High Performance of Induction Motor Based on New DTC-SVM

[1]Dr. Raaed Faleh Hassan, [2]Mahmood Sawadi Rahi
[1,2]College of electrical engineering technology, Iraq
drraaed1@gmail.com , mahmood.swadi@gmail.com

Abstract-Direct torque control (DTC) is one of the most important control techniques used in induction motor drives to obtain fast response torque control and high speed response. However, the classical DTC-SVM has disadvantage through transient, steady state and low speed. One of the most important defects is a high torque ripple and harmonics in stator current. In this paper, the proposed control system for solve these problems by utilizing space vector modulation upon the reference torque and flux (DTC-SVM). In this paper, the proposed technique, Proportional-Integral flux and Proportional-Integral torque controlling were designed to investigation calculated flux and torque with fast response and there is no steady state error. In addition, design Proportional-Integral flux and Proportional-Integral torque controller are utilized to improve voltage in d-q axis which feeding SVM. The DTC-SVM is pulse switching of the three-phase three-level neutral point clamped diode inverter (NPC) which fed the induction motor. This paper confirms using the Space Vector Pulse Width Modulation (SVPWM) technique for derivation of switching states. The proposed control is implemented using MATLAB/Simulink software package. Resulting tests which obtain from the new technique is better than the classical technique**.**

Index Terms— Direct torque control, space vector pulse width modulation (SVPWM), three-level inverter neutral point clamped (NPC), PI controller.

1. Introduction

The induction motor is the motor drive most widely used in the industry. With a development of technological advances in the field of microcontroller microcomputers, and simplify operations and control theory performance of induction motors so it can replace the role of the DC motor as electric drives. The induction motors have Simple construction, low cost and easy maintenance, it makes most popular than other electrical motors. While a lack of induction motor which is of its nature that is not linear, the pace setting techniques relatively difficult and requiring a high starting current about six to eight times the nominal current of the motor. Induction motor speed settings can be done in various ways such as control voltage/frequency (v/f) or known scalar control. The principle is to force the motor has a relationship constant between voltage and frequency. As well as vector control the set directly the current stator motor. Method vector control is today continuing to be developed is the method of the Direct Torque Control (DTC). That is a technique control which leads to a torque value settings that changed as needed load. The fundamental difference between vector control technique with DTC is on control vector input system is the speed and flow of stator. While in the DTC system is the input flux and torque [1-4]. However, classical DTC-SVM drive has ripples in stator currents, torque and flux during the transient and steady state [4-8]. The continuously these problems in the steady state effect on Speed estimation. It also leads to high acoustic noise and harmonic losses. For minimizing these problems using DTC-SVM depended on two PI speed controllers to estimation reference torque and flux. In addition, designing PI flux, PI torque controller to controlling amplitude stator voltage. In this method, the torque, flux and stator currents are very low ripples and high response for variation of loads as compared with classical DTC-SVM. The DTC-SVM with three phase three-level neutral point clamped inverter which fed induction motor is investigated. The proposed control system is described obviously.

2. Proposed method

The proposed control system DTC-SVM dependent on stator flux angle and amplitude stator voltage. The calculation of reference torque and flux based on design two PI speed controllers. In DTC-SVM design Proportional-Integral torque, Proportional-Integral flux for controlling in amplitude stator voltage. While controlling the flux angle by slip angular frequency and rotor angular frequency. DTC SVM system of a simple block diagram is shown in Figure 1. Its system consists of five main sections. These sections; stator flux and torque estimator, two PI speed controllers, PI torque, PI flux controller, PI controller for slip angular frequency and transformation from Cartesian to polar to estimation the magnitude of stator voltage, while transformation from polar to Cartesian to estimation stator voltages in d-q axis at next sampling time. The stator voltages in dq axis are transformed from the d-q axis to α-β axis by parks transformation to fed space vector modulation (SVM). The SVM is applied to three level NPC which feeding induction motor drive.

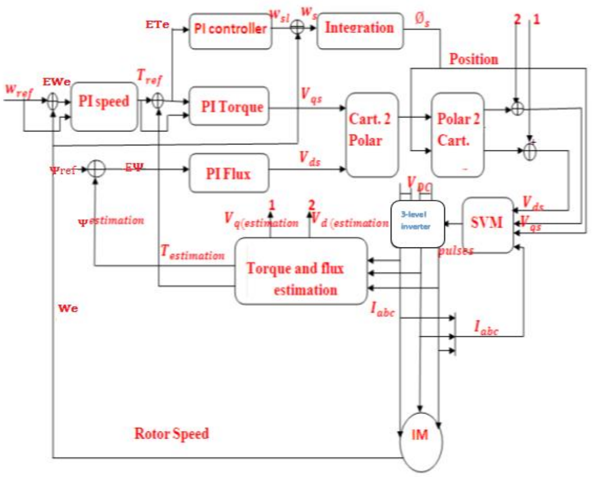

Fig.1. scheme proposed of DTC-SVM

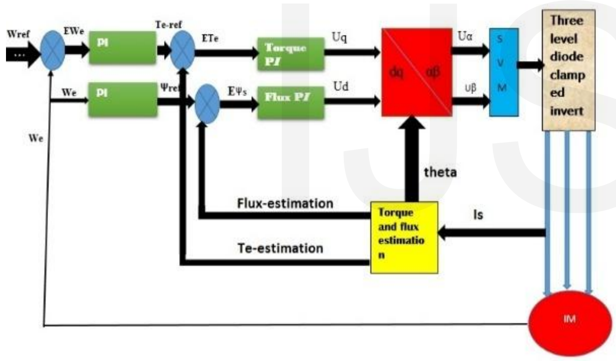

Fig.2 Scheme of classical DTC SVM

In the figure (1) the speed calculation is compare with absolute value of the reference speed and the error applied to the Proportional-Integral speed controlled to obtain reference flux linkage as shown in fig (3)

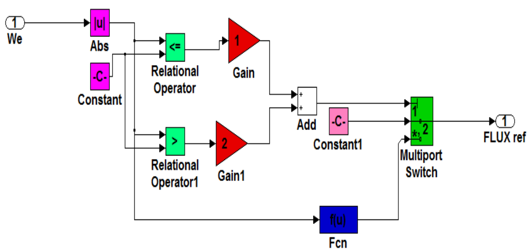

Fig.3.PI flux controller

The error between reference flux and actual stator flux linkage is applied to PI flux controller to produce stator voltage in dq axis as follow:

$$U_{sd} = Kp[E\Psi s + \frac{1}{Ti}\int E\Psi s \ dt] \quad (1)$$

The flux error is equal:

$$E\Psi s = \Psi s_{ref} - \Psi s_{cal}. \quad (2)$$

Where U_{sd}, EΨs is stator voltage and error flux, respectively.

The error between speed calculated and reference speed is applied to PI speed controller to obtain reference electromagnetic torque as follow:

$$T_{ref} = Kp[E\omega + \frac{1}{Ti}\int E\omega \ dt] \quad (3)$$

The speed error is equal:

$$E\omega = \omega e^{*} - \omega e_{cal} \quad (4)$$

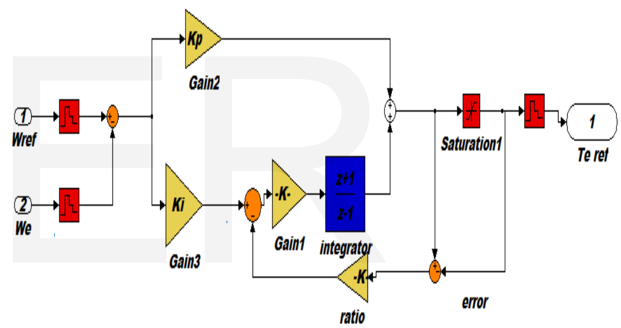

Fig.4.PI flux controller

Then the error from compared actual torque and reference torque of induction motor is feeding to Proportional-Integral torque controlled to produce stator voltage in dq axis as follow:

$$U_{sq} = Kp[ETe + \frac{1}{Ti}\int ETe \ dt] \quad (5)$$

The torque error is equal;

$$ETe = Te_{ref} - Te_{cal} \quad (6)$$

The stator voltage obtained by equation (1, 5) are transformed into amplitude voltage based on transformation Cartesian to polar. Output can be expressed as:

$$|U| = \sqrt{U_q^{\,2} + U_d^{\,2}} \quad (7)$$

Also, the error from comparative reference torque with an actual torque applied to PI slip angular frequency (W_{sl}) to estimate the value of (W_{sl}) required to regulate stator flux angle can be expressed as:

$$W_{sl} = Kp[ETe + \frac{1}{Ti}\int ETe \ dt] \quad (8)$$

Then the stator angular frequency equal

$$W_s = W_e + W_{sl} \quad (9)$$

Where, ws, we, wsl are rotor, stator and slip angular frequency, respectively.

Then obtain the stator flux angle as bellow:

$$\theta_s = \int W_s \ dt \quad (10)$$

based on the direction or position of the amplitude stator and stator flux angle it's switching selected to produce the appropriate voltage vectors to control on torque and flux. Then applying equations (7, 10) on polar to Cartesian transformation on both stator flux angle and amplitude stator voltage to obtain the stator voltage in d-q axis which can be expressed as:

$$U_{sd} = |U|\cos\theta_s \quad (11)$$

$$U_{sq} = |U|\sin\theta_s \quad (12)$$

Then the error of the votage can be expressed as:

$$EU_d = U_d - U_{d_{cal}} \quad (13)$$

$$EU_q = U_q - U_{q_{cal}} \quad (14)$$

The stator voltages in d-q axis are computed to make the stator voltage error is zero at next sample period. The following stator voltages can be expressed as:

$$U_{sd}(i+1) = EU_d + R_s.I_{sd}(i) \quad (15)$$

$$U_{sq}(i+1) = EU_q + R_s.I_{sq}(i) \quad (16)$$

The stator voltage obtain in dq axis by the above equation are converted to two phase system in alpha (α), beta (β) axis winch fed SVM using transformation can be written in matrix form:

$$\begin{bmatrix} U_\alpha \\ U_\beta \end{bmatrix} = \begin{bmatrix} \cos(wt) & -\sin(wt) \\ \sin(wt) & \cos(wt) \end{bmatrix} \begin{bmatrix} U_{sd} \\ U_{sq} \end{bmatrix} \quad (17)$$

3. Modelling OF DTC-SVM OF INDUCTION MOTOR.

reference frame theory is most widely used in mathematical modeling of DCT-SVM of induction motor to convert from three-phase quantities (abc) become two-phase quantities (dq) is required in order to facilitate the analysis in the setting of position or speed and also in order 3-phase induction motor has a behavior resembles the DC motor and thus more easily controlled. Convert from three phase system to dq axis system by park's transformation can be written in matrix form:

$$\begin{bmatrix} V_d \\ V_q \end{bmatrix} = \frac{2}{3} \begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} V_{an} \\ V_{bn} \\ V_{cn} \end{bmatrix} \quad (18)$$

Become equations induction motor after the conversion of the three-phase system to two-phase system as follows:

3.1 voltage equation in dq axis

$$U_{d1} = R_1.I_{d1} - \omega_1.\Psi_{q1} \quad (19)$$

$$U_{q1} = R_1.I_{q1} + \omega_1.\Psi_{d1} \quad (20)$$

$$U'_{d2} = R'_2.I'_{d2} + (\omega - \omega 1)\Psi'_{q2} \quad (21)$$

$$U'_{q2} = R'_2.I'_{q2} - (\omega - \omega 1)\Psi'_{d2} \quad (22)$$

Where the flux linkages:

$$\begin{bmatrix} \Psi_{d1} \\ \Psi_{q1} \end{bmatrix} = L_1.\begin{bmatrix} I_{d1} \\ I_{q1} \end{bmatrix} + L_h \begin{bmatrix} I'_{d2} \\ I'_{q2} \end{bmatrix} \quad (23)$$

$$\begin{bmatrix} \Psi'_{d2} \\ \Psi'_{q2} \end{bmatrix} = L'_2.\begin{bmatrix} I'_{d2} \\ I'_{q2} \end{bmatrix} + L_h \begin{bmatrix} I_{d1} \\ I_{q1} \end{bmatrix} \quad (24)$$

Where, Ud_1, Uq1, $U'd_2$, U'_{q2} is stator and rotor voltages in dq axis respectively. Then, Id1.Iq_1, $I'd_2$, $I'q_2$ is stator and rotor currents in dq axis respectively. The resistance and inductance with mutual inductance of the stator and rotor are denoted as R_1, R'_2, L_1, L'_2, Lh respectively. The stator flux linkages and rotor flux linkage are denoted as Ψ_{d1}, Ψ_{q1}, Ψ'_{d2}, Ψ'_{q2} respectively. While ω is angular frequency.

3.2 Stator flux linkages and electromagnetic torque calculation

Can rewrite equations of stator flux from the above voltage equations as follow:

$$\frac{\Psi_{d1}}{dt} = U_{q1} - R_1.I_{q1} \quad (25)$$

$$\frac{\Psi_{q1}}{dt} = U_{d1} - R_1.I_{d1} \quad (26)$$

The phase angle and magnitude of the stator flux (I_s) in dq axis can be expressed as

$$\Psi_s = \Psi_{d1} + j\Psi_{q1} \quad (27)$$

$$|V_{ref}| = \sqrt{\Psi_{d1}^2 + \Psi_{q1}^2} \quad (28)$$

$$\theta = \tan^{-1}\frac{\Psi_{q1}}{\Psi_{d1}} \quad (29)$$

The electromagnetic torque of the induction motor is obtained from flux linkages in stator and stator currents in dq axis. The flux linkages in the stator are obtaining from inductance and stator current in dq axis.

$$T_e = {}^3/_4 P(\Psi_{d1}.I_{q1} - \Psi_{q1}.I_{d1}) \quad (30)$$

The electromagnetic torque of the induction motor in terms of rotor speed can be expressed as follow:

$$T = T_e - T_w = \frac{J}{P}.\frac{d\omega}{dt} + B\ \omega_r \qquad (31)$$

Where,
TL is the load torque,
Te is the electromagnetic torque

P is the number of poles,

ωr is the rotor speed,

B is the damping coefficient

J is the moment inertia,

4. DTC-SVM with Three-Level Inverter.

In this scheme, the proposed control system DTC-SVM is shown in Figure (1) used three phase three-level NPC inverter instead of two level inverters. the three-level inverter used in high-power medium voltage applications due to the three-level inverter has more advantage over standard two-level inverter, for example, more level voltage in output side, reduce voltage on the power switches, less dv/dt, less basic mode voltage and less total harmonics distortion in output current and voltage [9-12]. for generate gate pulses applied on switching of the three-level inverter using space vector modulation due to has several advantages, for example, identifies each switching sector in (α, β) space and directly uses the control variable come by the control system. The SVPWM is suitable for digital signal processing implementation and optimizes switching sequences. Considering the three-level inverter shown in Fig.5, shows that each switch has three possible positions. The map of synthesizable vectors significantly expands, as shown in Fig. 6. At the end of each vector are indicated the positions of the switches synthesize column. Shown in the same figure, some vectors are obtained with more than one combination of states of the switches. Precisely all vectors make the internal hexagon have two possible combinations, while the null vector has three.

This redundancy feature can be summarized 19 different vectors 3^3= 27 possible combinations.

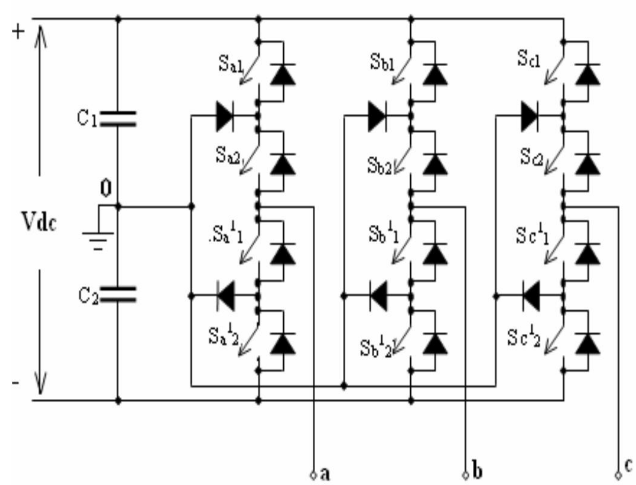

Figure.5 .3-level NPC inverter

In general, for N-level converter, there are N^3 different ways to combine column voltages, while the number of synthesizable vectors is given by the following expression: $L = 1 + 6\sum_{i-1}^{N-1} i$

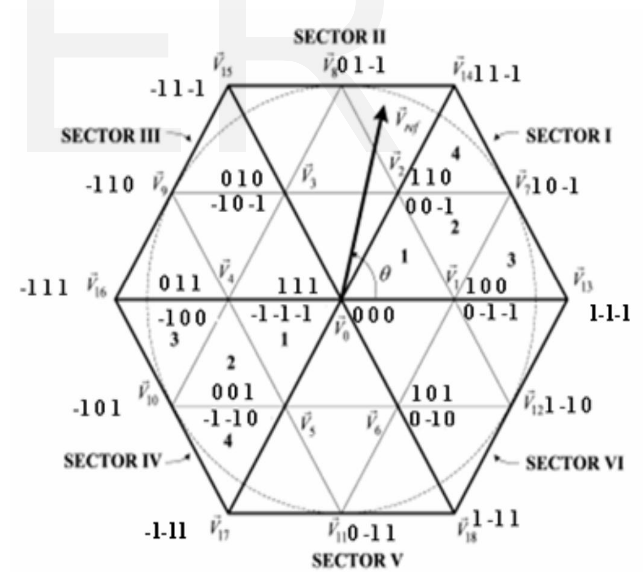

Figure. 6. Vector map for three levels NPC

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5. Simulation

The proposed DTC technique based on SVM with two PI speed controllers to calculated reference torque, flux, and design PI torque controller, PI flux controller for controlling the amplitude stator voltage. This proposed method was implemented and simulated using MATLAB/Simulink software package. The Simulink model of the overall proposed control method is shown in fig (7).

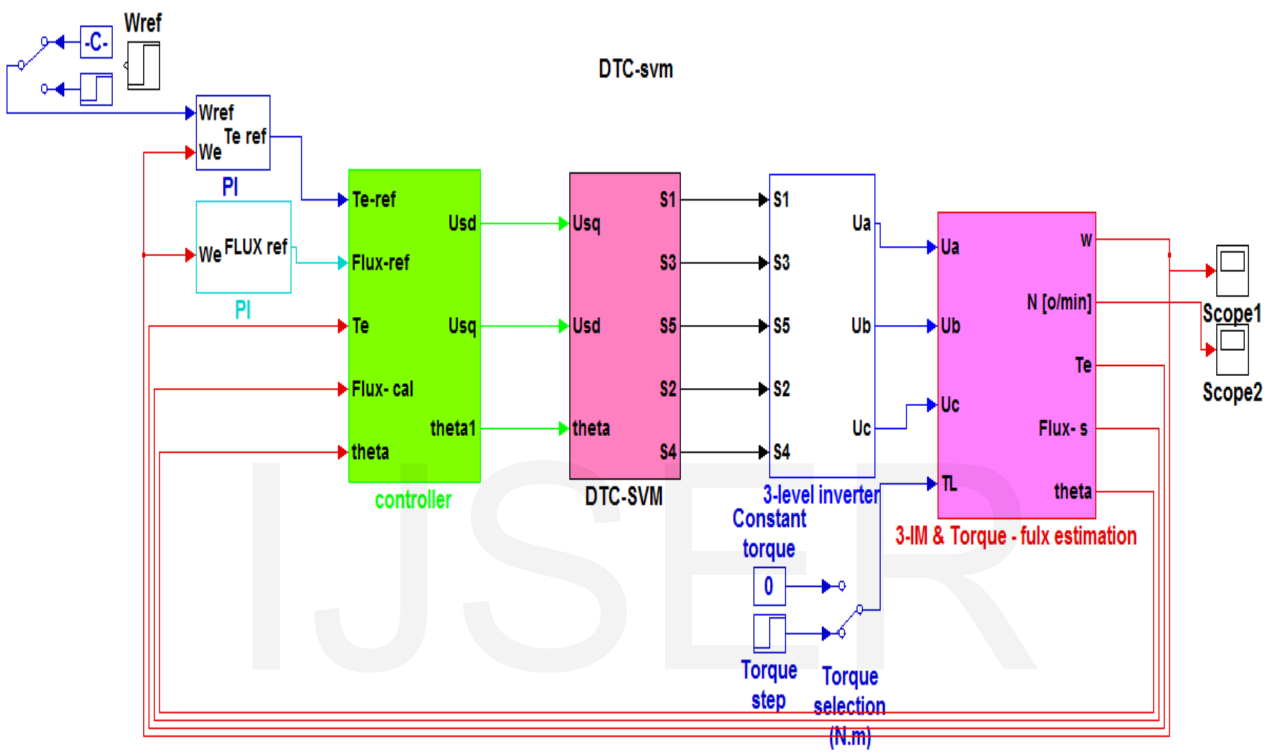

Fig.7. overall proposed DTC-SVM of induction motor

6. Results and Discussions

Implement the above Simulink model of the DTC-SVM in MATLAB/Simulink. The results obtained from the proposed method describes the performance of the induction motor at rating 750W/380V. When the speed reference varied from 147 rad/sec to 118rad/sec with load torque 3 N.m at duration 0.5. The performance of voltage, current, speed, torque, flux and comparison between speed estimator and reference speed also torque estimator and reference torque as shown in figs (6. A.1-6. A.4).in the proposed control method, fig.6. A.1 shows the stator currents are higher stability in the steady state and very low ripple with compared classical DTC-SVM. Figure 6.A.2 shows fast response with good tracking by reference speed with estimation speed and there is no steady state error as compared with classical DTC-SVM. While fig 6.A.3 shows high-performance and response with very low ripple by reference torque with estimation torque as compared with classical DTC-SVM. In fig 6.A.4 the Lucas of stator flux is improved with very low ripple as compared with classical DTC-SVM.

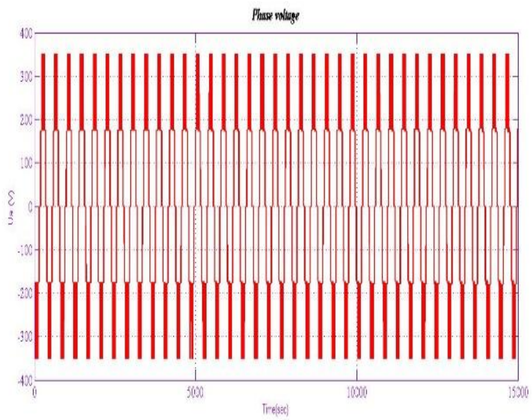

Fig.6.1. output phase voltage of inverter for proposed DTC-SVM

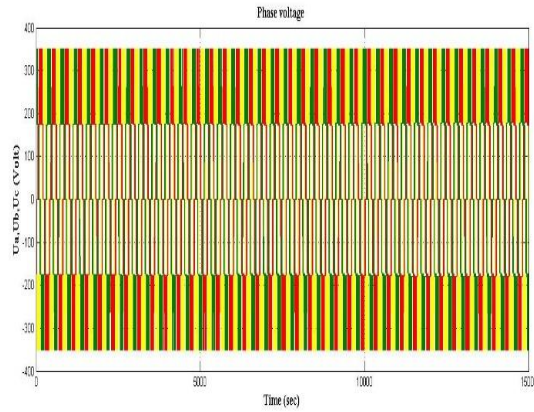

Fig.6.2. three phase output voltage of inverter for proposed DTC-SVM

A) Results of proposed DTC-SVM

B) Results of classical DTC-SVM

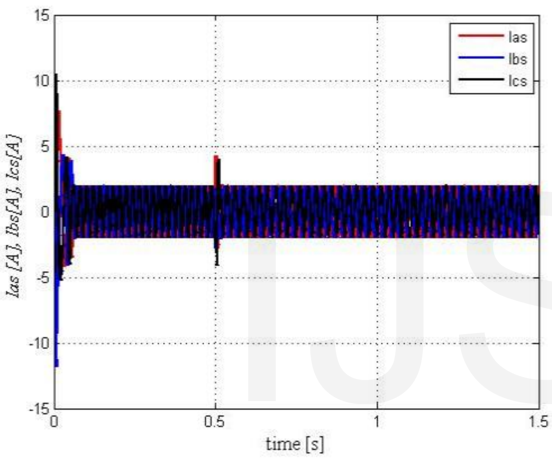

Fig.6.A.1. 3-φ stator currents

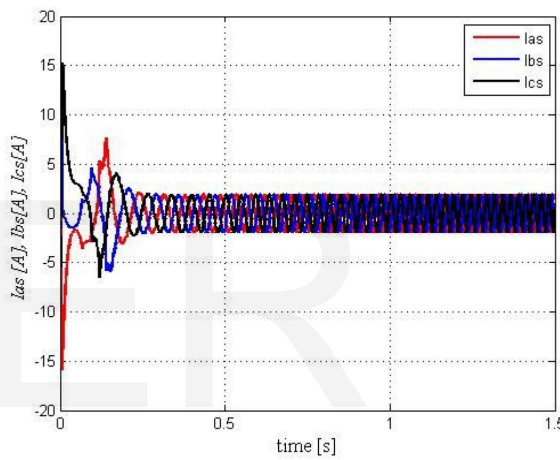

Fig.6. B. 1. 3-φ stator currents

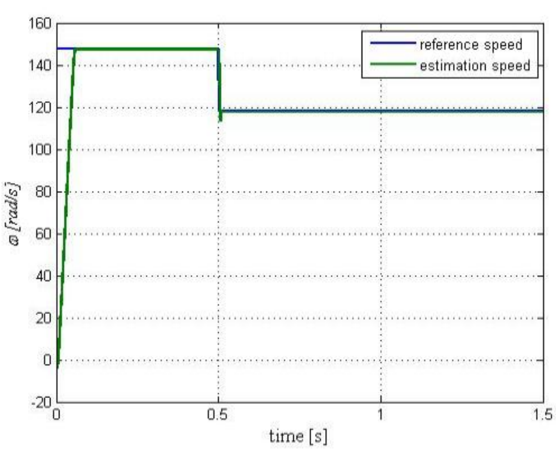

Fig.6. A. 2. Speed response

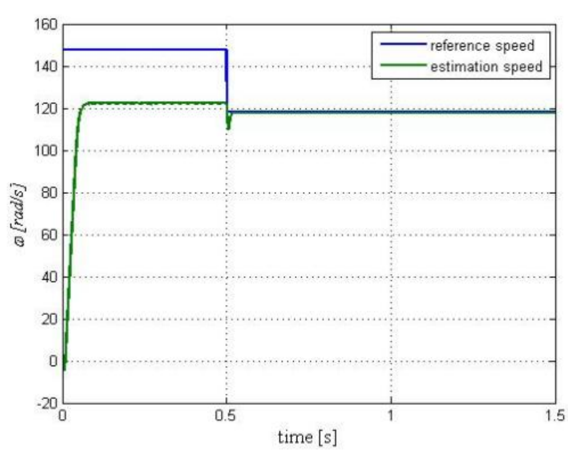

Fig.6. B. 2. Speed response

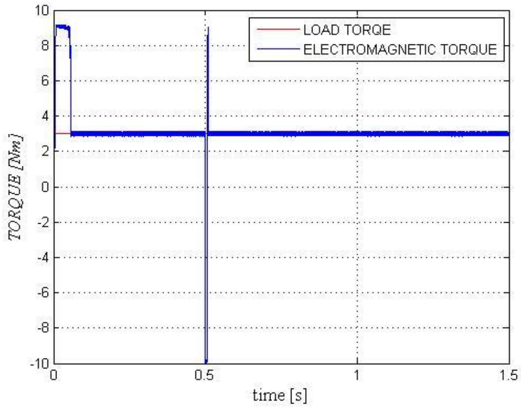

Fig 6.A.3. Performance of torque

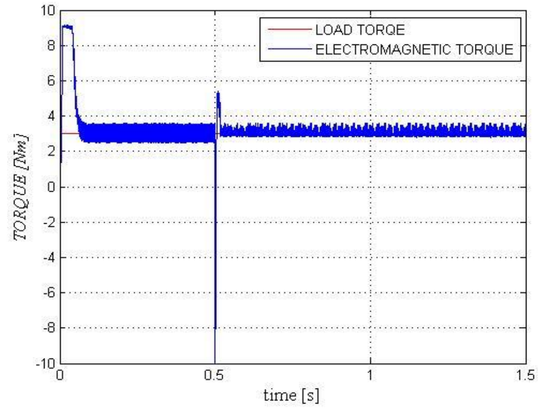

Fig 6.B.3. Performance of torque

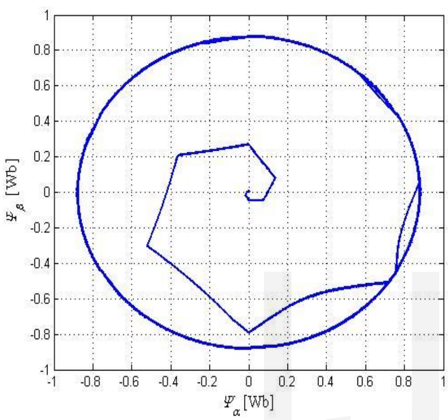

Fig 6. A.4. Locus of the Stator Flux.

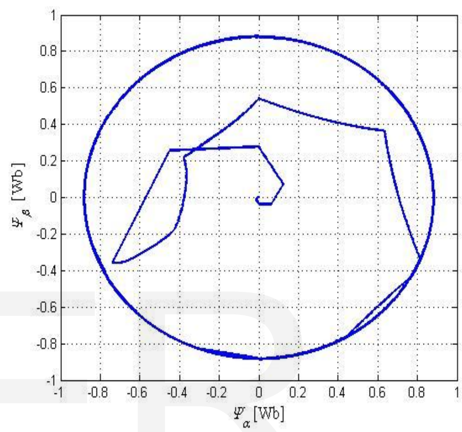

Fig 6. B.4. Locus of the Stator Flux.

7. Conclusion

This paper describes the proposed system of DTC depending on space vector modulation (SVM) that generate pulses to the power switching of the three-level NPC inverter which fed induction motor drive. In this method, optimize reference torque and flux using two PI speed controllers. The stator voltage in dq axis feeding space vector modulation is higher stability and no fluctuation because it depended on output stator voltage from two PI torque and flux controller. Based on the direction or position of the stator flux, it's switching selected to produce the appropriate voltage vectors to control both torque and flux. The new DTC-SVM shows a high dynamic performance of Flux and torque with reduction ripples when compared with classical DTC-SVM and other methods such as vector control.

APPENDIX

Table I: parameters of induction motor

Nominal Power	750 W
Nominal Phase Voltage	220 V
Nominal Frequency	50 Hz
Nominal Speed	1410 rpm
Stator Resistance	11.6 ohm
Rotor Resistance	10.4 ohm
Stator Inductivity	0.579 ohm
Rotor Inductivity	0.579 ohm
Mutual Inductivity	0.557 ohm
Inertia	0.002 kgm^2
Number of Poles	2

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