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FIVE-LEVEL DTC CONTROL OF INDUCTION MACHINE DRIVE USING FUZZY LOGIC CONTROLLER FOR LOW TORQUE RIPPLE

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Abstract: This paper presents an improved five-level direct torque control (DTC) based on fuzzy logic. The major problem that usually associated with DTC drive is the high torque ripple. To overcome this problem a torque hysteresis band with variable amplitude is proposed based on fuzzy logic. The fuzzy proposed based on fuzzy logic. The fuzzy proposed controller is shown to be able to reduce the torque and flux ripples and to improve performance DTC, especially at low speed. The validity of the proposed methods is confirmed by the simulative results.

Keywords: Direct torque control, Induction machine, Five-level inverter, Fuzzy logic controller, Torque hysteresis

INTRODUCTION

In many industrial applications, direct torque control (DTC) of induction motor is well-known control method which provides fast dynamic réponse compared with other control methods like field oriented control (FOC). The DTC has been proposed for induction motor control in 1985 by Takahashi and similar idea that the name of direct self-control developed in 1988 by Depenbrock [1]. The DTC provides very quick response with simple control structure and hence, this technique is gaining popularity in industries. Though, DTC has high dynamic performance [2]. However the DTC technique presents the disadvantage of large flux and torque ripples [3].

Over the past years, the utilization of multilevel inverter topology in the DTC system has gained popularity or the medium and high voltage applications [4]. Commercially three basic multilevel converters are presented in the literature as diode-clamped converters cascade H-bridge converters and flying-capacitor converters [5].

The multilevel inverter fed electric machine systems are considered as a promising approach in achieving high power/high voltage ratings. Moreover, multilevel inverters have the advantages of overcoming voltage limit capability of semiconductor switches, and improving 2 harmonic profiles of output waveforms. The output voltage waveform approaches a sine wave, thus having practically no common-mode voltage and no voltage surge to the motor [6].

To sleeve the problem of DTC, various techniques have been proposed including the use of variable hysteresis bands, predictive control schemes, space vector modulation techniques and intelligent control methods [2].

This paper is devoted to fuzzy logic five-level direct torque control (FLDTC) is used to improve dynamic response performance and decrease the stator flux and torque ripples.

STRUCTURE OF FIVE-LEVEL INVERTER

Multilevel inverters have been developed to overcome harmonics in output, and improve the shape of output to reach sinusoidal waveform [7]. Multilevel power conversion technology is a very fast growing area of power electronics with good potential for further development. The most attractive features of this technology are in the medium to high-voltage application range (2-13 kV), which include motor drives, power distribution, power quality and power conditioning applications [8]. 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 Figure 1. The voltage across the phase winding of the induction motor can attain one of the five levels –2 Vdc, -Vdc, 0, 2Vdc or VDC, depending upon the switching states of the inverters [9].

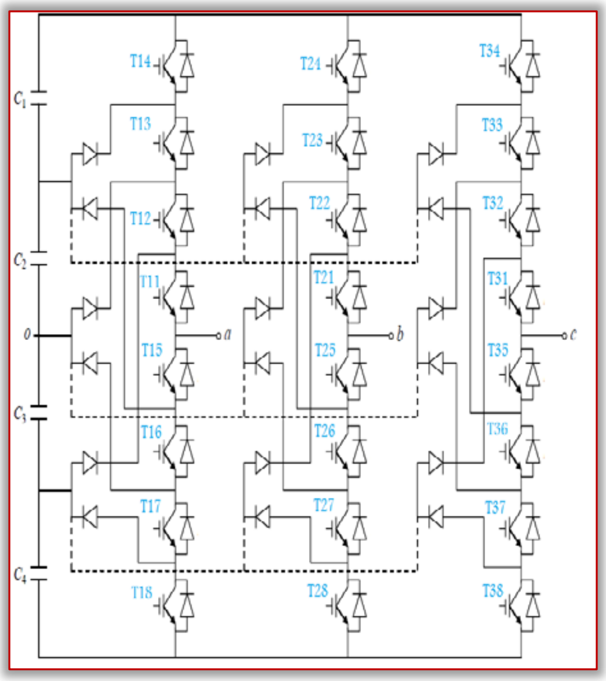


Figure 1. Five-level diode clamped voltage source inverter

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 Figure 2.

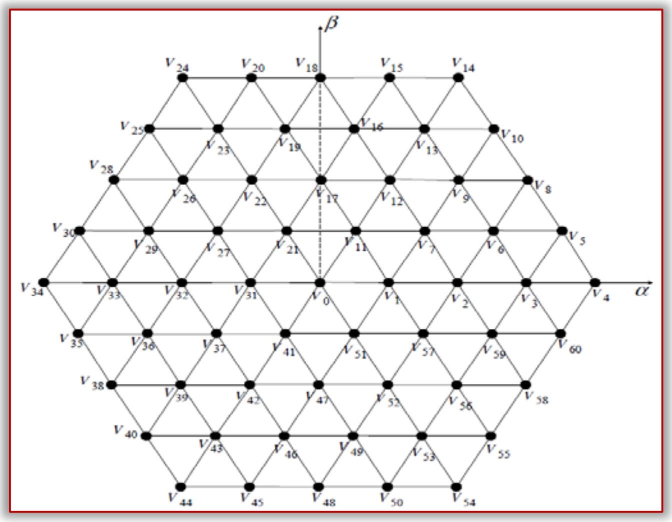


Figure 2. Space vector diagram of five-level inverter

DIRECT TORQUE CONTROL STRATEGY

The main idea of direct torque control is to directly control the torque and flux produced by the machine, without current control, as it is the case in FOC [11]. DTC technique can be easily implemented using two hysteresis controllers (one for flux and the other for torque), torque and flux estimators and a switching table to select the proper voltage vector. The basic functional blocks used to implement the DTC scheme are represented in Figure 3 [12].

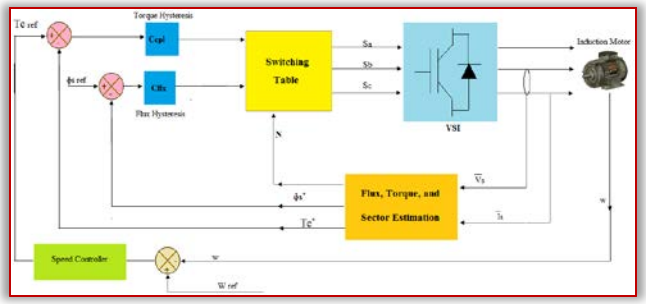


Figure 3. Block diagram of DTC of IM drives

In the DTC motor drive, the stator flux linkage and the electromagnetic torque can be directly controlled by the selection of optimum inverter switching states. The flux and the torque errors are kept within acceptable limits by hysteresis controllers. The DTC allows for very fast torque responses and flexible control of the induction motor [13].

The components of stator flux are given by [14]:

$$\begin{cases}\Phi_{s\alpha} = \int\limits_{0}^{t}\left(V_{s\alpha} - R_s \cdot i_{s\alpha}\right)dt \\ \Phi_{s\beta} = \int\limits_{0}^{t}\left(V_{s\beta} - R_s \cdot i_{s\beta}\right)dt\end{cases} \qquad (1)$$

The magnitude of the stator flux can be estimated by:

$$\Phi_s = \sqrt{\Phi_{s\alpha}^2 + \Phi_{s\beta}^2} \qquad (2)$$

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 [15]:

$$\theta = \mathrm{arctg}\left(\frac{\Phi s\beta}{\Phi s\alpha}\right) \qquad (3)$$

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

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

The switching selection block in Figure 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 inverter

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

The stator flux and torque are controlled by two comparators with hysteresis illustrated in Figure 4. The dynamics torque are generally faster than the flux then using a comparator hysteresis of several levels, is then justified to adjust the torque and minimize the switching frequency average [16].

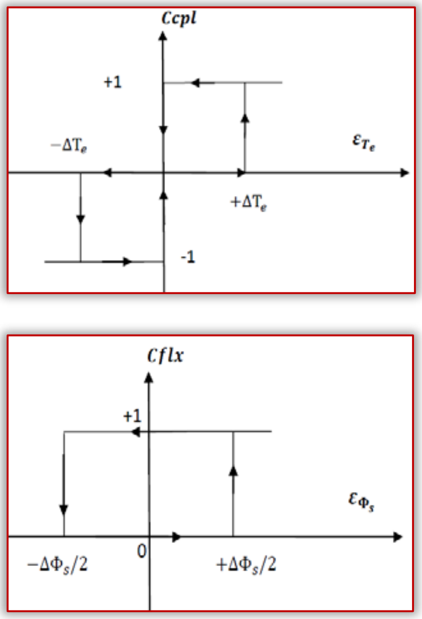


Figure 4. Comparators with hysteresis used to regulate flux and torque

DESIGN OF FLC TORQUE RIPPLE OPTIMIZATION

In order to improve the five-level DTC performances, a complimentary use of the fuzzy logic controller is proposed. Lotfi Zadeh, the father of fuzzy logic, has classified computing as hard computing and soft computing [17]. Fuzzy control is based on a logical system called fuzzy logic which is much closer in spirit to human thinking and natural language than classical logical systems. Nowadays fuzzy logic is used in almost all sectors of industry and science. One of them is load frequency control. The main goal of LFC in interconnected power systems is to protect the balance between production and consumption. Because of the complexity and multivariable conditions of the power system, conventional control methods may not give satisfactory solutions [18].

The principle of fuzzy logic direct torque control is similar to traditional DTC. The difference is using a fuzzy logic controller to replace the torque hysteresis loop controller. As shown in Figure 5.

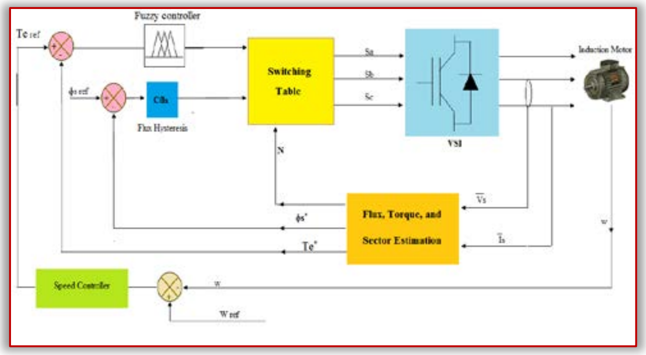


Figure 5. Fuzzy logic DTC scheme

To get a better control performance a fuzzy logic controller has been introduced to be a compliment to the hysteresis controller. The fuzzy controller design is based on intuition and simulation [19].

In this paper, a Mamdani-type FLC is developed to adapt the torque hysteresis band in order to reduce the ripples in the motor-developed torque. In conventional DTC technique, the amplitude of the torque hysteresis band is fixed. However, in this proposed scheme, the FLC controls the upper and lower limits of the torque hysteresis band on the basis of its feedback inputs. The fuzzy systems are universal function approximators. The FLC is used as a nonlinear function approximator producing a suitable change in the bandwidth of the torque hysteresis controller in order to keep the torque ripples minimum [2]. The block diagram for fuzzy logic based torque hysteresis controller is shown in Figure 6.

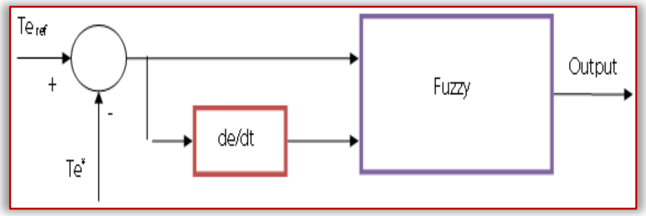


Figure 6. Fuzzy logic control of torque hysteresis controller

Since the two inputs and single output are having seven subsets, 49 rules are to be formed [20]. The rules are formulated and given in Table 2. The centre of gravity method is employed for defuzzification.

Table 2. Fuzzy rules of torque hysteresis controller

e Δe	NL	NM	NP	EZ	PS	PM	PL
NL	NL	NL	NL	NL	NM	NP	EZ
NM	NL	NL	NL	NM	NP	EZ	PS
NP	NL	NL	NM	NP	EZ	PS	PM
EZ	NL	NM	NP	EZ	PS	PM	PL
PS	NM	NP	EZ	PS	PM	PL	PL
PM	NP	EZ	PS	PM	PL	PL	PL
PL	EZ	PS	PM	PL	PL	PL	PL

The design of fuzzy rules involves writing rules that relate the inputs variables to the output variable [21]. These rules are expressed as IF-THEN statements and the syntax is as follows: IF e is NM AND Δe is PL THEN S is PS. Figure 7 and 8 show the membership functions of input and output variables respectively.

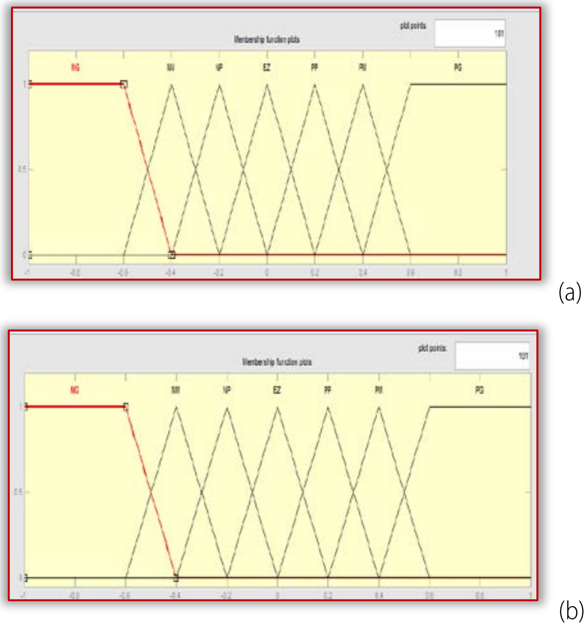


Figure 7. Input variables membership functions:
(a) Error; (b) Change in error

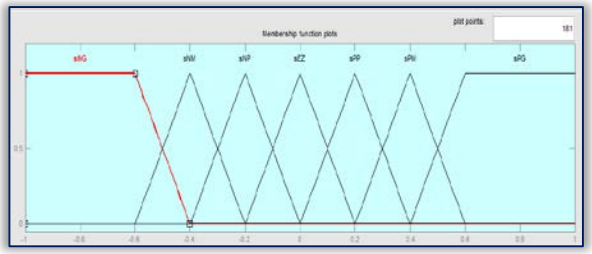
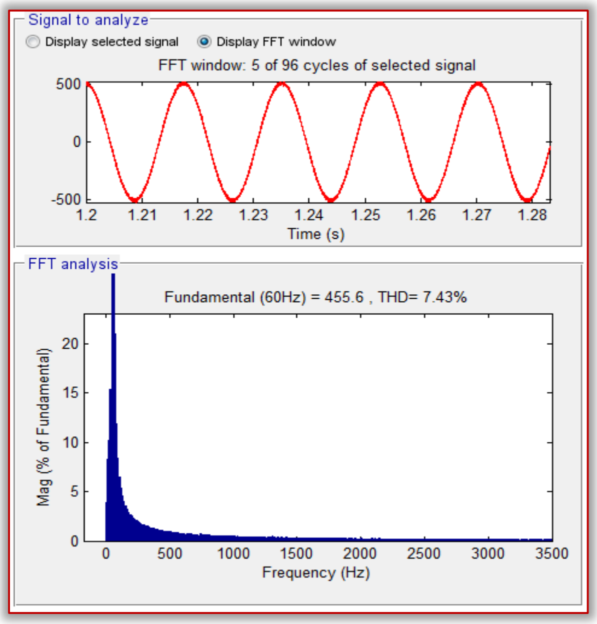


Figure 8. Output variable membership function

SIMULATION RESULTS

The simulations of the five-level FLDTC induction motor drive are compared with five-level DTC. 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 Figure 9. The dynamic performance of the five-level DTC control with Fuzzy logic controllers is shown Figure 10.



Signal to analyze

○ Display selected signal ● Display FFT window

FFT window: 5 of 96 cycles of selected signal

FFT analysis

Fundamental (60Hz) = 455.6 , THD= 7.43%

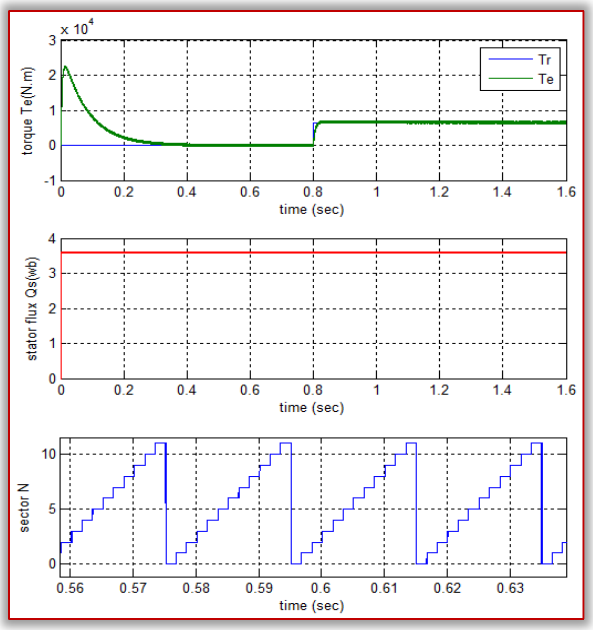
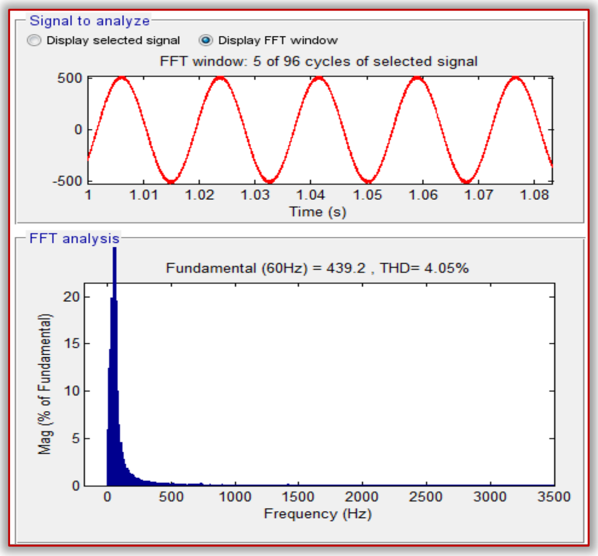


Figure 9. Dynamic responses of five-level DTC for induction motor



Signal to analyze

○ Display selected signal ● Display FFT window

FFT window: 5 of 96 cycles of selected signal

FFT analysis

Fundamental (60Hz) = 439.2 , THD= 4.05%

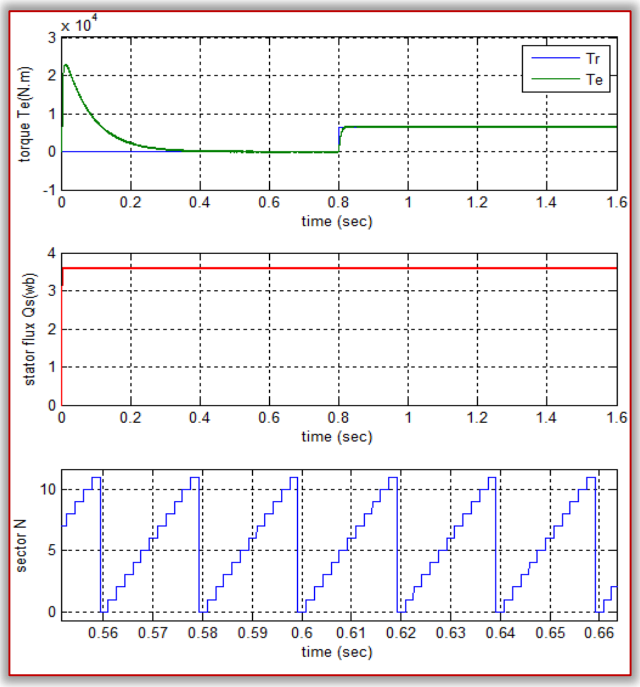
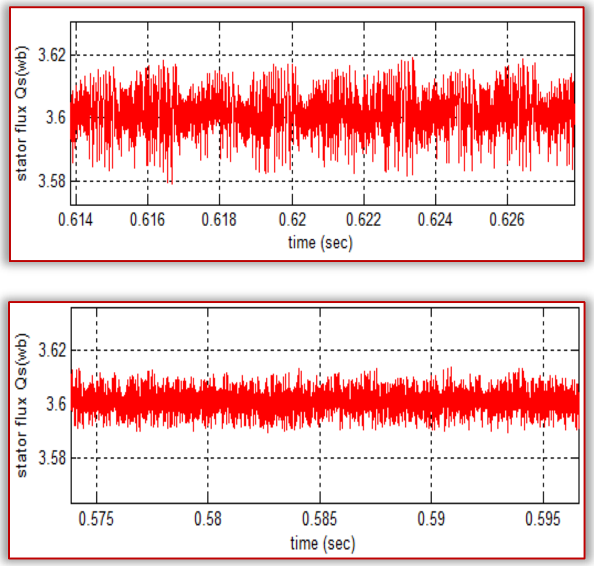


Figure 10. Dynamic responses of five-level DTC with fuzzy logic controller for induction motor

Figure 11 shows the stator flux responses of both the conventional and fuzzy five-level DTC schemes. It is found that the proposed variable band torque hysteresis controller based DTC scheme exhibits smooth response and lesser ripple in flux as compared to the conventional five-level DTC scheme.



(a)

(b)

Figure 11. Zoom of stator flux:
(a) Five-level DTC; b) Five-level DTC with fuzzy controller

Torque response comparing curves are shown in Figure 12. See figure the torque ripple is significantly reduced when the fuzzy controller is in use. The fuzzy controller provides the desired amplitude according to the torque ripple level and operating condition, as it is shown in the paper.

Steady state current comparing curves are shown in Figure 13. Compared with steady state current waveform, traditional five-level DTC model maintaining the current waveform of sine, but there is a little large pulsation, there are some harmonics which will lead to torque ripple in the wave form, while the fuzzy logic DTC current waveform is relatively smooth, so, effectively reduces the harmonic.

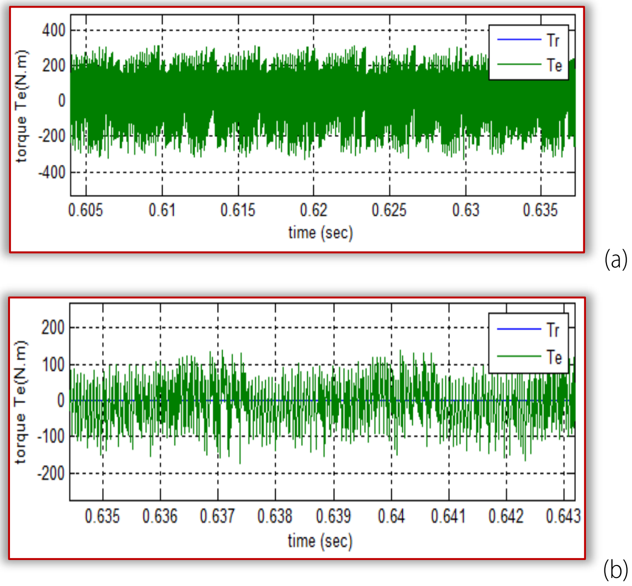


Figure 12. Zoom of torque:
a) Five-level DTC; b) Five-level DTC with fuzzy controller

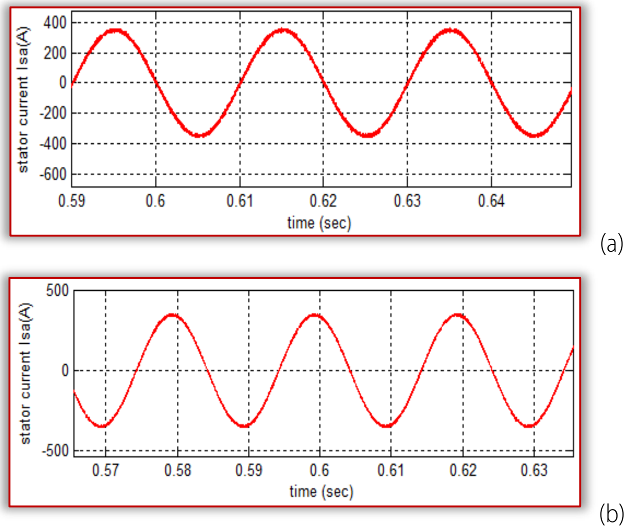


Figure 13. Zoom of stator current:
a) Five-level DTC; b) Five-level DTC with fuzzy controller

CONCLUSION

This paper presents a five-level DTC for the induction motor with fuzzy logic controller. This controller determinates the desired amplitude of torque hysteresis band. The five-level DTC with fuzzy logic controller decreases considerably the electromagnetic torque ripples and stator flux. The main advantage is the improvement of torque and flux ripple characteristics at low-speed region, this provides an opportunity for motor operation under minimum switching loss and noise. Thus the proposed DTC scheme has achieved better torque and stator flux under Simulink environment.

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