New Direct Torque Neuro-Fuzzy Control Based SVM for Dual Two Level Inverter-Fed Induction Motor

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Abstract: In this paper, a novel direct torque neuro-fuzzy control (DTCNF) based space voltage modulation (SVM) technique for dual two level inverter fed induction motor is presented. The proposed scheme produces voltage space vector locations identical to those of a conventional three-level inverter. In this new scheme an adaptive NF inference system (ANFIS) to replace the switching table and the hysteresis comparators, for generate the reference voltage using space vector modulation (SVM) techniques for dual two level inverter. Compared with conventional direct torque control (C_DTC), in this new technique, the ripples of both torque and flux are reduced remarkable, and switching frequency is maintained constant. Simulation results verify the validity of the proposed method.

Keywords: Induction motor, Neuro-fuzzy, Space vector modulation, Dual two level inverter.

1. INTRODUCTION

For over fifty years, DC motors have been widely used in variable speed drives applications principally due to their fast torque response, high precision of regulation and the possibility to use these motors in whichever mode of operation [1]. However DC motors with drawbacks of spark, corrosion and necessity of maintenance, this motor has been replaced by AC induction motors (IMs)[2].Induction motors (IMs) are widely used in many industrial applications due to their mechanical robustness and low cost [1,2]. However, it is known that the control of induction motors is relatively difficult compared to other kinds of motors, such as DC motors and synchronous motors due to their coupled and nonlinear model [1-4].

To solve this problem and achieve high performance, field-oriented control (FOC) schemes have been proposed by F. Blaschke in 1972 [4]. This method can provide at least the same performance from an inverter-driven induction motor as is obtainable from a separately excited DC motor [5].

Today field oriented controlled drives are an industrial reality and are available on the market by several producers and with different solutions and performance [6]. However in this method, it is necessary to determine correctly the orientation of the rotor flux vector [1], and she is very sensitive to the deviation of motor parameters, particularly the rotor time-constant [2]. For reduction of the complexity of the algorithms involved in a field oriented control, several researches have been devoted to find out new technique for the Induction motor control having the features of precise and quick torque response [6,7].Thirteen years later, a new technique for the torque control of induction motors was developed and presented by I. Takahashi as direct torque control (DTC) [8], and by M. Depenbrock as direct self control (DSC) [9].Since its introduction, the direct torque control principle was widely used for IM drives with fast dynamics [10]. This method provides a good performance with a simpler structure and control diagram. In DTC it is possible to control directly the stator flux and the torque by selecting the appropriate VSI state [11]. The main advantages offered by DTC are [6, 10,11]:

- Absence of coordinate transformation and current regulator and PWM signals generator.
- DTC is able to produce fast torque and flux control.
- DTC allows a good torque control in steady-state and transient operating conditions to be obtained.
- Decoupled control of torque and stator flux
- Robustness for rotor parameters variation.

However, in spite of its simplicity, the DTC allows some drawbacks that are summarized in these points [11,12]:

- Variable switching frequency behaviour, due to the presence of hysteresis controllers.
- Very sensitive for stator resistance variation, is needed for the torque and stator flux estimator.
- Flux and current distortion caused by sector changes of the flux position.
- High ripple level at low speed.

But, in the last nine years, many researches have been carried out to overcome some of the drawbacks of the basic DTC [6,11,12]. In particular some solutions proposed are: direct torque and flux control based on SVM (DTC-SVM) for IM sensorless drives. This way, the DTC transient performance and robustness are preserved and the steady-state torque ripple is reduced [10,13].Additionally, the switching frequency is constant and totally controllable. In [11][14–16]; the author's presents a new control scheme based on DTC designed to be applied to an Induction Motor fed with a three-level voltage source inverter (VSI). The major advantage of the three-level VSI topology when applied to DTC, especially for low switching frequency inverter system, illustrates quite reduced torque ripple characteristics all over the operating speed region [16].

Actually, because of their success, intelligent controllers such as neural networks and fuzzy logic have become one of the most favorable areas of research for controlling nonlinear systems [12]. In [18] a novel switching vector selector using the ANN (Artificial neural network) is trained under the tutor of the method mentioned above. By the usage of the ANN, when the error of the torque and stator flux is made certain, the output vector can be expediently acquired in [12,19] fuzzy-logic controllers are proposed for vector-controlled drives. The principle of the strategy is to replace the two-hysteresis controllers and the selection table by these intelligent controllers.

Later in [7],[20-22], the author's presents a direct torque neuro-fuzzy control (DTCNF) is used for a DTC drive. The methods based on the combination of artificial neural networks and fuzzy systems take a remarkable place. The same system was implemented with excellent results; however additional calculations were needed to reach zero-steady-state error [20].

The paper presents the, a novel direct torque neuro-fuzzy control (DTCNF) scheme based SVM-Three level Inverter-Fed Induction Motor. This scheme uses a controller based on an adaptive NF inference system (ANFIS) to replace the switching table and the hysteresis comparators [21].

The ANFIS evaluate the voltage space vector (reference voltage) which is used by a space vector modulator (SVM) to generate the inverter switching states within a fixed time period [7], using torque error, stator flux error and the angle of stator flux [21,22]. Compared with conventional direct torque control (DTC), in this new technique, the ripples of both torque and flux are reduced remarkable, and switching frequency is maintained constant. Simulation results verify the validity of the proposed method.

2. CONVENTIONAL DIRECT TORQUE CONTROL

The block diagram of classical DTC is presented in Fig.1. The commanded electromagnetic torque Ce* is delivered from outer PI speed controller. The reference values for the stator flux magnitude φs* and the torque Ce* are compared with the estimated values, the resulting error values are fed into a two-level and a three-level hysteresis block respectively [6-11].

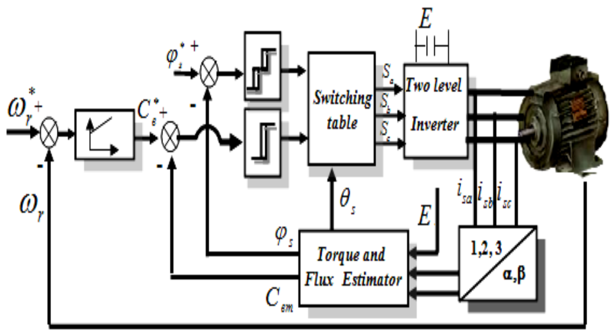

Fig.1 Basic direct torque control scheme

The selection of the appropriate voltage vector is based on the switching table given in Table I. The input quantities are the stator flux position sector (N) and the digitized output variables ΔCe and Δφs,. Thus, the selection table generates pulses Sa,Sb,Sc to control the power switches in the inverter [6,22]

The above considerations allow construction of the selection table as presented in Table. 1.

Table1. Switching table for conventional DTC

Sector N		1	2	3	4	5	6
Flux	Torque						
Δφs=1	ΔCe=1	V_2	V_3	V_4	V_5	V_6	V_1
	ΔCe =0	V_7	V_0	V_7	V_0	V_7	V_0
	ΔCe =-1	V_6	V_1	V_2	V_3	V_4	V_5
$\Delta\varphi_s=0$	ΔCe =1	V_3	V_4	V_5	V_6	V_1	V_2
	$\Delta C_e=0$	V_0	V_7	V_0	V_7	V_0	V_7
	$\Delta C_e=-1$	V_5	V_6	V_1	V_2	V_3	V_4

In voltage source inverters eight switching combinations can be selected according to the following relationship:

$$\overline{V}_s = \sqrt{\frac{2}{3}}E\left[S_a + S_b e^{j\frac{2\pi}{3}} + S_c e^{j\frac{4\pi}{3}}\right] \tag{1}$$

In the classical DTC method the plane is divided for the six sectors (Fig.2).

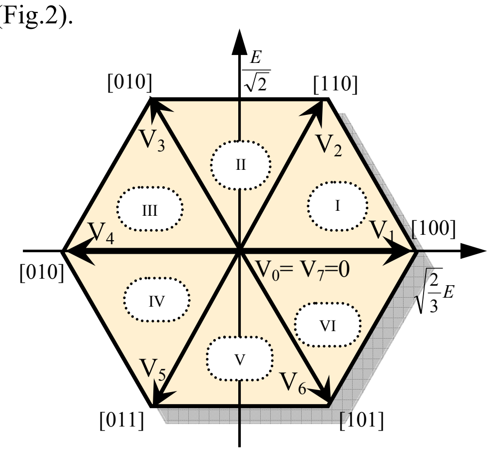

Fig.2 Partition of the (α,β) plane into six sectors

The stator flux is estimated by equations (2):

$$\overline{\varphi}_S = \int_0^t (\overline{V}_S - R_S \overline{I}_S)\, dt \tag{2}$$

With the voltage drop across the stator resistance neglected, the relation between the stator voltage space vector and the variation of stator flux can be established as [15,17,19]:

$$\Delta\overline{\varphi}_S(t) \approx \overline{V}_s T_s \tag{3}$$

The equation (3) indicates that φ_s The stator flux variation is nearly proportional to voltage vector, as the sampling period is constant, and stator flux space vector will move fast if non-zero switching vectors are applied [19], It is then possible to drive φ_s along any prefixed track curve. In steady state conditions, for sinusoidal waveforms, the stator flux vector has to describe a circular locus [6], shown in the figure.3.

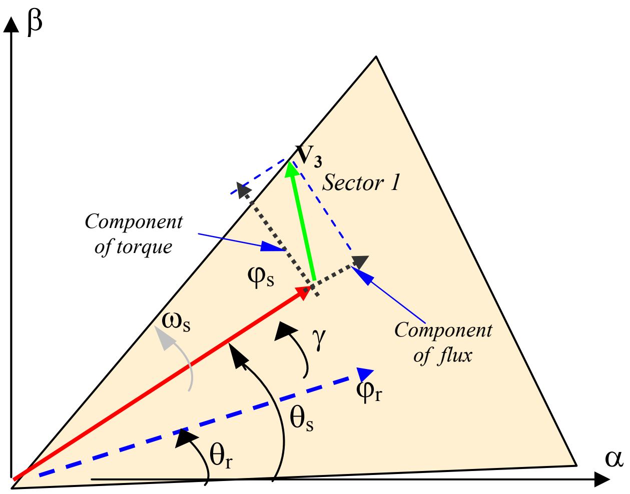

Fig.3 An example for stator flux deviation

The stator flux vector is in is in sector 1, the voltage vector V_3 is used to increase both the torque and the flux linkage. V4 is used to decrease both the flux linkage and the torque. V_2 is used to increase torque and reduced the amplitude of the flux linkage. V_5 is used to reduce the torque and increase the flux linkage [17].

3. DIRECT TORQUE NEURO-FUZZY CONTROLLER

The strategy of the direct torque neuro-fuzzy controller (DTNFC) is presented in Fig.4. The principle of the strategy is to replace the two-hysteresis controllers and the selection table by the adaptive NF inference system (ANFIS) controller based neuro-fuzzy structure, to generate a voltage space vector (reference voltage) which is used by a space vector modulator to generate the inverter switching states [7, 20-22].

The stator flux ($e_{\varphi s}$) and torque (e_{ce}) errors are the controller inputs. The outputs of the regulator are the reference voltage phase (φ_{Vs}) and amplitude (Vs) which are directly delivered to the voltage modulator.

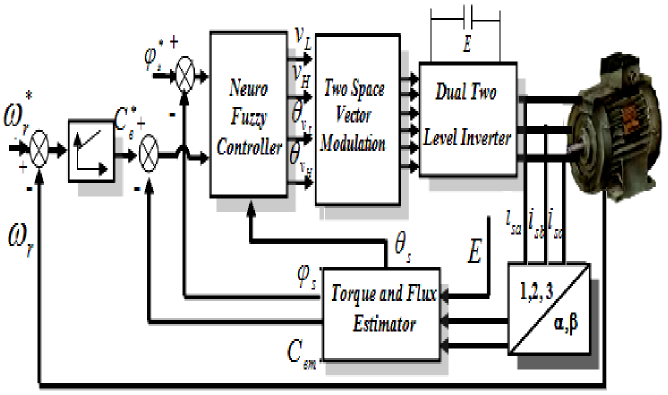

Fig.4. Schematic of DTC Neuro-fuzzy control strategy.

The circuit configuration for a 3-level inverter which is realized by connecting a dual two-level inverter two level inverters two voltage source inverters are commonly connected to a DC power source[25].

3.1. Three Level Inverter

The schematic a dual-inverter fed open-end winding induction motor drive, where INV1 and INV2 are conventional two-level inverters shown in Figure.5 This type of VSI has several advantages over the standard two-level VSI [7,23].

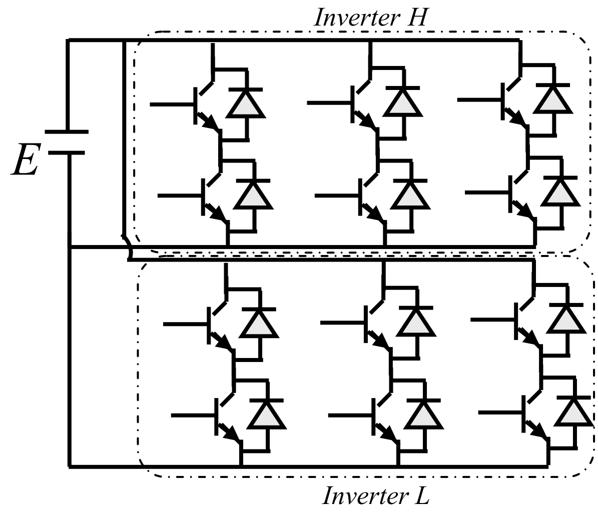

Fig.5 The power circuit of dual two-level inverter[23,25]

A three-level inverter structure is realized, when the open-end winding induction motor is fed by two two-level inverters with half the DC power supply E voltage compared to the dc-link voltage of the conventional neutral point clamped three-level inverter. The proposed scheme produces voltage space vector locations identical to those of a conventional three-level inverter. Each inverter can produce its own voltage space phasor locations, resulting in a combined voltage space phasor locations and combinations as shown in Fig. 2 [25,27].

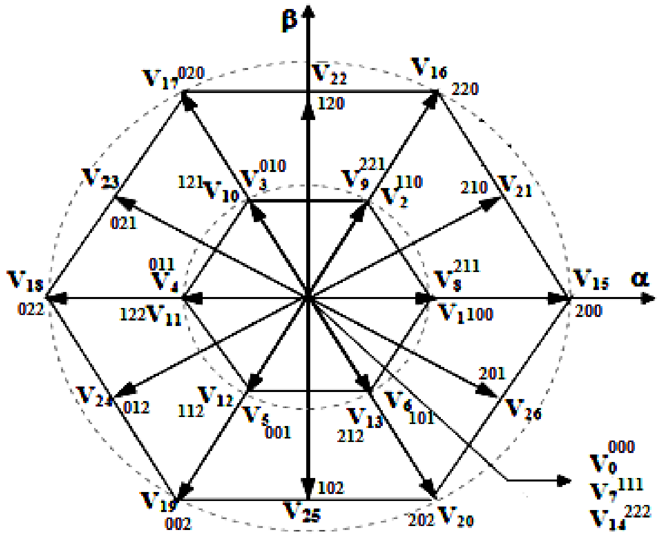

Fig. 6. Voltage vectors for a three-level inverter

They are the zero voltage vectors ($V_0V_7V_{14}$) group, the low voltage vector ($V_1V_2V_3V_4V_5V_6V_8V_9V_{10}$ $V_{11}V_{12}V_{13}$) group, the intermediate voltage vector ($V_{21}V_{22}V_{23}V_{24}V_{25}V_{26}$) group and high voltage vector ($V_{15}V_{16}V_{17}V_{18}V_{19}V_{20}$) group, show in Fig6 [11,14,15].

3.2. Space Vector Modulation

Space Vector Modulation (SVM) is one of the most widely utilized techniques to generate sinusoidal line-to-line voltages and currents with a three-phase inverter. Is base on the concept of approximating a rotating reference voltage vector V_{ref} using a combination of two out of the eight possible vectors that can be generated from a three-phase inverter [19,26]. This process is illustrated in fig. 7.

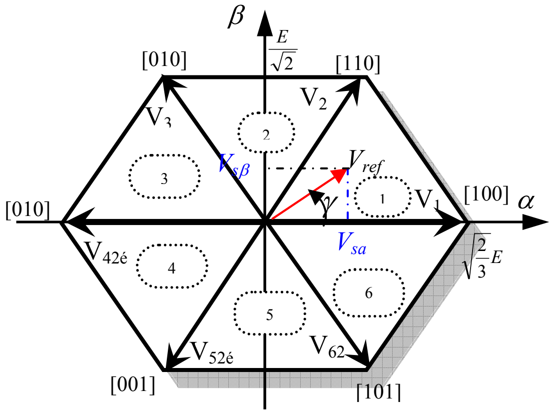

Fig. 7. Space vector diagram

The magnitude of this vector is related to the magnitude of the output voltage and the time this vector takes to complete one revolution is the same as the fundamental time period of the output voltage [26].

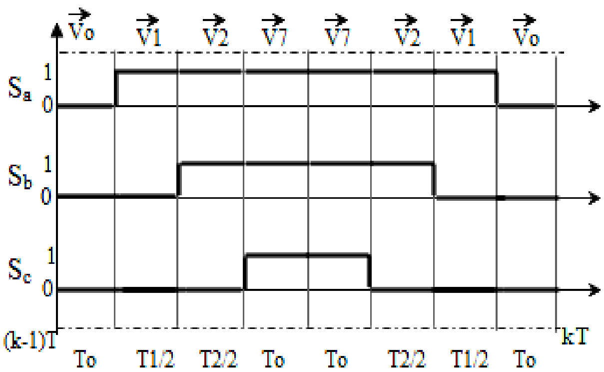

Fig. 8. Commutation sequence for the inverter [9].

However the general idea is based on sequential switching of active and zero (V_0 or V_7) vectors [9]. Equating the volt-sec integral of reference vector V_{ref} obtained from the controller with the inverter output voltage vectors over a single space vector modulation cycle gives [19,26]:

$$\int_0^{T_s} \bar{V}_{ref}\, dt = \int_0^{T_1} \bar{V}_k\, dt + \int_{T_1}^{T_1+T_2} \bar{V}_{k+1}\, dt + \int_{T_1+T_2}^{T_s} \bar{V}_0\, dt \tag{4}$$

V_0 does not affect the magnitude of the voltage since it is a null vector. Assuming that the vectors V_k or V_{k+1} are constants and given that V_0 is a null vector [26]:

$$\bar{V}_{ref} T_s = \bar{V}_k T_1 + \bar{V}_{k+1} T_2 \tag{5}$$

Expressing (5) in the d-q reference plane and considering the region $0<\gamma<\pi/3$, it follows that [26].

$$\frac{2}{3} T_1 E \begin{bmatrix} 1 \\ 0 \end{bmatrix} + \frac{2}{3} T_2 E \begin{bmatrix} cos(\pi/3) \\ sin(\pi/3) \end{bmatrix} = T_s V_{ref} \begin{bmatrix} cos(\gamma) \\ sin(\gamma) \end{bmatrix} \tag{6}$$

The amplitude of the vector is depended on the duration times, which for discrete system with sampling time Ts, can be calculated by the equations.

$$T_1 = \frac{\sqrt{3} T_s V_{ref}}{E} \sin\left(\frac{\pi}{3} - \gamma\right) \tag{7}$$

$$T_2 = \frac{\sqrt{3} T_s V_{ref}}{E} . \sin(\gamma) \tag{8}$$

$$T_3 = T_o - (T_1 + T_2) \tag{9}$$

In order to determine the duration of the pulses in the other regions, the reference vector is rotated $-n\pi/3$ radians until its angle is equal to $0<\gamma<\pi/3$ [26].

In dual two level inverter each inverter the required voltage space vector can be synthesized using two space vector modulation, the space vector modulation for Inverter L he is shifted by (30°) of SVM for inverter H [24]. The output voltage vector v is given by the contribution of the voltage vector v_H and v_L, generated by inverter H and inverter L, respectively [28].

$$\bar{v} = \bar{v}_H + \bar{v}_L \tag{10}$$

In order to synthesize an output vector v, the two inverters must generate the corresponding fraction of v by applying only their active (v_k v_{k+1}) vectors and null vector. Being v_H and v_L in phase, they lay in the came sector and can be synthesized using the same adjacent active vectors (v_k v_{k+1}) as shown in Fig.(9a and 9b) [28].

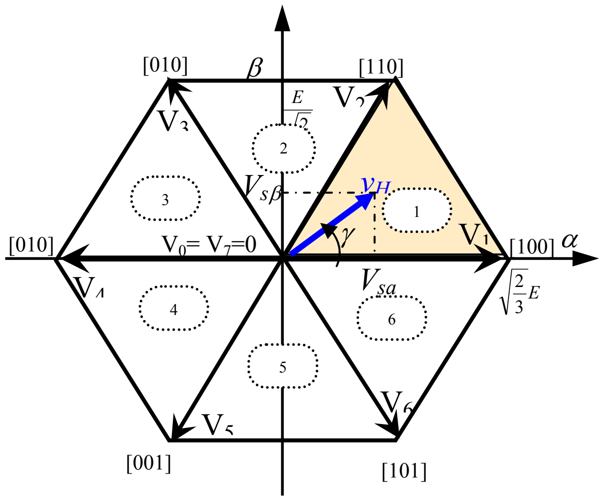

Fig. 9a. Space vector diagram for inverter H

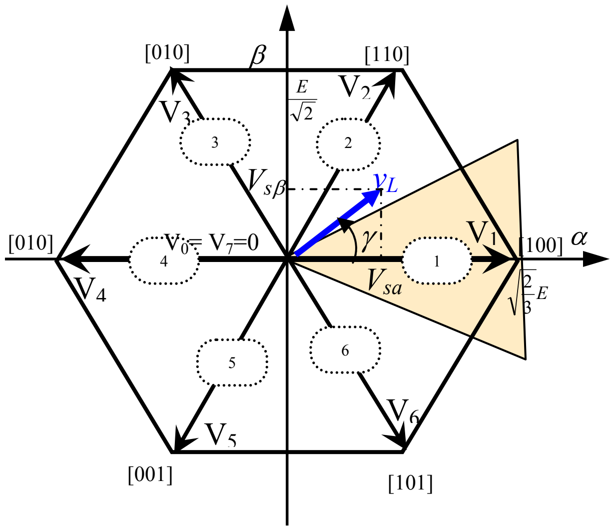

Fig. 9b. Space vector diagram for inverter L

3.3. Neuro-Fuzzy Controller

The precisely example scheme of the adaptive NF inference system (ANFIS) is one of the proposed methods to combine fuzzy logic and artificial neural networks for decoupled flux and torque control. Fig10, shows the adaptive NF inference system structure [20].It is composed of five functional blocks (rule base, database, a decision making unit, a fuzzyfication interface and a defuzzyfication interface)[20].The structure proposed in [7,20-21] (Fig.10) contains five network layers:

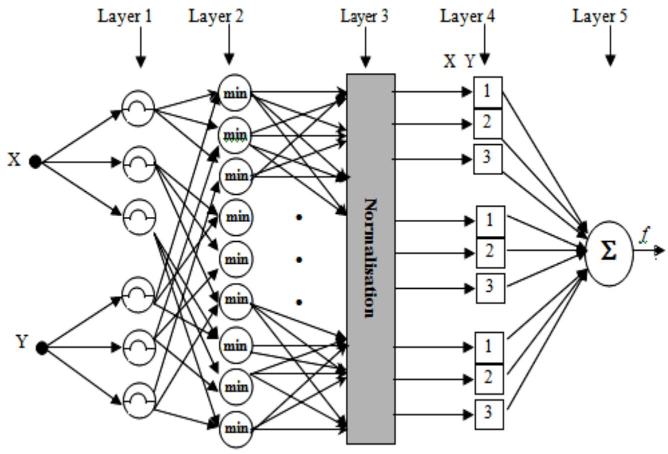

Fig. 10. Two-input NF controller structure

Layer1: Every node in this layer contains membership functions. Usually, triangular or bell-shaped functions are chosen.

Layer 2: This layer chooses the minimum value of two input weights.

Layer 3: Every node of these layers calculates the weight which is normalized.

Layer 4: This layer includes linear functions which are functions of the input signals.

Layer 5: This layer sums all the incoming signals.

Why in this case it uses two neuro-fuzzy controllers (DTNFC), One for Small hexagon and the other for the big hexagon. The structure of the DTNFC structure is presented in Fig.11.

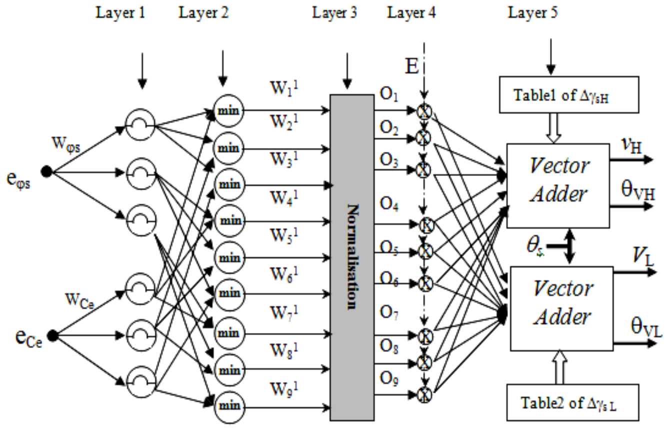

Fig. 11. Proposed Neuro-Fuzzy Controller scheme.

In the first layer of the NF structure, sampled flux error ($e_{\varphi s}$) and torque (e_{ce}), multiplied by respective weights w_φ and w_{ce}, are each mapped through three fuzzy logic membership functions. These functions are chosen to be triangular shaped.

The second layer calculates the minimum of the input signals. The output values are normalised in the third layer, to satisfy the following relation [7,20]:

$$O_i = \frac{w_i}{\sum_k w_k} \tag{11}$$

where w_i and O_i, are the i[th] output signal of the second and third layer respectively. The O_i is considered to be the weight of both the increment angle and the amplitude of the desired reference voltage i[th] component [7,20], so that.

$$v_H = v_L = O_i E \tag{12}$$

The output voltage space vector $\vec{v}$ can be equivalently represented as the sum of the voltage space vectors generated by the two two level inverters. If and are the voltage space vectors generated by H and L, respectively, the resultant voltage space vector is given by [27] :

$$\vec{v} = \vec{v}_H + \vec{v}_L \tag{13}$$

In the structure of DTNFC given by [20] the increment angle of each desired voltage component is chosen from a table independently of the weight O_i and is calculated from the following equations [20]:

$$\begin{cases} \theta_{VH} = \theta_s + \Delta\gamma_H \\ \theta_{VL} = \theta_s + \Delta\gamma_L \end{cases} \tag{14}$$

The regulator chooses the increment angle $\Delta\gamma_H$ and $\Delta\gamma_L$ respectively value from Tab(2 and 3).

Table 2. Increment angle $\Delta\gamma_H$

$\Delta\gamma_H$		Flux error P	Flux error Z	Flux error N
Torque error	P	$\frac{\pi}{4}$	$\frac{\pi}{2}$	$\frac{3\pi}{4}$
	Z	$0°$	$\frac{\pi}{2}$	π
	N	$-\frac{\pi}{4}$	$-\frac{\pi}{2}$	$-\frac{3\pi}{4}$

Table 3. Increment angle $\Delta\gamma_L$

$\Delta\gamma_L = \Delta\gamma_H + \pi/6$		Flux error P	Flux error Z	Flux error N
Torque error	P	$\frac{5\pi}{12}$	$\frac{4\pi}{6}$	$\frac{11\pi}{12}$
	Z	$\frac{\pi}{6}$	$\frac{4\pi}{6}$	$\frac{7\pi}{6}$
	N	$-\frac{\pi}{12}$	$\frac{\pi}{3}$	$-\frac{11\pi}{12}$

4. SIMULATION RESULTS

The induction machine used for the simulations has the following parameters: Pn□3kW,Rs□2.89Ω, Rr=2.39Ω, P□2,Ls□0.220H Lr□0.225H, Lm□0.214H.

To compare with conventional DTC and new control technique DTCNF_3L for IM are simulated. All Figs are the responses to step change speed command from [0 to105 to 21] rad/sec.
The results of simulation of C_DTC and DTCNF_3L are shown in Figs(12-21) respectively.

In Figs 13 and 14, the number of voltage levels delivered by the two-level VSI is 5, while in the case of the three level VSI this number is increased to 9 voltage levels, achieving a more sinusoidal and motor-friendly waveform.

From these results it can be seen that good tracking performances can still be achieved even at the speed (see Fig.14), and good torque responses for two methods, However in DTCNF for dual two level VSI technique shown Fig.16b, the ripple of torque in steady state is reduced remarkably compared with C_DTC(Fig.16.a).

In conventional DTC the effects of the two hysteresis controllers caused by any change in their band width are reflected in the dynamic behavior of the whole system. For instance where the rotor speed is decreasing stator current has more distortions (Fig.19a) became not sinusoidal, and the total harmonic distortion is increased (Fig.20a).

In conventional DTC the effects of the two hysteresis controllers caused by any change in their band width are reflected in the dynamic behaviour of the whole system. For instance an increment in the flux hysteresis band width caused a variable switching Frequency see Fig.21a (Switching inverter given its not regularly state), However if high switching frequency is used, this will result in significantly increased switching losses (leading to reduced efficiency) and increased stress on the semiconductor devices of the inverter .

This is why a constant value of switching frequency allows the system to get a better performance than that obtained in conventional DTC drive.

In the DTCNF_3L, as shown Figs.(17.b and 18b), the stator flux has the fast response in transient state and in steady state its trajectory is more approximately circle than it of the conventional DTC (Figs17.a and 18a), as illustrated in Fig.19b, the current have less harmonic distortion and the total harmonic distortion is reduced in the 0.4859% (fig20b), consequently and the switching frequency is fixed to 5kHz, show Fig.21b (state of Switching inverter its regularly).

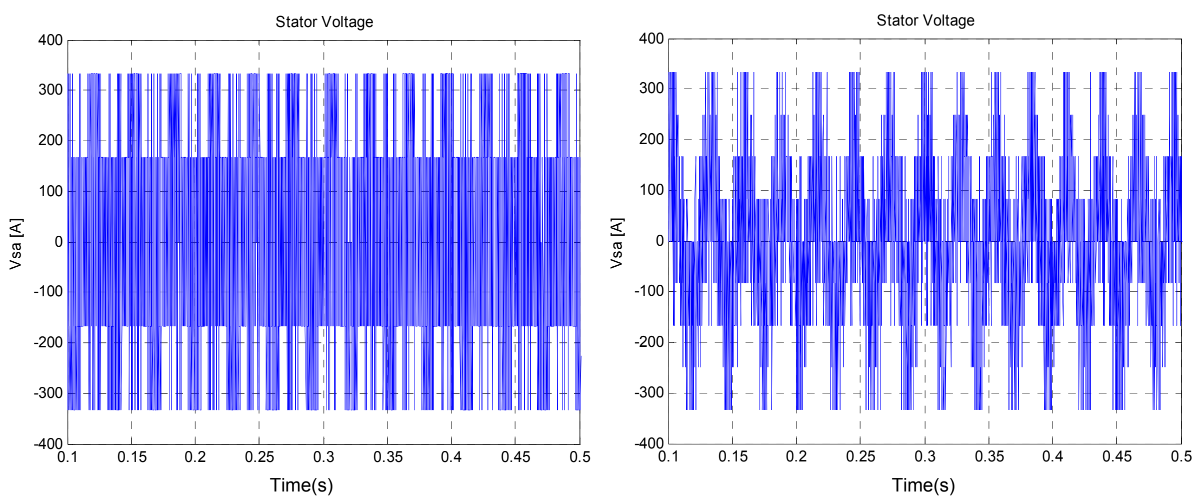

Fig. 12. Stator phase voltage. (a) Conventional DTC two level VSI; (b) DTCNF for dual two level VSI

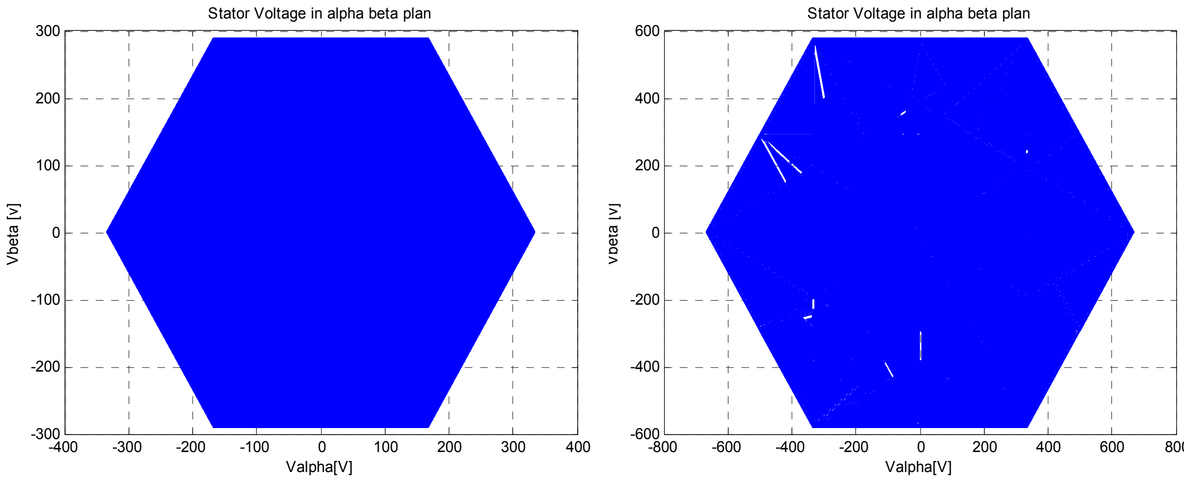

Fig. 13. Stator voltage in plan (α,β). (a) Conventional DTC two level VSI; (b) DTCNF for dual two level VSI

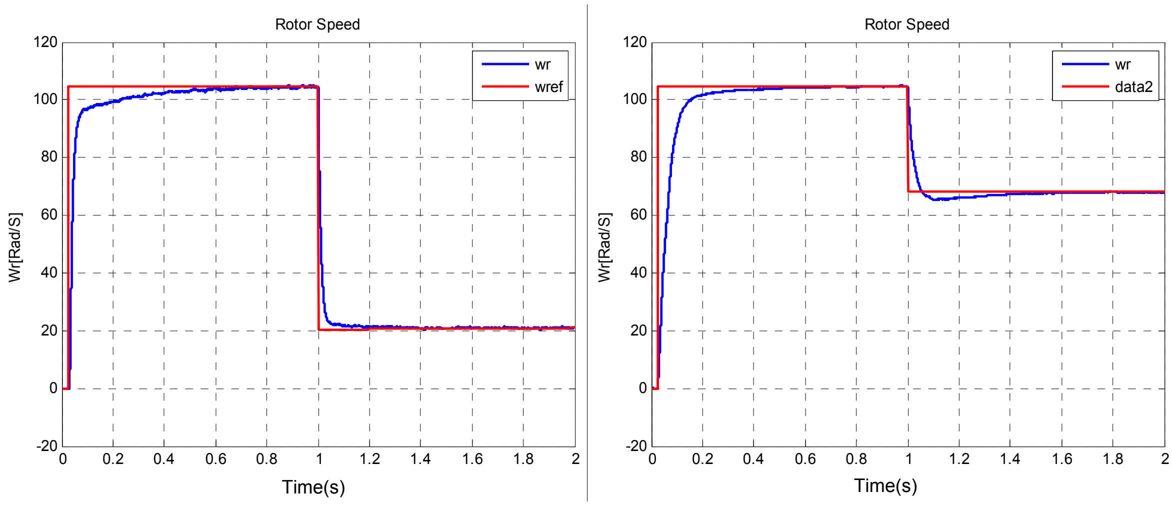

Fig. 14. Rotor speed. (a) Conventional DTC two level VSI; (b) DTCNF for dual two level VSI

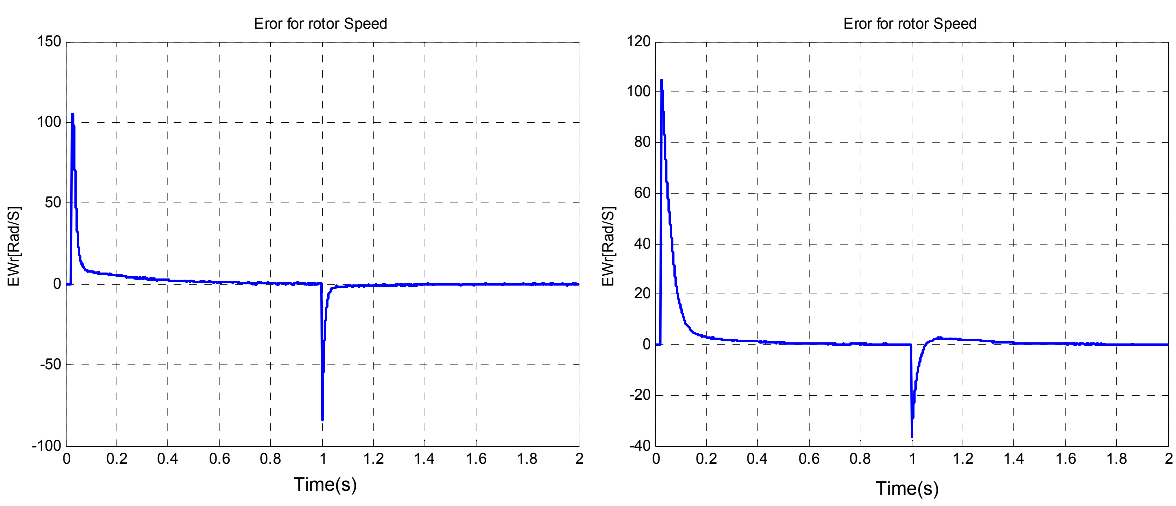

Fig. 15. Error for rotor speed. (a) Conventional DTC two level VSI; (b) DTCNF for dual two level VSI

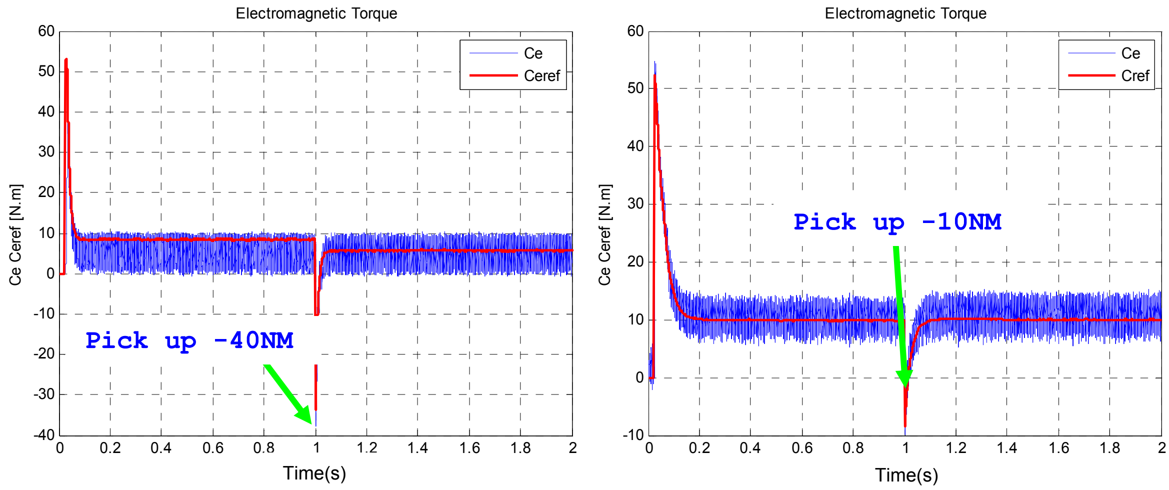

Fig. 16. Electromagnetic torque. (a) Conventional DTC two level VSI; (b) DTCNF for dual two level VSI

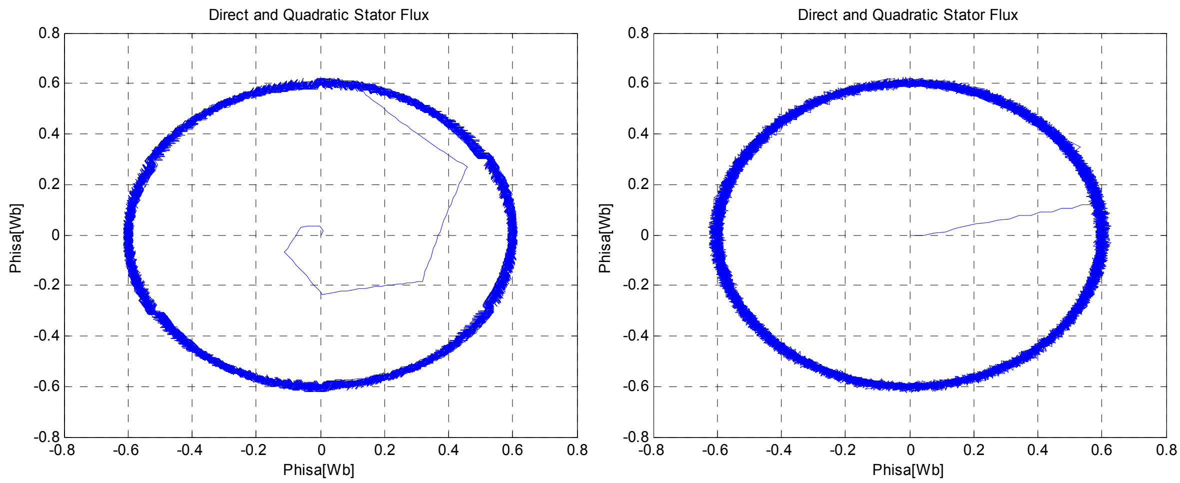

Fig. 17. Stator flux space vector (a) Conventional DTC two level VSI; (b) DTCNF for dual two level VSI

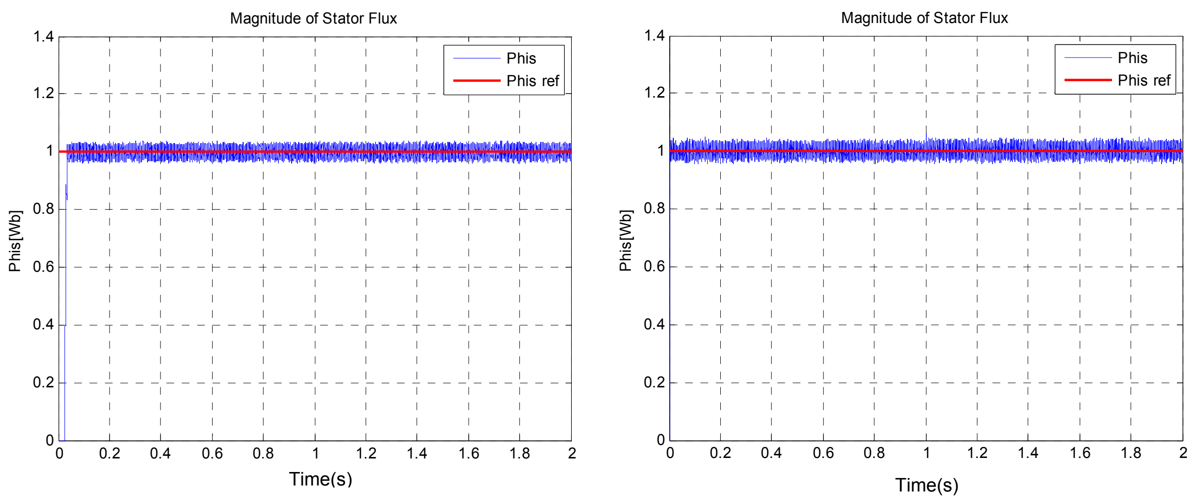

Fig. 18. Magnitude of Stator flux (a) Conventional DTC two level VSI; (b) DTCNF for dual two level VSI

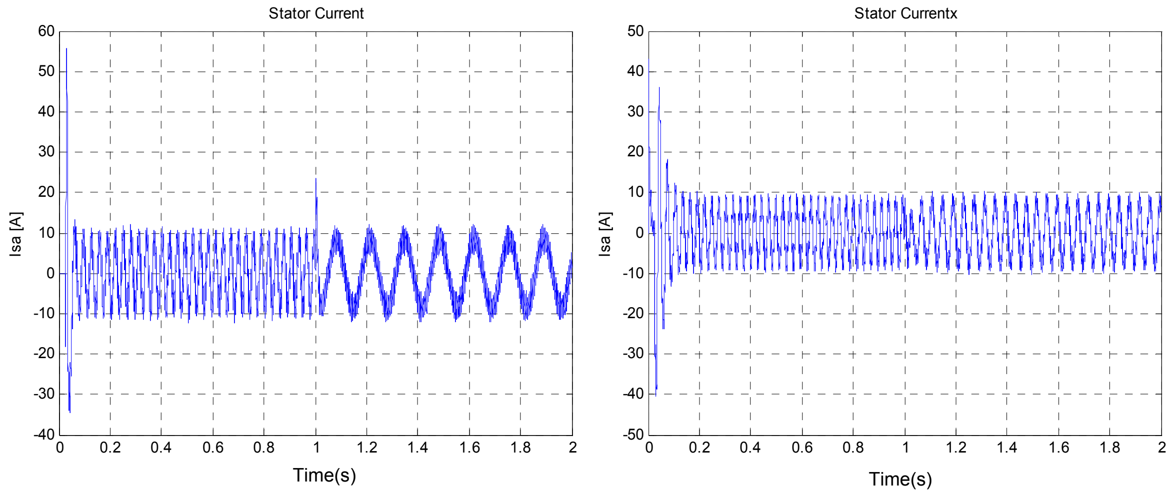

Fig. 19. Stator current (a) Conventional DTC two level VSI; (b) DTCNF for dual two level VSI

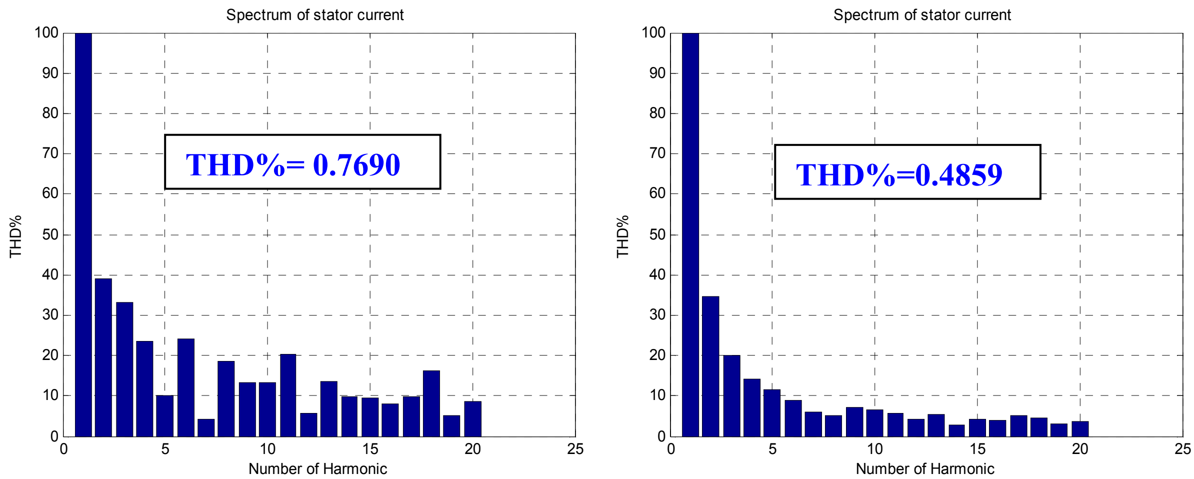

Fig. 20. Spectrum of stator current (a) Conventional DTC two level VSI; (b) DTCNF for dual two level VSI

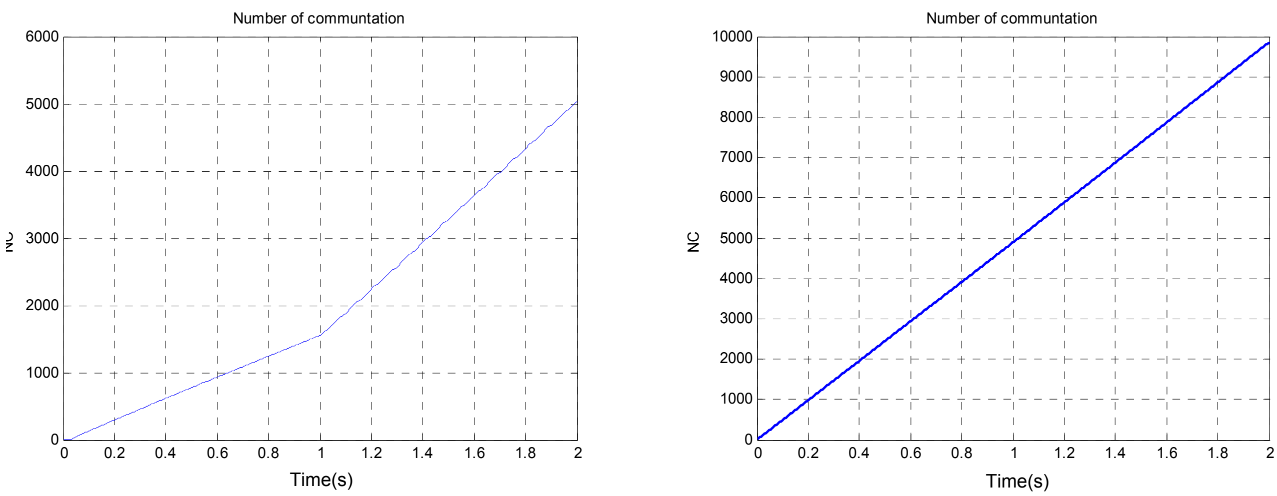

Fig.21. number of switching commutation (a) Conventional DTC two level VSI; (b) DTCNF for dual two level VSI

5. CONCLUSION

In this paper, a new direct torque control strategy for induction machines has been proposed to achieve both constant switching-frequency regulation and reduced torque and stator flux ripple control.The simulation results verify that the application of an NF approach for direct torque control of a SVM for dual two level inverter fed induction motor improves the torque control characteristic without deteriorating the flux control capability, and show that the DTNFC for dual two level inverter scheme has the following features:

- No flux droppings caused by sector flux changes and constant switching frequency
- Torque and current harmonics are reduced;
- No problems during low-speed operation.

REFERENCES

Baiju M. R., Mohapatra K. K., Kanchan R. S., and Gopakumar K..(2004), A Dual Two-Level Inverter Scheme With Common Mode Voltage Elimination for an Induction Motor Drive, *IEEE Transactions On Power Electronics*, Vol. 19, No. 3.

Blaschke F. (1979),, “The Principle of Field Orientation as Applied to the New Transvektor Closed-Loop Control System for Rotating -Field Machines”. *Siemens Rev.,* 39, 5, pp. 2 17-220.

Casadei, D.; Profumo, F.; Serra, G.; and Tani, A .(2002), FOC and DTC: Two Viable Schemes for Induction Motors Torque Control, *Power electronics, IEEE Transactions* on volume 17, issue 5, Sep 2002 page(s): 779 – 787.

Chady E.M., Mendes.E, and Razek.A, . (2002), Decoupled Direct Control for PWM Inverter-Fed Induction Motor Drives, *IEEE Transactions on Industry Applications,* Vol. 38, No. 5, Sept/Oct 2002

Cristian. L, Boldea.I, and Blaabjerg.F.(2000), A Modified Direct Torque Control for Induction Motor Sensorless Drive, *IEEE Transactions on Industry Applications*, Vol. 36, No. 1.

Depenbrock.M., .(1988),Direct Self-Control (DSC) of inverter-fed induction Machine, *IEEE Transactions on Power Electronics*, Vol. 13, N°. 2.

Filipek.P.(2001), Neuro-Fuzzy Control of Inverter-Fed Induction Motor Drives, *Ph.D . Lublin University of Technology Poland.*

Gama.V, Romero. D.(2004), Improvement of an Induction Motor Drive-Based Direct Torque Control Strategy Using a Neuro-Fuzzy Controller, *Electrical and Electronics Engineering, 1st International Conference* ; pp(s): 439- 444

Grandi, G. Rossi, C. Lega, A. Casadei, D.(2006), Power balancing of a multilevel converter with two insulated supplies for three-phase six-wire loads, *Power Electronics and Applications, European Conference* .

Halasz,S.H, Zakharov.B.T. .(2000),A Two-phase modulation technique for three-level inverter-fed AC drives. *Industrial Electronics, IEEE Transactions* .

Hu, X.; Zhang, L.(1999), A predictive direct torque control scheme for a three-level VSI-fedinduction motor drive ‘’ Electrical Machines and Drives, *Ninth International Conference* on Conf. Publ. No. 468 Volume , pp(s):334 – 338

Hung.P.P, Hoang.L.H. (2003), Direct torque control with switching frequency limitation for three-level inverter-fed induction motors ‘’ *Industrial Electronics Society,IECON '03. The 29th Annual Conference of the IEEE.*

Jabeur.S, C.B.; Fnaiech,F.(2005), DTFC and DTNFC: Two Intelligent Techniques for Induction Motors Torque Control, *Industrial Electronics. Proceedings of the IEEE International Symposium*,Issue , June 20-23, pp: 131 – 138.

Kazmierkowski.M.P., .(2000) ,Control Strategies for PWM Rectifier/Inverter-Fed Induction Motor, *Industrial Electronics. ISIE. Proceedings of the IEEE International Symposium* on. Issue , pp(s):15 -23 vol.1

Kyo.B.L,Joong.H.S, Ick.C, and Ji-Yoon.Y.(2002), Torque Ripple Reduction in DTC of Induction Motor Driven by Three-Level Inverter with Low Switching Frequency, *IEEE on Power Electronics*, Vol. 17, N°. 2.

Lin.C, Kang.L.F And Zi-Fan.H.(2005), A Scheme of Fuzzy Direct Torque Control for Induction Machine, *Proceedings of the Fourth International Conference on Machine Learning and Cybernetics, Guangzhou*,

Miloudi.A, Eid A. al-radadi, A. Draou.D. (2007), A Variable Gain PI Controller Used for Speed Control of a Direct Torque Neuro Fuzzy Controlled Induction Machine Drive, *J Elec Engin*, Vol.15, No.1 2007. Tubitak.

P.Ponce, Monroy.A. Sampe.F, Paz.M, Fernández.R, Pontecorvo.F.(2006),Using Space Vector Modulation in a DTC Scheme, *Científica México*.Vol.10 Núm. 1 pp(s):15-21

Pedro.P.C. Jaime.J. R.R. (2000), Induction Motor Space Vector Control Using Adaptive Reference Model Direct and Indirect Methods, *Industrial Electronics, Proceedings IEEE International Symposium*, Issue , Page(s):300 - 305 vol.1

Rodriguez.J,Pontt.J,Silva.C,Kouro.S. And . Mirand H.(2004), A Novel Direct Torque Control Scheme for Induction Machines with Space Vector Modulation, *PESC'04 :IEEE 35th annual power electronics specialists conference, Aachen, Germany*, 20-25, pp. 1392-1397,

Rong.J.W, Jeng-D.L and Kuo-Min.L. (2005), Robust Decoupled Control of Direct Field-Oriented Induction Motor Drive, *Industrial Electronics, IEEE Transactions* on Vol.52, Issue3, pp:837 – 854

Scott.W, Matthew.W.D, and Barry W. W. (1997), Modeling and Simulation of Induction Machine Vector Control with Rotor Resistance Identification;

Somasekhar.V.T. ;Gopakumar.K.; Baud M. R. ; Mohapatra K. K. ; Umanand L.(2002), A PWM scheme for a 3-level inverter cascading two 2-level inverters, *Journal of the Indian Institute of Sciences* vol. 82, no1, pp. 23-36.

Takahashi, I. - Noguchi, T. (1986), A new quick-response and high-efficiency control strategy of induction motor, *IEEE Transactions*. On IA, Vol.22, N°.5, pp.820-827.

Takahashi.I., Toshihiko.N.(1997),Take a Look Back Upon the Past Decade of Direct Torque Control'', IECON. 23rd International Conference on Vol 2, Issue, 9 pp(s): 546 – 551

Tang, L.; Zhong, L.; Rahman, A.F.; Hu, Y.(2002), An investigation of a modified direct torque control strategy for flux and torque ripple reduction for induction machine drive system with fixed switching frequency, *Industry Applications Conference, 37th IAS Annual Meeting*, pp: 837 - 844 vol.2

Xavier.D.T.G, Antoni.A, Marcel.G.J, and Phil A. Witting, Vicenç M. Sala and Jose Luis Romeral .(2005), New DTC Control Scheme for Induction Motors fed with a Three-level Inverter", *Journal Automatika* 2005. ISSN 0005–1144, ATKAAF 46(1–2), 73–81.

Xuezhi.W; Lipei.H.(2001), Direct torque control of three-level inverter using neural networks as switching vector selector, *Industry Applications Conference,IEEE* Volume 2, 30 pp:939 - 944 vol.2.