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Torque ripples minimization in five-level DTC based IM drive using ANFIS controller

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Abstract. This paper presents a five-level direct torque control (DTC) is applied to an induction motor using ANFIS. The DTC is an advanced and simple control method has many advantages over other variable frequency control methods, but it has a common disadvantage of high torque and high flux ripples. To overcome this problem a torque hysteresis band with variable amplitude is proposed based on ANFIS. The ANFIS proposed controller is shown to be able to reduce the torque, current and stator flux ripples and to get better performance of the motor. The validity of the proposed controls scheme is verified by simulation tests of an induction motor. The stator current, stator flux and torque are determined and compared with the above technique.

Keywords: *DTC, Induction motor, ANFIS, Torque hysteresis, Flux ripple, Torque ripple.*

1. Introduction

The apparition of the field oriented control (FOC) made induction machine drives a major candidate in high performance motion control applications. However, the complexity of field oriented algorithme led to the development in recent years of many studies to find out different solutions for the induction motor control having the features of precise and quick torque response [1]. The direct torque control (DTC) method was first applied for the induction motor by Depenbrock and Takahashi in 1980's [2]. The DTC has been recognized as the most promising solution to achieve these requirements. The DTC is based on the decoupled control of flux and torque providing a very quick and robust response [3]. The DTC method is a simple control structure and hence, this technique is gaining popularity in industries [4]. However, the main limit of conventional DTC scheme is high torque ripple, variable switching frequency and the torque does not match the torque demand [5].

The DTC control is shown in Fig. 1. There are three important parameters namely electromagnetic torque, flux and the angular sector of flux plays major role in calculating the switching vector to select proper switching state of a switch [6]. In the DTC control two hysteresis comparators are used to estimate the torque and flux values respectively.

Since DTC was first introduced, several variations to its original structure were proposed to overcome the inherent disadvantages in any hysteresis-based controller, such as variable switching frequency, high sampling requirement for digital implementation, and high torque ripple. To solve this problem, various techniques have been proposed [4]. Including the use of variable hysteresis bands, predictive control schemes, space vector modulation techniques and intelligent control methods [4].

This paper proposes a novel scheme to improve the drive performance. This scheme uses a hysteresis controller based on an adaptive NF inference system (ANFIS). ANFIS direct torque control is used to improve dynamic response performance and decrease the torque and flux ripples.

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2. Five level inverter

A different approach to improve DTC features is to employ different inverter topologies (Multilevel Inverter) from the standard two-level VSI [7]. Commercially three basic multilevel converters are presented in the literature as diode-clamped converters cascaded H-bridge converters and flying-capacitor converters [8]. Multilevel inverters are increasingly being used in high-power medium voltage applications due to their superior performance compared to two-level inverters, such as lower common-mod voltage, lower dV/dt, lower harmonic in output voltage and current, greater number of levels in the output voltage waveforms, and reduced voltage on the power switches [7].

The topology that has been used in this paper is a three phase full bridge five levels diode clamped inverter and this topology is shown in Fig. 2. The voltage across the phase winding of the induction motor can attain one of the five levels –2*V*dc, -Vdc, 0, 2Vdc or *V*DC, depending upon the switching states of the inverters [9].

The five-level diode-clamped inverter leg has 4 DC link capacitors, 8 switches, five-levels output phase voltage and 9 levels output line voltage. Although each active switching device is required to block only a voltage level equal to the capacitor voltage of Vc= E /4, the clamping diodes require different ratings for reverse voltage blocking. The necessary conditions for the switching states for the five-level inverter are that the dc-link capacitors should not be shorted, and the output current should be continuous [10]. The representation of the space voltage vectors of a five-level inverter for all switching states is given by Fig. 3.

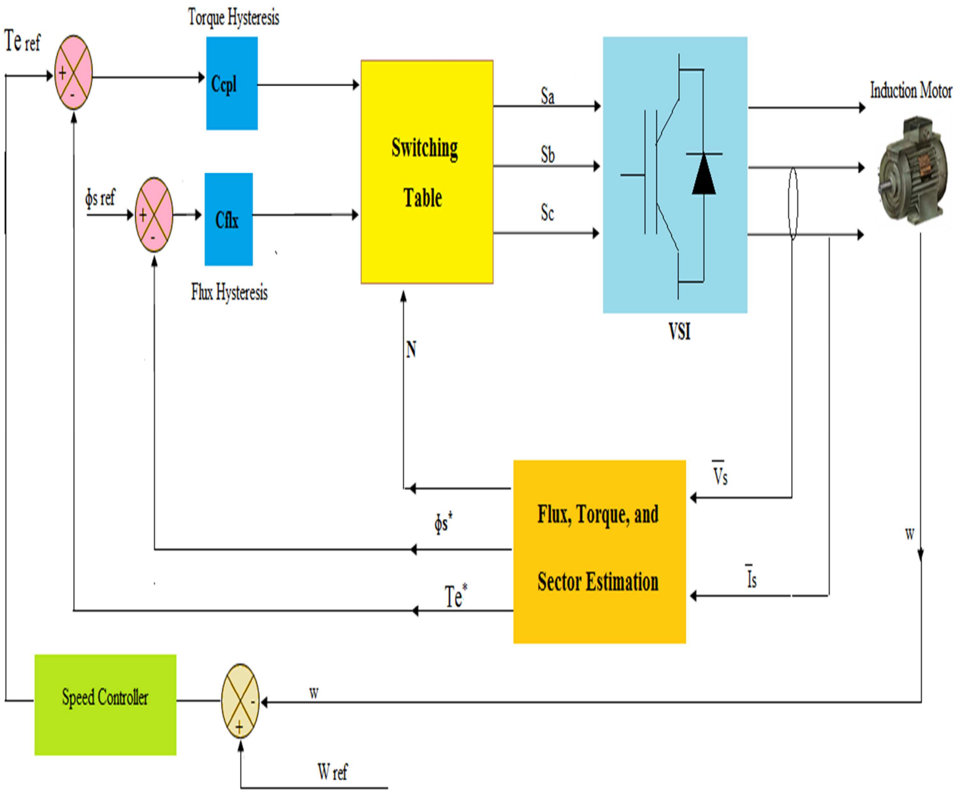

Fig. 1 Block diagram of DTC of IM drives.

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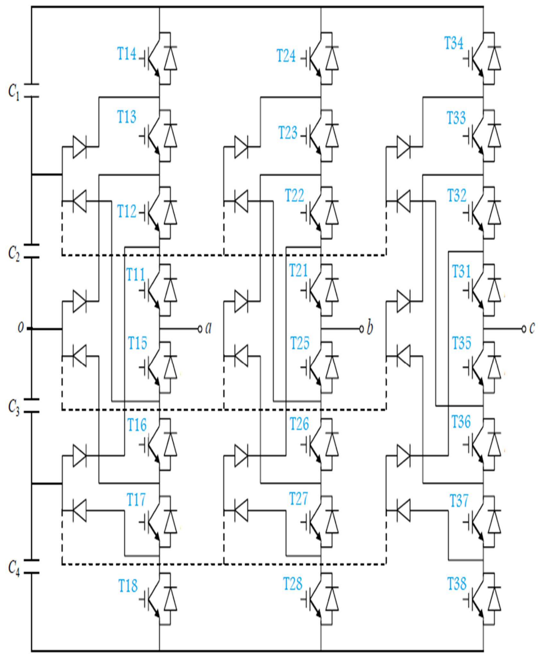

Fig. 2 Five-level diode clamped voltage source inverter

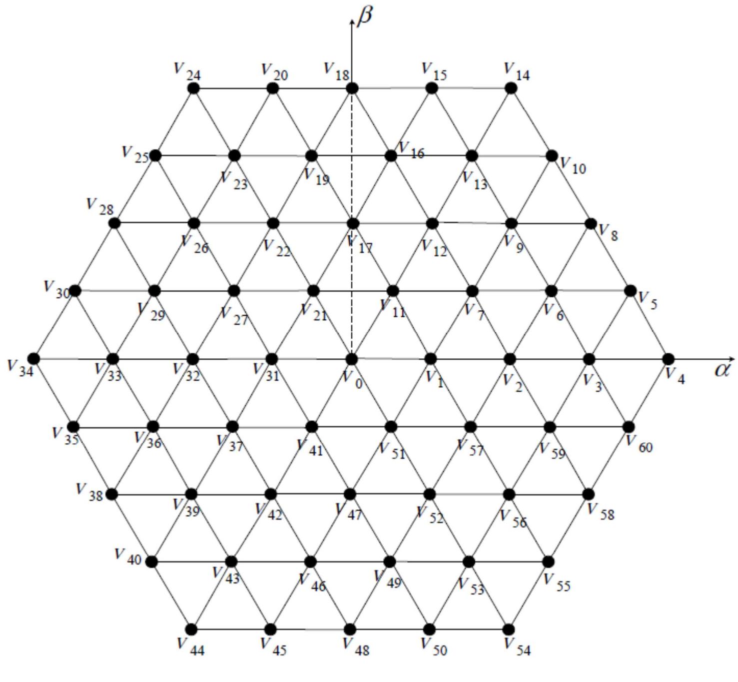

Fig. 3 Space vector diagram of five-level inverter.

3. Five level DTC control

One of the main direct torque control types of a voltage inverter powered induction machine is the stator flux direct control, by means of the optimal inverter switching state selection [11]. In the five-level DTC structure, it employs a pair of hysteresis comparator, one utilizes a two-level hysteresis

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comparator for controlling the flux and the other one uses a three-level hysteresis comparator for controlling the torque.

The stator flux can be evaluated by integrating from the stator voltage equation [12]:

$$\Phi_S = \int_0^t (V_S - R_S \cdot i_S) dt \quad (1)$$

The magnitude of the stator flux can be estimated by :

$$\Phi_S = \sqrt{\Phi_{s\alpha}^2 + \Phi_{s\beta}^2} \quad (2)$$

The stator flux sector is determined by the components $\Phi_{s\alpha}$ and $\Phi_{s\beta}$. The angle between the referential and Φ_s is equal to [4]:

$$\theta = arctg(\frac{\Phi s\beta}{\Phi s\alpha}) \quad (3)$$

Torque can be calculated using the components of the estimated flux and measured currents:

$$Te = \frac{3}{2} p(\Phi s\alpha \, is\beta - \Phi s\beta \, is\alpha) \quad (4)$$

The switching selection block in Fig. 3 receives the input signals Ccpl, Cflx and N generate the desired control voltage vector as given in look-up table shown in Table 1.

Table 1 Switching Table of five-level DTC with 12 sectors

Sector N	**Cflx**					
	1			**0**		
	Ccpl					
	1	**0**	**-1**	**1**	**0**	**-1**
1	14	2	54	24	32	44
2	18	7	58	28	37	48
3	24	12	4	34	42	54
4	28	17	8	38	47	58
5	34	22	14	44	52	4
6	38	27	18	48	57	8
7	44	32	24	54	2	14
8	48	37	28	58	7	18
9	54	42	34	4	12	24
10	58	47	38	8	17	28
11	4	52	44	14	22	34
12	8	57	48	18	27	38

4. Design of ANFIS torque ripple optimization

In order to improve the five-level DTC performances, a complimentary use of ANFIS controller is proposed. ANFIS is one of the popular neuro-fuzzy methods that is the hybrid combination of artificial

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neural networks (ANNs) and is based on Takagi–Sugeno fuzzy inference system (FIS) [13]. The Adaptive Neuro-Fuzzy Inference System is developed using Matlab ANFIS editor [14].

The principle of ANFIS direct torque control is similar to traditional DTC. The difference is using an ANFIS controller to replace the torque hysteresis loop controller. As shown in Fig. 4.

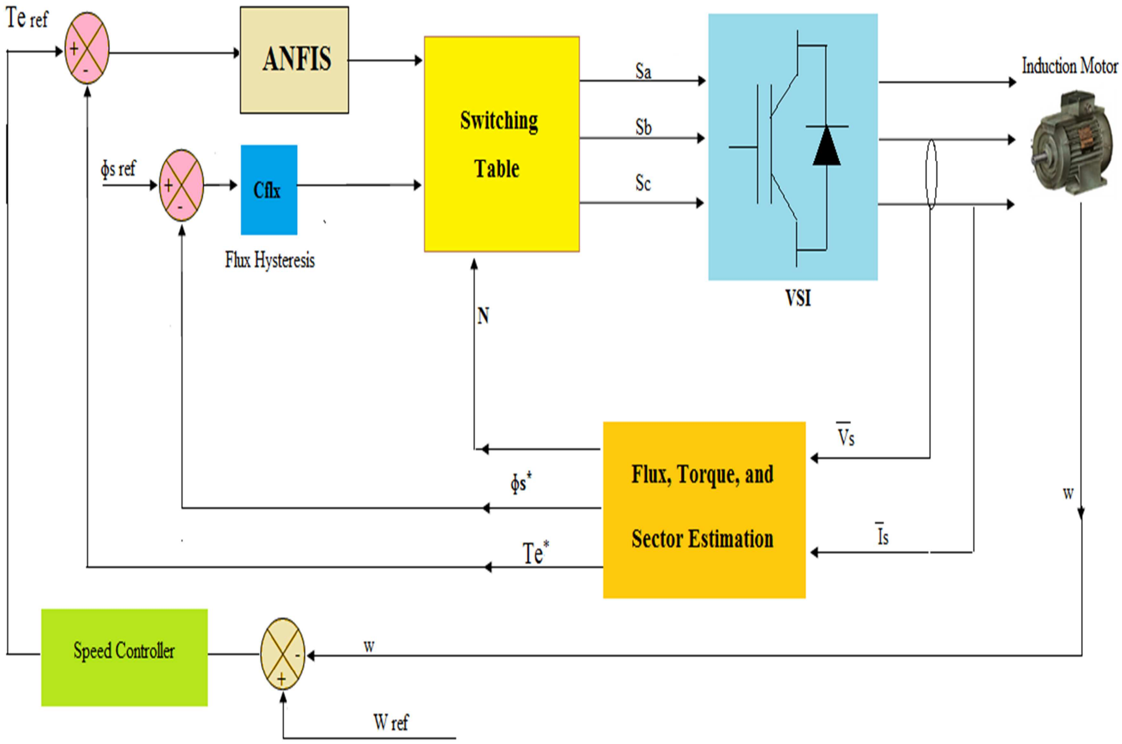

Fig. 4 DTC scheme with ANFIS hysteresis controller.

The block diagram for ANFIS based torque hysteresis controller is shown in Fig. 5.

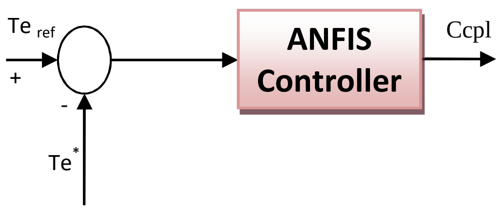

Fig. 5 ANFIS control of torque hysteresis controller.

Then the designed ANFIS has two inputs namely, the reference torque and estimated torque while the output is the Ccpl. The structure of ANFIS torque controller is shown in Fig. 6.

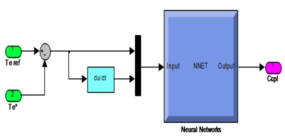

Fig. 6 ANFIS structure for five-level DTC.

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5. Results

The simulations of the five-level DTC with ANFIS of induction motor drive are compared with five-level DTC classique. A 3-phase, 3 pole, induction motor with parameters of Rs=0.228Ω, Rr=0.332Ω, Ls=0.0084H, Lr=0.0082H, Lm=0.0078H, J=20 Kg.m2 are considered.

The performance analysis is done with stator current, stator flux and torque plot. The dynamic performance of the five-level DTC control with induction motor is shown Fig. 7. The dynamic performance of the five-level DTC control with ANFIS controller is shown Fig. 8.

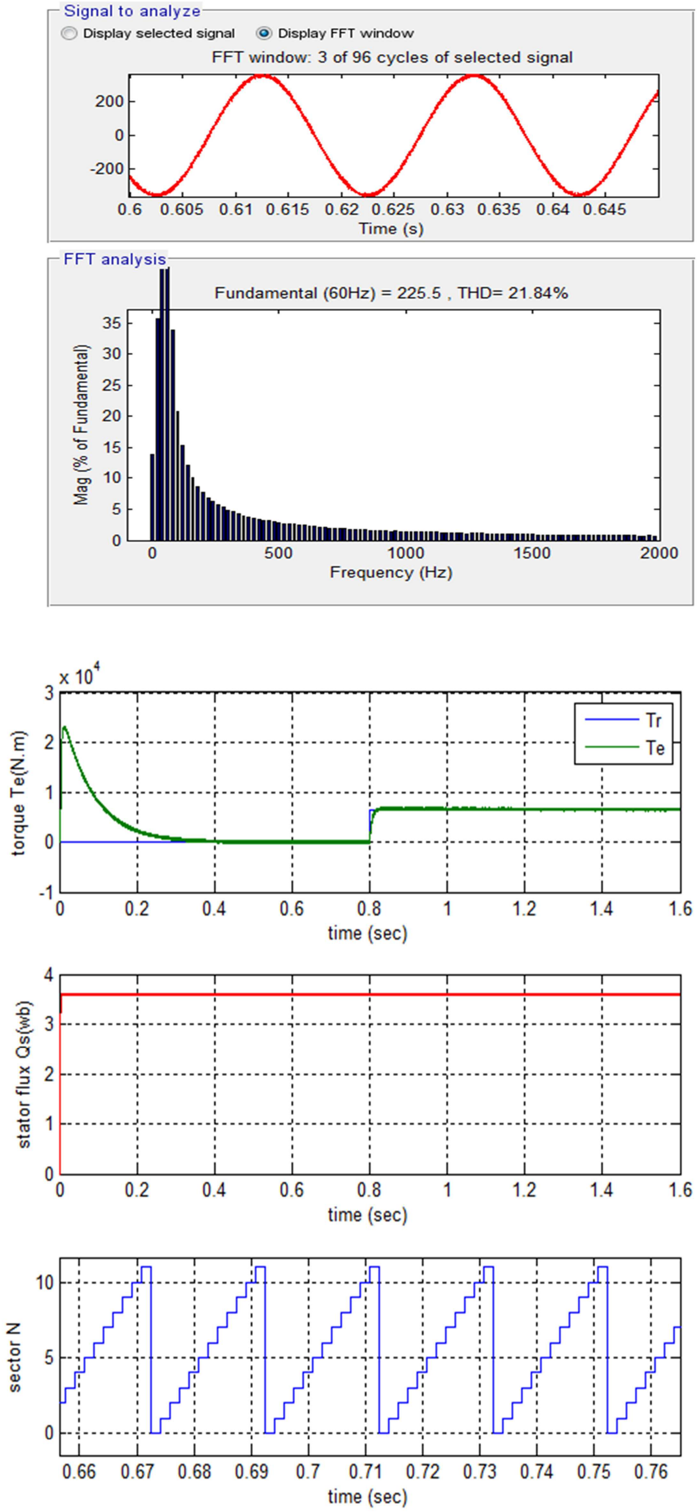

Fig. 7 Dynamic responses of five-level DTC for IM

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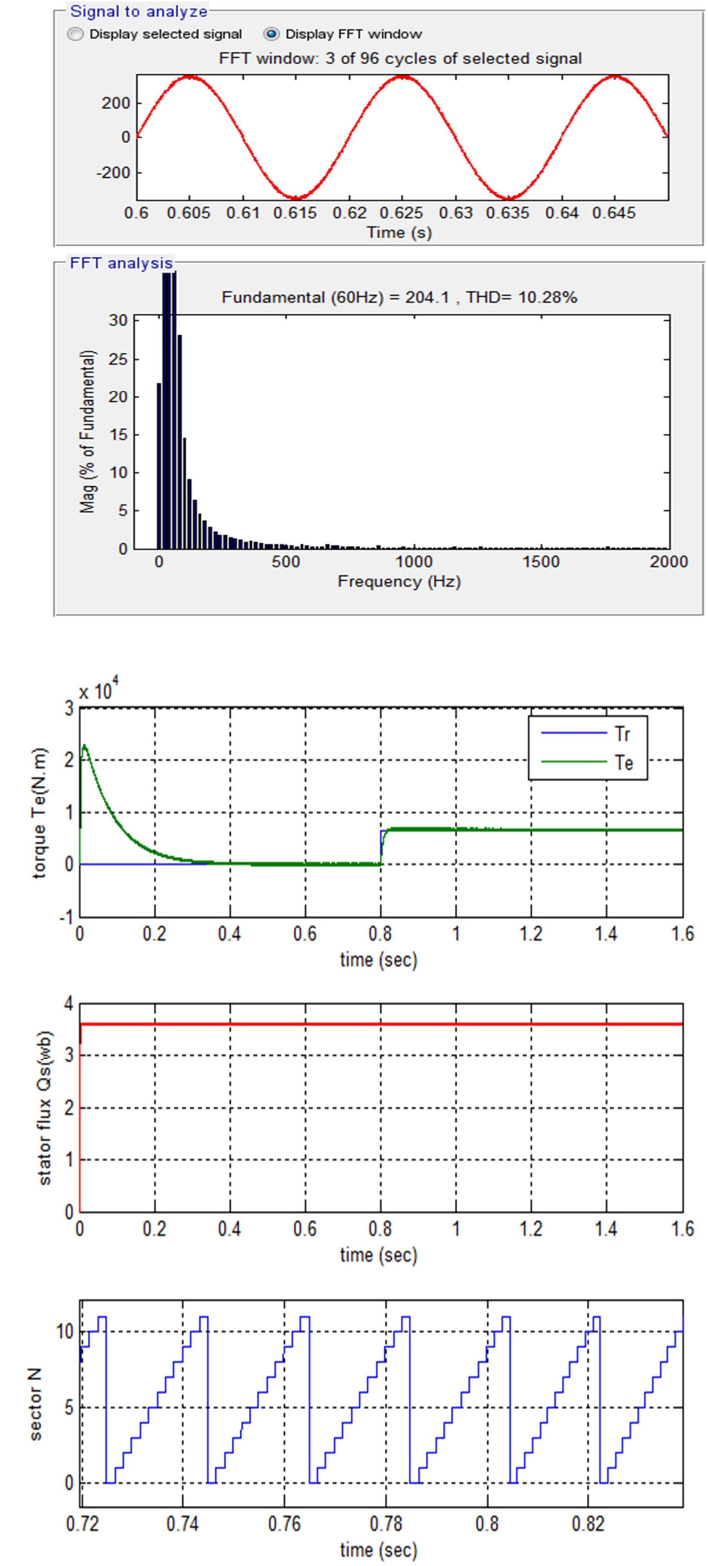

Fig. 8 Dynamic responses of five-level DTC with ANFIS controller for IM.

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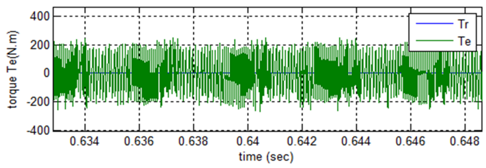
From the simulation results presented in Figs. 7-8 it is apparent that the THD value of stator current for the five-level DTC with ANFIS is considerably reduced. Table 2 shows the comparative analysis of THD value for stator current.

Table. 2 Comparative analysis of THD value

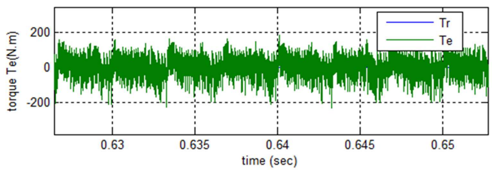
Five-level DTC	**Five-level DTC with ANFIS**
21.84%	**10.28%**

In the other hand, the dynamics of the components of the stator flux are not affected by the application of these load guidelines.

Torque response comparing curves are shown in Fig. 9. See figure the torque ripple is significantly reduced when the ANFIS controller is in use.

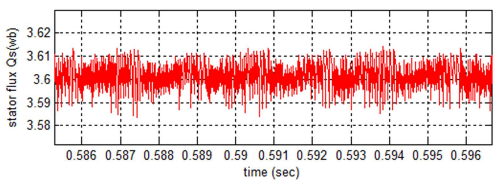


a) Conventional five-level DTC

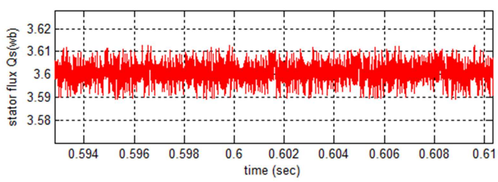


b) Five-level DTC with ANFIS
Fig. 9 Zoom in the torque

Fig. 10 shows the stator flux responses of both the conventional and five-level DTC with ANFIS controller. It is found that the proposed variable band torque hysteresis controller based DTC scheme exhibits smooth response and lesser ripple in stator flux as compared to the conventional five-level DTC scheme.



a) Five-level DTC



b) Five-level DTC with ANFIS
Fig. 10 Zoom in the stator flux

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6. Conclusions

In this paper, I'm proposed an ANFIS controller for torque hysteresis of induction motor controlled by five-level DTC. Using ANFIS controller reduces the THD value of stator current, torque and stator flux ripple of induction motor performance compared to obtain with a classical hysteresis controller. The simulation results obtained were satisfactory, and system stability has been insured.

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