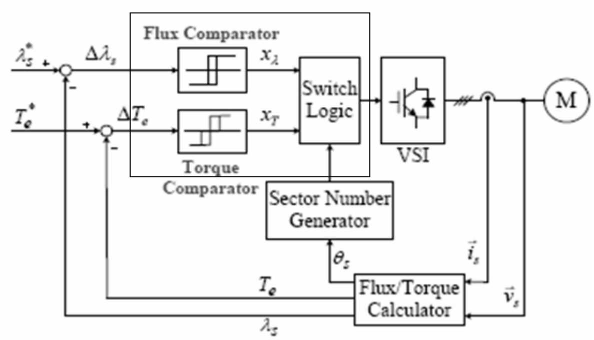


Figure 1. Schematic of Classical stator-flux-based DTC [5]

In a voltage fed three phase inverter, the switching commands of each inverter leg are complementary. So for each leg a logic state C_i (i=a,b,c) can be defined. C_i is 1 if the upper switch is commanded to be closed and 0 if the lower one in commanded to be close (first). Since three are 3 independent legs there will be eight different states, so 8 different voltages. Applying the vector transformation described as

$$V_s = \sqrt{\frac{2}{3}} U_0 \left[C_1 + C_2 e^{j\frac{2\pi}{3}} + C_3 e^{j\frac{4\pi}{3}} \right] \quad (1)$$

Out of 8 voltage vectors, there are six non-zero voltage vectors and two zero voltage vectors which correspond to (C1, C2, C3) = (111)/ (000) as shown by Figure.2

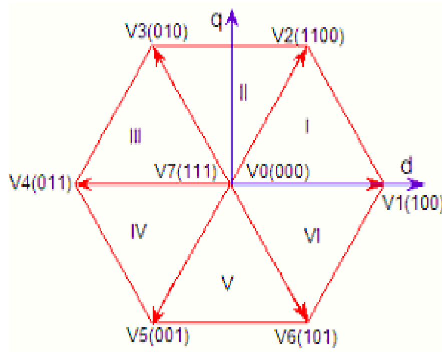


Figure2. Partition of the d-q planes in to six angular sectors

As shown in Figure 2, eight switching combinations can be selected in a voltage source inverter, two of which determine zero voltage vectors and the others generate six equally spaced voltage vectors having the same amplitude.

The Switching logic block receives the input signals X_λ, X_T and θ generates the appropriate control voltage vector (switching states) for the inverter by lookup table, which is shown in table I. The inverter voltage vector (six active and two zero states) and a typical Ψ_s are shown in Figure1. Neglecting the stator resistance of the machine, we can write

$$\overline{V_s} = \frac{d}{dt}(\lambda_s) \quad \textbf{(2)}$$

Or

$$\Delta\overline{\lambda}_s = \overline{V_s}\,.\Delta t \quad \textbf{(3)}$$

Which means that λ_s can be changed incrementally by applying stator voltage V_s for time increment Δt. The flux in machine is initially established to at zero frequency (dc) along the trajectory. With the rated flux, the command torque is applied and the $\overline{\lambda}_s^*$ vector starts rotating.

Consider the total and incremental torque due to $\Delta\overline{\lambda}_s$ the stator flux vector changes quickly by, but the $\overline{\lambda}_r$ change is very sluggish due to large time constant T_r. Since $\overline{\lambda}_r$ is more filtered, it moves uniformly at frequency ω_e, whereas λ_s movement is jerky. The average speed of both, however, remains the same in the steady-state condition.

According to the principle of operation of DTC, the selection of a voltage vector is made to maintain the torque and stator flux within the limits of two hysteresis bands. The switching selection table for stator flux vector lying in the first sector of the d-q plane is given in Table1.

Table 1: Switching table of inverter voltage vectors

H_λ	H_{Te}	S(1)	S(2)	S(3)	S(4)	S(5)	S(6)
1	1	V2	V3	V4	V5	V6	V1
	0	V0	V7	V0	V7	V0	V7
	-1	V6	V1	V2	V3	V4	V5
-1	1	V3	V4	V5	V6	V1	V2
	0	V7	V0	V7	V0	V7	V0
	-1	V5	V6	V1	V2	V3	V4

Torque is increased by the $\overline{V_2}$,$\overline{V_3}$, and $\overline{V_4}$ Vectors, but decreased by the $\overline{V_1}$,$\overline{V_5}$, and $\overline{V_6}$ vectors. The zero vectors (V_0 or V_7) short-circuit the machine terminals and keep the flux and torque unaltered.

A major concern in DTC of induction motor drives is torque and flux ripples, since none of the inverter switching vectors is able to generate the exact stator voltage required to produce the desired changes in torque and flux. Possible solutions involve the use of high switching frequency or alternative inverter topologies. Increased switching frequency is desirable since it reduces the harmonic content of the stator currents, and reduces torque ripple. High switching frequency results in significantly increased switching losses leading to reduced efficiency and increased stress on the inverter semiconductor devices. Furthermore, in the case of high switching frequency, a fast processor is required since the control processing time becomes small. When an alternative inverter topology is used [16], it is possible to use an increased number of switches, but this also increases the cost. However, if instead of applying a voltage vector for the entire switching period, it is applied for a portion of the switching period, then the ripple can be reduced. This is defined as duty ratio control in which the ratio of the portion of the switching period for which a non-zero voltage vector is applied to the complete switching period is known as the duty ratio.

Duty ratio control the selected inverter switching state is applied for a portion of the sample period as a duty ratio δ, and the zero switching state is applied for the period [7, 9]. 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 $\Delta\tau$ and the position of the stator flux linkage us according on sector) and one output (duty ratio δ).

The duty ratio controller prepares an optimal voltage vector for optimization outputs, which generate fuzzy DTC. So, the fuzzy controller generates a number between 0 and 1, it is a filling of signal in one period (0 to 100%).

III. DESIGN OF THE DUTY RATIO FUZZY CONTROLLER

The Fuzzy logic based duty ratio controller which generates optimal voltage vector for optimization output is design using Matlab base fuzzy toolbox. Two Mamdani type Fuzzy controllers are developed one for stator flux above the reference value another for below the reference value. Each fuzzy controller has two inputs (torque error, angle) and one output (duty ratio). Figure 3 shows the membership functions of inputs and outputs. As shown in Figure3 Gaussian membership functions are employed. The fuzzy logic controller is a Mamdani type and contains a rule base. This Rule base comprises two groups of rules, each of which contains nine rules as shown in table3.The Centroid method is employed for defuzzification.

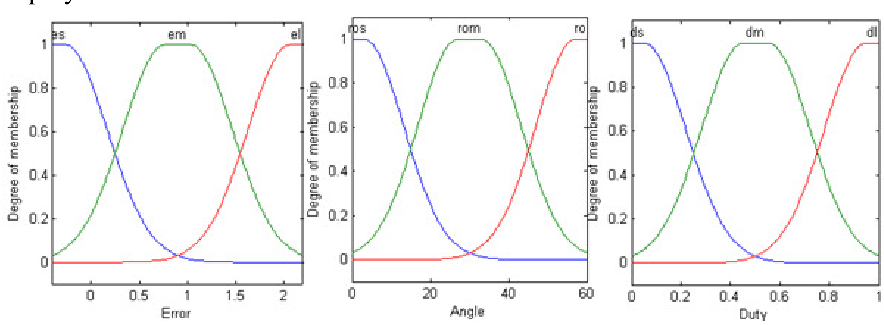
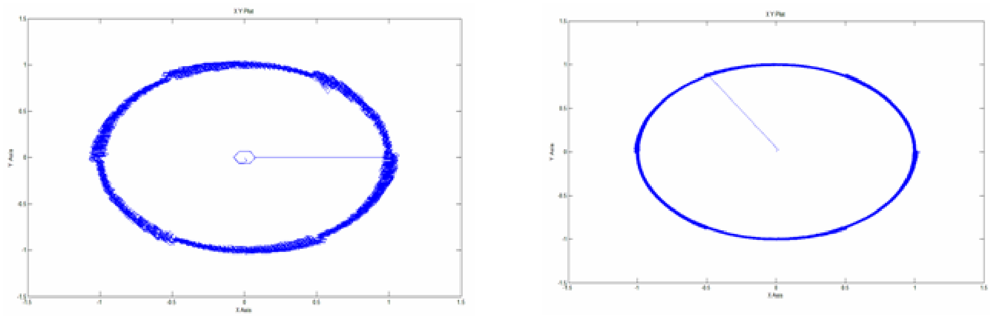


Figure3. Fuzzy membership functions

Table 2. Rules for fuzzy Duty ratio controllers

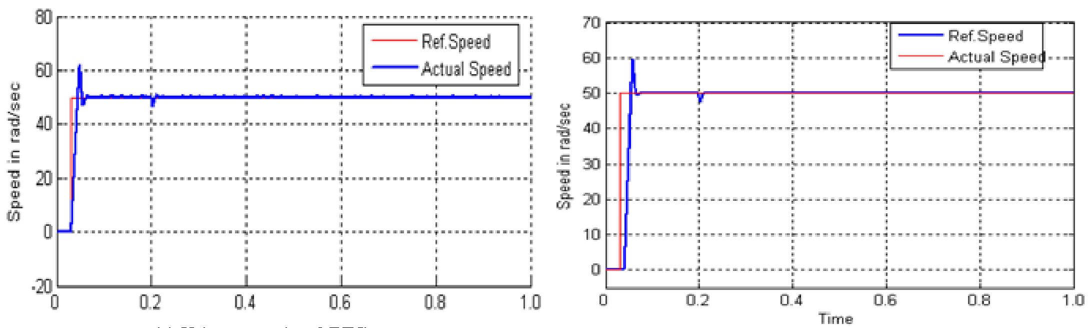
	Torque error	Position of stator flux error		
		Small	medium	large
Stator flux< Ref.Value	small	Medium	Small	Small
	medium	Medium	medium	medium
	large	Large	large	Large
Stator flux> Ref.Value	small	Small	Small	medium
	medium	Medium	medium	Large
	large	Large	large	Large



(a) Using conventional DTC

(b) Using Fuzzy Duty Ratio Controllers

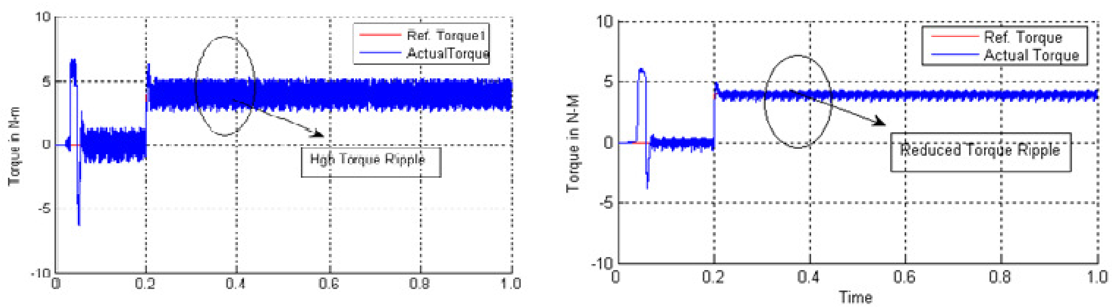
Figure 4. Flux response



(a) Using convetional DTC

(b)Using Fuzzy Duty Ratio Controllers

Figure 5. Speed response



(a) Using Conventional DTC

(b) Using Duty Ratio Controller

Figure 6. Electrical Torque Response

IV. Results and Analysis

In order to study the performance of the developed Conventional DTC and fuzzy duty ratio controller based DTC their Simulink model is developed in Matlab 7.1 environment for 11Kw, 400V, 4pole, 50Hz, 3-phase induction motor. The Simulink model of Fuzzy logic duty ratio controller direct torque control developed is used to obtain the results. The Fuzzy controllers are developed using fuzzy toolbox. The above simulink models are subjected to Sampling period of the system is 0.001s. To compare with Conventional DTC and Fuzzy Duty ratio DTC the load torque is varied in step initially it started with 0 N-m at t=0.2sec its is increased to 4 N-m. Initially the reference speed is kept at 0 rad/sec and it is increased to 50 rad/sec at t=0.03 sec.

Figure 4(a) and 4(b) shows stator flux trajectory for classical DTC and proposed Duty ratio DTC. Classical DTC flux path contains more ripples compares to proposed DTC scheme where the trajectory path is smooth and less ripples.

Figure 5(a) and 5(b) shows that the Speed response of conventional DTC and Proposed Fuzzy logic Duty Ratio DTC. The reference speed is subjected to step change of 0 to 50 rad/sec to study the dynamic response both conventional and proposed schemes. From the results we can observe that the peak overshoot Duty ratio DTC is decreased and shows improved steady state response compared to conventional DTC.

Figure 6(a) and 6(b) shows electric torque response of classical DTC and Proposed Duty ratio DTC respectively. To study both dynamic ad steady state behavior initially it is subjected to no-load later load is suddenly increased to 4 N-m. As shown in 6(a) the classical DTC causes high torque ripple between 5 N-m to 3N-m when subjected to 4N-m. Torque ripple in proposed DTC scheme has been reduced as shown in Figure 6(b) where the torque steady state response is in line with reference value. The peak overshoot when torque is subjected to sudden perturbation from 0 to 4 N-m is 6.4 N-m in conventional DTC and in proposed DTC scheme it is reduced to 4.8 N-m which represents better dynamic response.

The simulation results suggest that proposed Fuzzy Logic Duty Ratio controlled DTC of induction machine can achieve precise control of the stator flux and torque. On comparison of results derived from simulation shows that Fuzzy Logic Duty Ratio DTC is superior to conventional DTC and minimizes the Torque ripple to large extent.

V. CONCLUSIONS

In this paper Fuzzy logic Duty Ratio controller based DTC have been proposed. An improved Torque and Speed response is obtained using fuzzy Duty ratio Controller DTC for induction motor. The simulation results suggest that Fuzzy logic Duty Ratio Controller DTC of induction machine can achieve precise control of the stator flux and torque. Compared to Conventional DTC, presented method is easily implemented, and the steady performances of ripples of both torque and flux are considerably improved.

The main improvements shown are:

- Considerable reduction in torque and Speed ripples.
- Simulation results shows the validity of proposed method in achieving considerable reduction in torque and speed ripples, adaptation of proposed controller, maintaining good performance and reducing the energy consumption from supply mains.
- The method of selection on duty ratio between active and null state is promising and easier to implement.
- Reduction of over and undershoots in speed and Torque response.
- Smoother flux trajectory path.

As a future work we can develop duty ratio controller for SVPWM based fuzzy direct torque control of induction machine and development of adaptive fuzzy controller suitable for any type of motor.

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Authors

Sudheer Hanumanthakari received the B.Tech degree in EEE from JNTU, Hyderabad and M.Tech Degree in Power Electronics from NTU, Hyderabad and currently pursuing PhD. in Electrical Engineering at JNTU, Anantapur. He has got a teaching experience of nearly 8 years He is currently working as Asst. Professor in FST-IFHE (ICFAI University), Hyderabad. His areas of interests are neural networks and fuzzy logic applications in power electronics drives like FOC and DTC.

Kodad S.F. received the B.E. degree in EEE from Karnataka University and the M.Tech degree in Energy Systems Engg. from JNTU, Hyderabad. He received his Ph.D. degree in Electrical Engg. from JNTU, Hyderabad, India in the year 2004. He has got a teaching experience of nearly 20 years. Currently, he is working as Principal in Krishna Murthy Institute if Tech. and Engineering. His area of interests are neural networks, Fuzzy logic, Power electronics, power systems, artificial intelligence, Matlab, Renewable energy sources, etc.

Sarvesh Botlaguduru received the B.Tech degree in EEE from JNTU, Anantapur and M.Tech in Instrumentation and Control from SV University, Tirupathi. He received his Ph.D. degree in Electrical Engg. from IIT, Kharaghpur India in the year 1995. He has got a teaching experience of nearly 30 years. Currently, he is working as Professor and Head of EEE in JNTUA, Anantapur, and Andhra Pradesh, India. His areas of interests are Instrumentation and Control, Control Systems.