DIRECT-AXIS CALCULATION OF DIRECT TORQUE CONTROL OF INDUCTION MOTOR USING SVM

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ABSTRACT

In this research article author wants to investigate a direct torque control for induction motor. There are drawbacks of DTC method for induction motor. These problems include the inadequacy of electromagnetic torque and the large estimated error of magnetic flux while motor operated in low speed, and generating torque ripples. This critique provided filter feedback, magnetic flux compensation and fixed flux variation DTC method to reduce the estimated error of magnetic flux; furthermore, it provided a strategy of effectively producing the output electromagnetic torque while the motor operated in low speed. Motor could be operated more smoothly by reducing current harmonic waves and power consumption. It could effectively decrease speed error and improve the efficiency of driver. A method is provided to modify the magnetic flux estimator of the direct torque control and improve the inadequacy of electromagnetic torque while motor operated in low speed. It is because that the rotors flux changes slowly while motor operated in low speed. If the stator flux is still operated in the fixed flux, the stator flux will not be able to control effectively which may decrease the output electromagnetic torque and increase in the speed error. This article provides a method to raise the stator flux which makes it effectively produce electromagnetic torque in the low speed and reduces the speed error. Then, applying the DTC for the motor operation is to select a vector from the list of voltage (V_k) vector table. This traditional method is not able to generate a smooth

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sine wave voltage. Thus it produces torque ripples during the process of switching over between voltage vectors. Torque ripples cause high noise and oscillation. Then it is difficult to apply in the high-accuracy control. This paper provides fixed flux variation DTC method which uses the space vector modulation (SVM) to compose of the voltage vectors. It effectively reduces the torque ripples during the motor operation.Finally MATLAB simulation software is used to show the possibility of control system.Then simulation results verifies the feasibility and optimality of the new-type direct torque control for induction motor drive system.

Keywords: Direct Torque Control, Induction Motor, Space Vector Modulation.

1. INTRODUCTION

At the time of origin of Electrical Motors from 1820 onwards, when Hans Christian Oersted discovered the magnetic effect of an electric current. Before the introduction of integrated circuits and high switching frequency semiconductor devices, variable speed actuators and controllers were predominated by DC motors.[22,19,8] Now a days, using modern high and fast switching frequency power converters controlled by power electronic devices, the frequency, phase and magnitude of the input to an AC motor can be changed and hence the motor's speed and torque can be controlled. AC motors combined with their drives have replaced DC motors in industrial applications due to their lower cost, better reliability, lower weight, and reduced maintenance requirement. Squirrel cage Induction motors are frequently used than all the rest of the electric motors combine together as they have advantages of AC motors and they are easy to build [1].

The main advantage is that induction motors is air-gap between stationary and rotating parts of the motor and flux linkage takes place through air-gap. Therefore, they do not need any mechanical commutator (brushes), therefore they are maintenance free motors.[17,16,22]
With the enhanced semiconductor and power converter technology during past few decades, the desired conditions for developing a suitable induction drive are present. These conditions can be divided mainly in two groups:

- The decreasing cost and improved performance in power electronic switching devices.[2]

- The possibility of implementing complex algorithms in the new microprocessors.

However, one predefined role had to be designed, which was the development and establishment of suitable methods to control the speed of induction motors, because in contrast to its mechanical simplicity their complexity regarding their robust structure (multivariable and non-linear) is not a complex matter to be resolved.

Fig.1 shows a block diagram of an AC motor drive system [3]. A single-phase or three-phase AC power supply and an AC/DC converter provide a DC input to an inverter. A micro-controller decides the switching states for the inverter to control the motor's torque or speed. A sensing unit feeds back terminal values such as motor speed, voltage and current to the micro-controller as needed for the closed-loop control of the motor. Controllers used in AC motor drives are generally referred to as vector or field-oriented controllers.

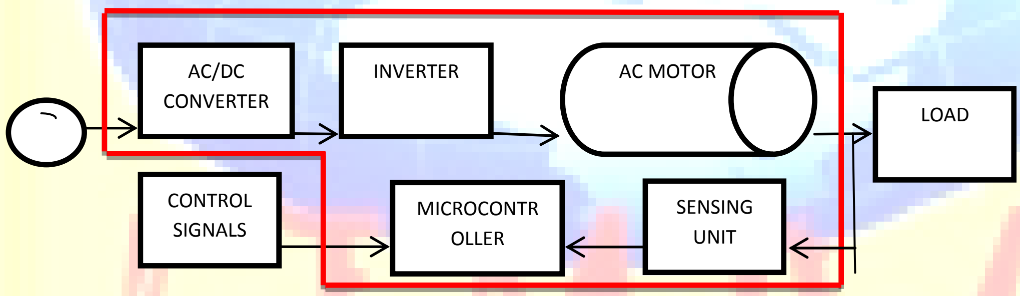


Fig 1. Block diagram for AC motor drive system

2. MOTIVE

The main motive of this paper is to study the direct torque control (DTC) based on Space Vector Modulation (DTC-SVM) applied to induction motor. With DTC-SVM, it is possible to achieve fixed switching frequency and low torque ripple, hence overcoming the major drawbacks of conventional DTC. This paper will simulate and perform analysis on the present DTC-SVM drives using MATLAB/SIMULINK simulation package. It will be proved by means of MATLAB/SIMULINK simulation. Then, the technique of direct torque control based on Space

Vector Modulation will be presented and also the pros and cons of the present DTC-SVM control strategies will be highlighted.

3. INDUCTION MOTOR MODEL AND GENERALITIES

A Static model was insufficient to explain the speed regulation and other interlinked features of induction motor such as flux and torque variant where as dynamic model of the machine subjected to control must be known in order to design vector controlled drives which are rotating vector in respect of time and space. Nevertheless, the model should be suitable for all the important dynamic effects occurring during both steady-state as well as transient operations. Furthermore, it should be suitable for defined changes in the inverter's supply such as voltages or currents including direct flux and voltage vectors [3] [4]. following model obtained by means of either the space vector phasor theory or two-axis theory of electrical machines in which d-axis and q-axis modelling phasor response has been calculated. Despite the compactness and the simplicity of the space phasor theory, both methods are actually close and both methods will be explained. for simplicity, the induction motor considered will have the following assumptions, Symmetrical two-pole, three phase windings. the slotting effects are neglected.[10,9,20] The permeability of the iron parts is infinite taking an ideal condition, the flux density is radial in the air gap and Iron losses are neglected, the stator and the rotor windings are simplified as a single and multi-turn full pitch coil situated on the two sides of the air gap.

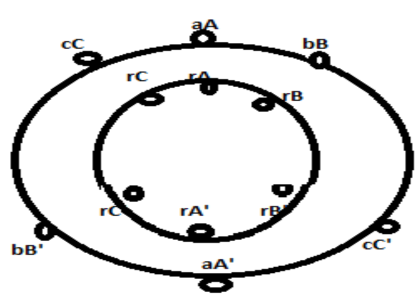


Fig 2. Cross-section of an elementary symmetrical three-phase machine [5]

4. VOLTAGE EQUATIONS

The stator voltages are explain in this section from the motor natural frame, which is the stationary structure reference frame fixed to the stator. Defined value is same as, the rotor voltages will be formulated to the rotating frame fixed to the rotor well denoted by equivalent circuit of 3-phase Induction machine. In the stationary equivalent circuit structure reference frame, the equations can be expressed as follows:

$$V_{sA} = R_s i_{sA}(t) + \frac{d\varphi_{sA}(t)}{dt} \quad (1)$$

$$V_{sB} = R_s i_{sB}(t) + \frac{d\varphi_{sB}(t)}{dt} \quad (2)$$

$$V_{sC} = R_s i_{sC}(t) + \frac{d\varphi_{sC}(t)}{dt} \quad (3)$$

Similar expressions can be obtained for the rotor:

$$V_{rA} = R_r i_{rA}(t) + \frac{d\varphi_{rA}(t)}{dt} \quad (4)$$

$$V_{rB} = R_r i_{rB}(t) + \frac{d\varphi_{rB}(t)}{dt} \quad (5)$$

$$V_{rC} = R_r i_{rC}(t) + \frac{d\varphi_{rC}(t)}{dt} \quad (6)$$

The instantaneous stator flux linkage values per phase can be expressed as:

$$\left.\begin{aligned}
\varphi_{sA} &= \overline{L_s l_{sA}} + \overline{M_s l_{sB}} + \overline{M_s l_{sC}} + \overline{M_{sr}}\cos\theta_m\, i_{rA} + \overline{M_{sr}}\cos(\theta_m + 2\pi/3)\, i_{rB} \\
&\quad + \overline{M_{sr}}\cos(\theta_m + 4\pi/3)\, i_{rC} \\
\varphi_{sB} &= \overline{L_s l_{sB}} + \overline{M_s l_{sA}} + \overline{M_s l_{sC}} + \overline{M_{sr}}\cos\theta_m\, i_{rB} + \overline{M_{sr}}\cos(\theta_m + 2\pi/3)\, i_{rC} \\
&\quad + \overline{M_{sr}}\cos(\theta_m + 4\pi/3)\, i_{rA} \\
\varphi_{sC} &= \overline{L_s l_{sC}} + \overline{M_s l_{sA}} + \overline{M_s l_{sB}} + \overline{M_{sr}}\cos\theta_m\, i_{rC} + \overline{M_{sr}}\cos(\theta_m + 2\pi/3)\, i_{rA} \\
&\quad + \overline{M_{sr}}\cos(\theta_m + 4\pi/3)\, i_{rB}
\end{aligned}\right\} \quad (7)$$

Similarly' the rotor flux linkages can be explained as follows:

$$\left.\begin{aligned}
\varphi_{rA} &= \overline{L_r l_{rA}} + \overline{M_r l_{rB}} + \overline{M_r l_{rC}} + \overline{M_{rr}}\cos(-\theta_m)\, i_{sA} + \overline{M_{rr}}\cos(-\theta_m + 2\pi/3)\, i_{sB} \\
&\quad + \overline{M_{rr}}\cos(-\theta_m + 4\pi/3)\, i_{sC} \\
\varphi_{rB} &= \overline{L_r l_{rB}} + \overline{M_r l_{rA}} + \overline{M_r l_{rC}} + \overline{M_{rr}}\cos(-\theta_m)\, i_{sB} + \overline{M_{rr}}\cos(-\theta_m + 2\pi/3)\, i_{sC} \\
&\quad + \overline{M_{rr}}\cos(-\theta_m + 4\pi/3)\, i_{sA}
\end{aligned}\right\}$$

(8)

$$\varphi_{rC} = \overline{L_r i_{rC}} + \overline{M_r i_{rA}} + \overline{M_r i_{rB}} + \overline{M_{rr}}\cos(-\theta_m) i_{sC} + \overline{M_{rr}}\cos(-\theta_m + 2\pi/3)\, i_{sA} + \overline{M_{rr}}\cos(-\theta_m + 4\pi/3)\, i_{sB}$$

5. TORQUE CONSTANT

The value of the torque constant can take two different values. These depend on the constant used in the space phasor. Both possibilities are shown in table below.

Table 1. Torque constant values

	Non power invariant		Power invariant	
Torque Constant	3/2		1	
Space Phasor constant	3→2	2→3	3→2	2→3
	2/3	1	$\sqrt{\frac{2}{3}}$	$\sqrt{\frac{2}{3}}$

"3→2" means the change from three axis to either two axis or space phasor notation, and "2→3" either two axis or space phasor notation to three axis.

6. DIRECT TORQUE CONTROL OF INDUCTION MOTORS

a. DTC CONTROLLER

The selection of power electronic module the required stator flux is by means of choosing the most suitable Voltage Source Inverter state. If the resistive voltage drop is neglected for accountability, then the stator voltage imposes directly the stator flux in accordance with the following equations which is suitable voltage vector change with respect to time.

$$\Delta\overline{\psi_s} = \overline{V_s}.\Delta t \qquad (9)$$

Decoupled control of the stator flux matrix equation and torque matrix equation is achieved by acting on the radial and tangential components respectively of the stator flux-linkage space vector in its locus (basically air-gap structure or 360 degree space plane).The two components are directly proportional (R_s=0) to the components of the same voltage space vector in the same directions.[12,14] So imposing of proper voltage vector (as taking PWM Technique of suitably

180 or 120 degree space orientation) is important in direct torque control of induction motor by considering span of 360 space plane. This will obtain by using voltage source inverter.

b.VOLTAGE SOURCE INVERTER

There are many topologies for the voltage source inverter used in DTC control induction drive that give high number of possible output voltage vectors [6], [7] but commonly one is the six step inverter. A six step voltage inverter provides the variable frequency AC voltage input to the induction motor in DTC method. The DC supply to the inverter is provided either by a DC source like a battery, or a rectifier supplied from a three phases (or single phase) AC source. Fig. 4 shows a six step voltage source inverter. The inductor L is inserted to limit shot through fault current.[13,18] A large electrolytic capacitor C is inserted to stiffen the DC link voltage.The switching devices in the VSI bridge must be capable of being turned off and on. Insulated gate bipolar transistors (IGBT) are used because they have this ability in addition; they offer high switching speed with enough power rating. Each IGBT has an inverse parallel-connected diode. This diode provide alternate path for the motor current after the IGBT, is turned off [2].

Each leg of the inverter has two switches one connected to the positive side (+) of the DC link and the other to the negative side (-)depending upon the voltage level of power converter circuit module; only one of the two can be on at any instant. When the high side gate signal is on the phase is assigned the binary number 1, and assigned the binary number 0 when the low side gate signal is on. Considering the combinations of status of phases a, b and c the inverter has eight switching modes (VaVbVc=000-111) two are zero voltage vectors V0 (000) and V7 (111) where the motor terminals is short circuited and the others are nonzero voltage vectors V1 to V6.

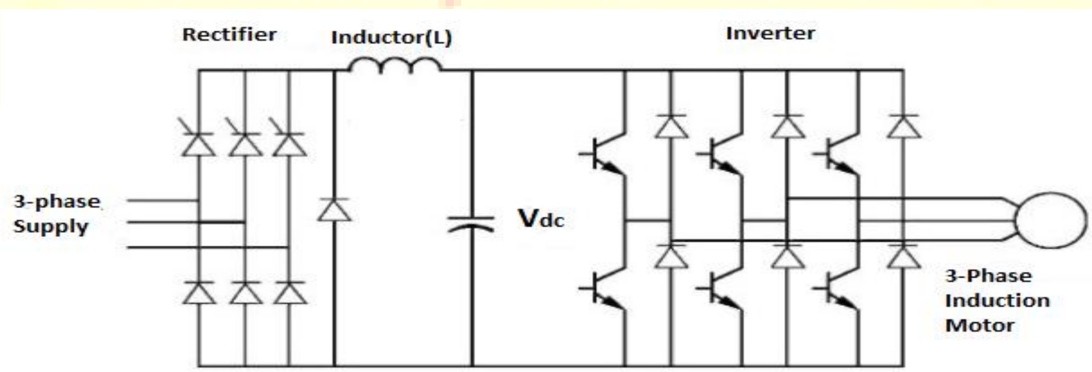
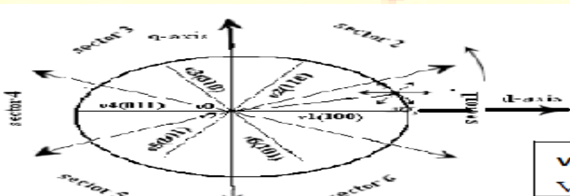
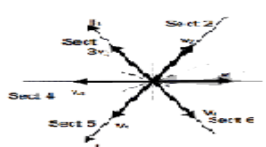


Fig 4. Voltage Source Inverter

The dq model for the voltage source inverter in the stationary reference frame is obtained by applying the dq transformation Equation to the inverter switching modes,6 nonzero voltages space vectors will have the orientation shown and also shows the varying dynamic locus of the stator flux, and its different variation depending on the VSI states chosen. The possible global locus is divided into 6 different sectors or segments signalled by the discontinuous line. Each vector lies in the centre of a sector of 60^owidth named S1 to S6 according to the voltage vector it contains.

From Equation 9 it can be seen that the inverter voltage directly force the stator flux, the required stator flux locus will be obtained by choosing the appropriate inverter switching state. Thus the stator flux linkage move in space in the direction of the stator voltage space vector at a speed that is proportional to the magnitude of the stator voltage space vector. By selecting step by step the appropriate stator voltage vector, it is then possible to change the stator flux in the required way. If an increase of the torque is required then the torque is controlled by applying voltage vectors that advance the flux linkage space vector in the direction of rotation. If a decrease in torque is required then zero switching vector is applied, the zero vector that minimize inverter switching is selected, if the stator flux vector lies in the k-th sector and the motor is running anticlockwise then torque can be increased by applying stator voltage vectors Vk+1 or Vk+2, and decreased by applying a zero voltage vector V0 or V7. Decoupling control technique of the torque and stator flux is achieved by acting on the radial and tangential components of the Stator voltage vector in the same directions, and thus can be controlled by the appropriate inverter switching. In general, if the stator flux linkage vector lies in the k-th sector its magnitude can be increased by using





Voltage Vector	Angle Range
V1	$0^\circ < \alpha_s \le 60^\circ$
V2	$60^\circ < \alpha_s \le 120^\circ$
V3	$120^\circ < \alpha_s \le 180^\circ$
V4	$180^\circ < \alpha_s \le 240^\circ$
V5	$240^\circ < \alpha_s \le 300^\circ$
V6	$300^\circ < \alpha_s \le 360^\circ$

Fig 5.Stator flux vector locus and different possible switching voltage vectors. FD: flux decrease. FI: flux increase. TD: torque decrease. TI: torque increase.

switching vectors Vk-1 (for clockwise rotation) or Vk+1 (for anticlockwise rotation), and can be decreased by applying voltage vectors Vk-2 (for clockwise rotation) or Vk+2 (for anticlockwise rotation). In Accordance with figure 2.1, the general table can be written. It can be seen from table, that the states Vk and Vk+3 , are not considered in the torque because they can both increase (first 30 degrees) or decrease (second 30 degrees) the torque at the same sector depending on the stator flux position.

Table 2. General Selection Table for Direct Torque Control, "k" being the sector number.

VOLTAGE VECTOR	INCREASE	DECREASE
Stator Flux	V_k, V_{k+1}, V_{k-1}	V_{k+2}, V_{k-2}, V_{k+3}
Torque	V_{k+1}, V_{k+2}	V_{k-1}, V_{k-2}

This can be tabulated in the look-up Table (Takahashi look-up table). Finally, the DTC (Direct Torque Control) classical look up table is as follows:

Table 3. Look up table for Direct Torque Control. FD/FI: flux decrease/increase. TD/=/: torque decrease/equal/increase. S_x: stator flux sector.Φ: stator flux modulus error after the hysteresis block.τ: torque error after the hysteresis block.

Φ	τ	S_1	S_2	S_3	S_4	S_5	S_6
FI	TI	V	V	V	V	V	V
	T=	V_2	V_3	V_4	V_5	V_6	V_1
	TD	V_0	V_7	V_0	V_7	V_0	V_7
FD	TI	V_3	V_4	V_5	V_6	V_1	V_2
	T=	V_7	V_0	V_7	V_0	V_7	V_0
	TD	V_5	V_6	V_1	V_2	V_3	V_4

The sectors of the stator flux space vector are denoted from S_1 to S_6. Stator flux modulus error after the hysteresis block (Φ) can take just two values. Torque error after the hysteresis block (τ) can take three different values. The zero voltage vectors $V_0$and $V_7$are selected when the torque error is within the given hysteresis limits, and must remain unchanged.[15,11,17]

However, flux and torque estimations can be performed using other magnitudes such as two stator currents and the mechanical speed, or two stator currents again and the shaft position.[8]

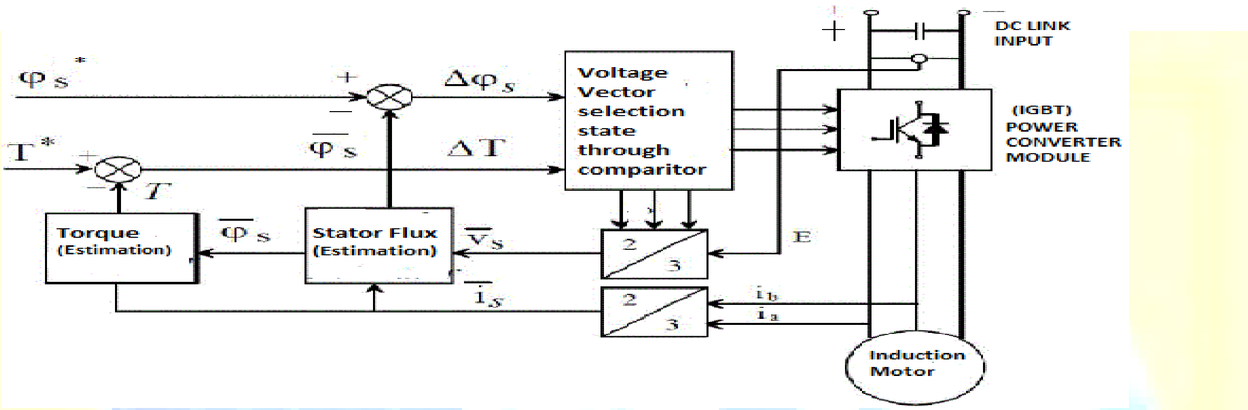


Fig 6. Direct Torque Control Schematic.

7. DIRECT TORQUE CONTROL SPACE VECTOR MODULATION

In principle classical DTC selects one of the six voltage vectors of equal magnitude and two zero voltage vectors generated by a Voltage source Inverter keeping stator flux and torque within the limits of two hysteresis bands. The right application of this principle allows a decoupled control of flux and torque without the need of coordinate transformations, PWM pulse generation and current regulators. [4][9]with the application of this principle, the control system should be able to generate the desired voltage vector, using the SVM technique. These methods require more complex control schemes than basic DTC scheme and present motor parameters dependence. more voltage vectors in space or an span of 360^0 allows the definition of more accurate switching tables in which the selection of the voltage vectors is operated according to the rotor speed, the flux error and the torque error, with no increase the complexity of classical DTC scheme.[20,22]

The problem of switching table based DTC methods is that just after the stator flux vector changes its position from one sector to another sector, there is no active vector available that can assure an increase of stator flux. Therefore, at low speed, especially with heavy load, stator flux droops systematically, causing the stator flux trajectory to be nearly hexagonal and stator current distortions.[10] Clearly the above DTC techniques present reciprocally advantages and disadvantages. Study of various DTC methodologies (Classical DTC and SVM-DTC) will been made in order to evaluate the influence of the motor operating condition on steady state performance.

a.IMPLEMENTATION OF DTC-SVM

This section describes the implementation of direct torque control using space vector modulation in detail. A number of advances on the implementation originally published [Habetler, Profumo et al., 1991] are possible. These are primarily due to the more sophisticated power electronic and controller hardware that are being used. These advances an IGBT inverter switching at 10 kHz is used instead of a BJT inverter switching at 2 kHz,a three-level inverter is used instead of a two-level inverter. This enabled a higher quality stator voltage waveform to be synthesised and due to a higher inverter switching frequency and more sophisticated controller hardware platform, the controller update rate has been reduced from 250/-ls to 100/-ls.

8. SIMULATION AND ITS RESULTS

a.SIMULINK MODEL

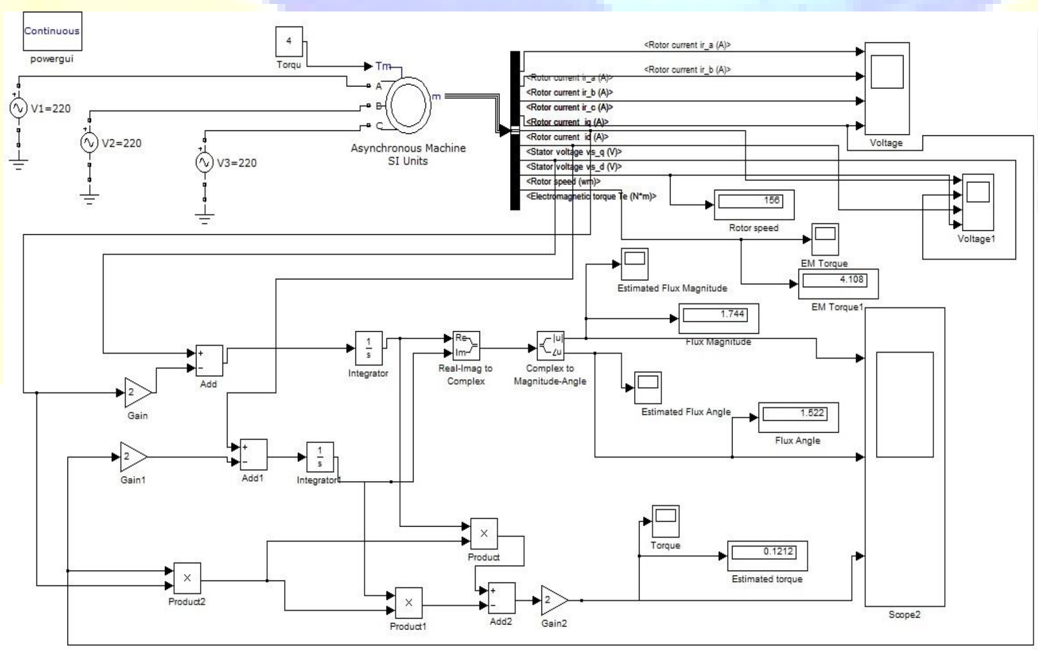


Fig 9. Simulink Model

The simulink model of "Direct Torque control of Induction Motor" is shown in above figure . For the given project reference is taken from "Alnasir, Z.A. et al. / International Journal of Engineering and Technology (IJET)". In this model we are to control both flux and torque. In the above figure constant value of torque given which is controlling both flux and speed of the motor. If the value of torque increases speed of the motor will decrease. Also we know that if the value of torque is negative than the machine will run as generator. If torque is positive the machine will run as motor.

a.OUTPUT OF THE MODEL

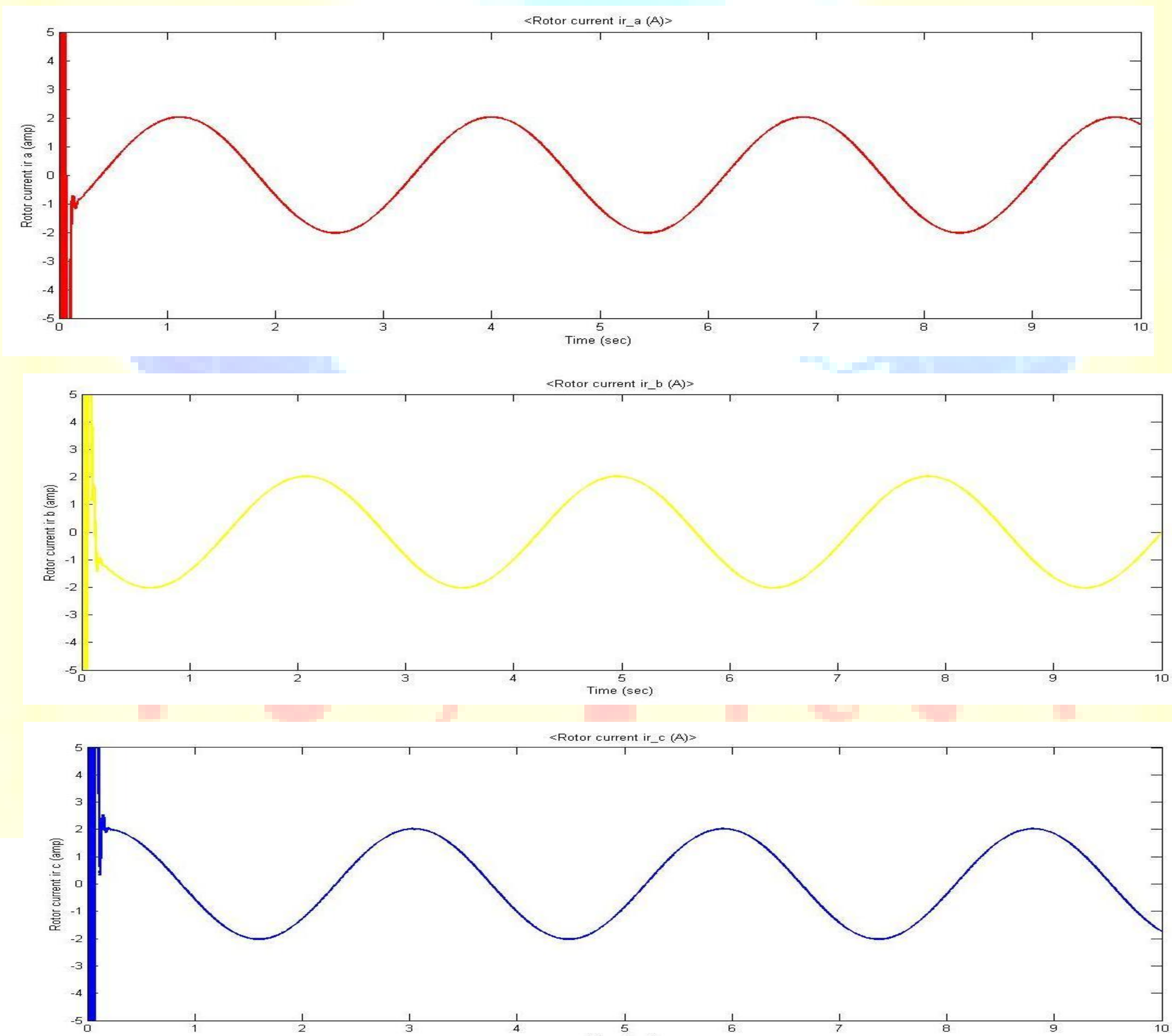
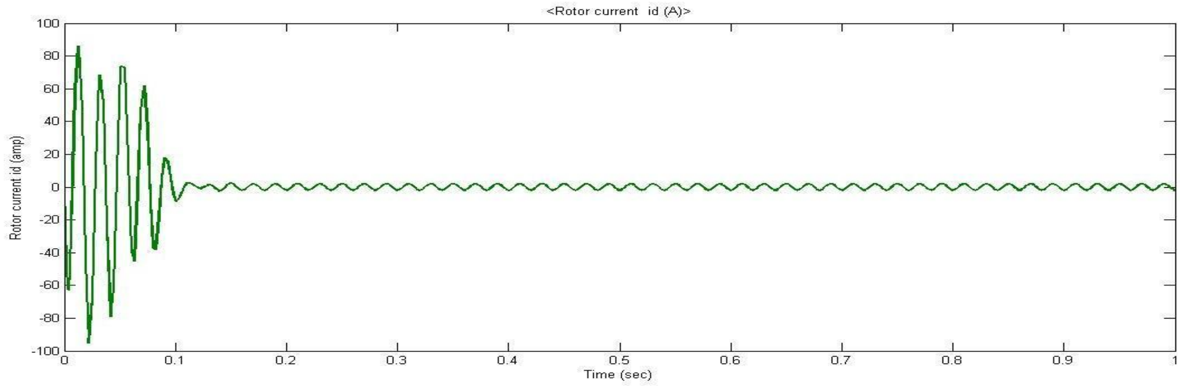


Fig10. 3-phase supply of rotor current

In the 3-phase supply of rotor current the phase difference of 0, -120 and 120 degree and its magnitude 2 amp are given in fig 10.(a), (b) and (c) respectively. The graph is plotted with respect to time (second).



(a)

(b)

Fig 11. Rotor current of d- and q- axis

The rotor current of current of d- and q- axis of magnitude 2 amp is given in fig11. (a) and (b) respectively.

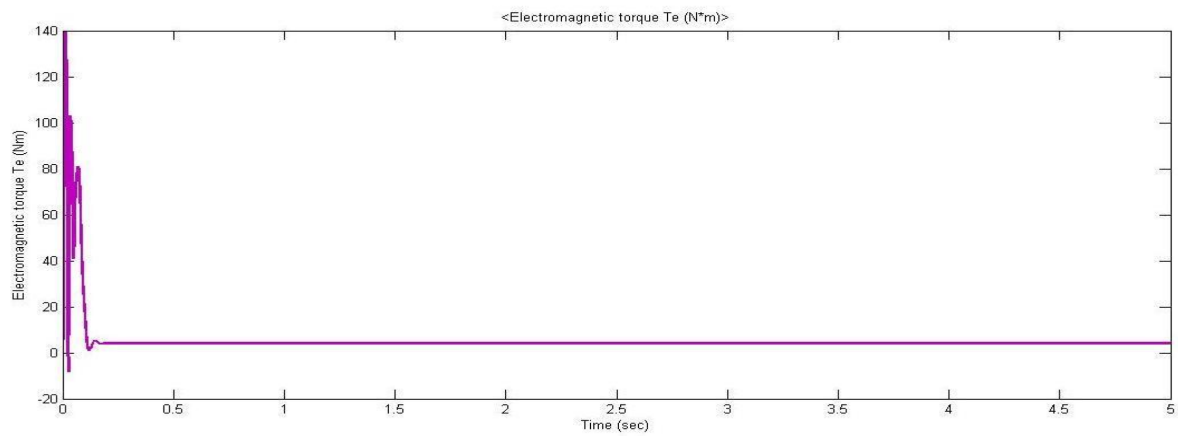


Fig 12. Electromagnetic torque

Electromagnetic torque of magnitude 4 Nm is given in figure 12. In this figure first there is trasient till 0.18 sec then afterwards there is a constant value of approximate 4 Nm.

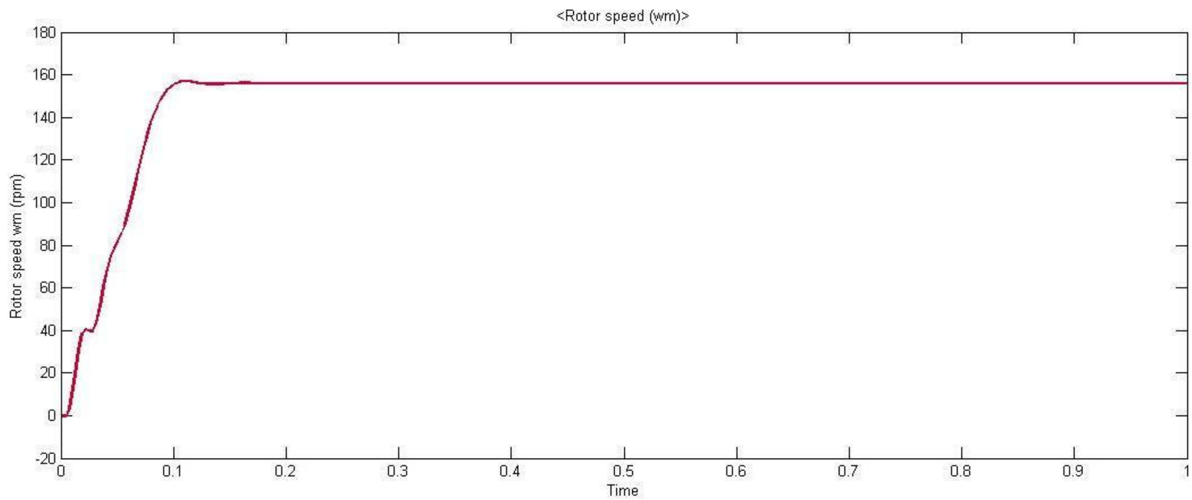


Fig 13. Rotor speed (wm)

In figure 13.first there is a transient value in speed till 0.1 sec then there is a constant speed 156 rpm. Greater the value of torque lower will be value of speed.

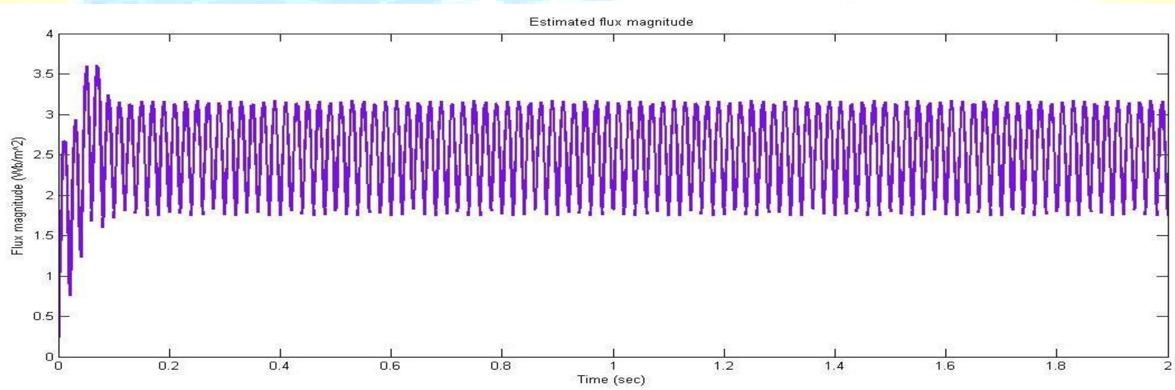


Fig 14. Estimated flux magnitude

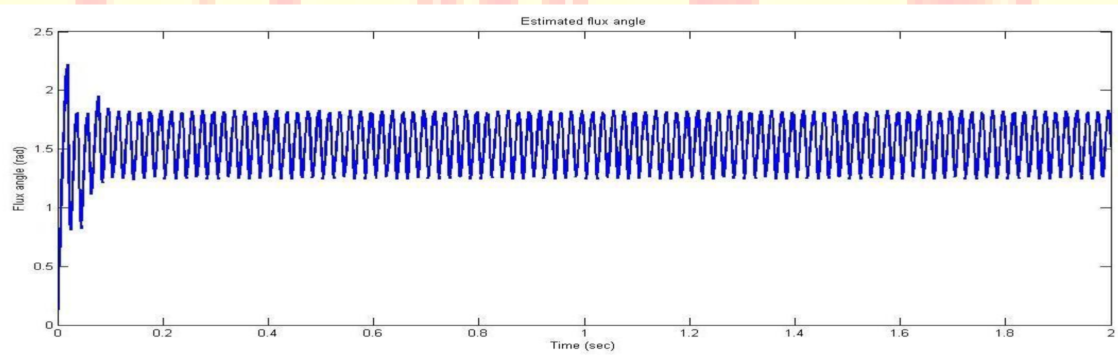


Fig 15. Estimated flux angle

The estimated flux magnitude and flux angle are shown in figure 14 and 15 respectively. The value of flux magnitude and flux angle varies due to the effect of load (that is imaginary quantity present in the load). The value of estimated flux magnitude and estimated flux angle is approximately 1.7 Wb/m^2 and 1.5 rad respectively at 2 sec.

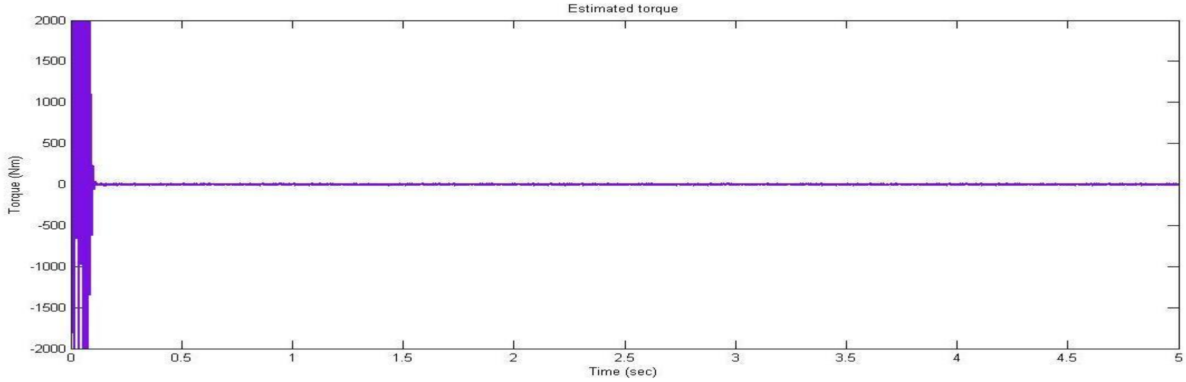


Fig 16. Estimated torque

The value of estimated torque shown in figure 16 is approximately 0.14 Nm at 5 sec and it varies with respect to time due to the effect of load.

9. CONCLUSION

DTC is assumed to be the best controllers for induction motor drive. Its principles and basic concepts have been introduced and thoroughly explained, as the method of direct torque control also allows the decoupled control of motor torque and motor stator flux. according to the analysis, the DTC strategy is simpler to implement than the flux vector control method because it does not require voltage modulators, and co-ordinate transformations. However, it introduces undesired torque ripple. Several different methods for improving classical DTC can be described as the search of a better look up table. Following some research that have been done in this field, optimum look up table cannot be remarkably improved the DTC performance. Nevertheless, some improvement can be achieved and it will give the fundamental idea for the development of ideal controller.Implies on the predictive method, which requires acquiring space vector modulation and the calculation of the proper voltage reference. This method exists in various control manners such as torque or flux only control and its aims are to overcome the drawbacks of conventional DTC. The application of the fuzzy logic for implementing a simple modulation between the selected active state and a zero state is another method to improve conventional DTC,another method that looks promising is the regulation of the stator flux reference value. This method can be applied in any motor drive like (D.C motor and Induction motor) instead of reduces the torque ripple; it also reduces the power reactive consumption taken from main supply.

REFERENCES

[1] Takahashi, I. and Noguchi, T. "A new quick-response and high efficiency control Strategy of an induction motor." IEEE Transactions on Industry Applications, vol.22, no. 5, pp. 820-827, 1986.

[2] Novotny, D. W. and Lipo, T. A. "Vector Control and Dynamics of AC Drives." Oxford University Press Inc, New York, 1996.

[3] Vas, P. " Sensor less Vector and Direct Torque Control". Oxford University Press 1998.

[4] Bose, B. K.; "Power Electronics and AC Drives". Prentice-Hall. 1986.

[5] Mohan, Undeland, Robbins. "Power Electronics". Wiley. Second edition. 1989.

[6] Ludtke, I.; Jayne M.G. "A comparative study of high performance speed control strategies for voltage sourced PWM inverter fed induction motor drives", Seventh International Conference on electrical Machines and Drives, 11-13 September 1995, University of Durham, UK.

[7] Tamai, S., Sugimoto, H. and Yano, M. "Speed sensorless vector control of induction motor with model reference adaptive system." IEEE Industrial Applications Society Annual Meeting, Atlanta, pp.189-195, 1987.

[8] Schauder, C. "Adaptive speed identification for vector control of induction motors without rotational transducers." IEEE Transactions on Industrial Applications, vol.28, pp. 1054-1061, 1992.

[9] Doki, S., Sangwongwanich, S. and Okuma, S. "Implementation of speed sensorless field oriented vector control using adaptive sliding observer." IEEE-IECON, San Diego, pp. 453-458, 1992.

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[10] Kawamura, A. and Hoft, R. "An analysis of induction motor for field oriented or vector control." IEEE Power Electronics Specialists Conference, Albuquerque, New Mexico, pp. 91-100, 1983.

[11] Kubota, H. and Matsuse, K. "Speed sensorless field oriented control of induction machines." IEEE IECON, Bologna, Italy, pp. 1611-1615, 1994.

[12] Mir, S. and Elbuluk, M. "Precision torque control in inverter fed induction machines using fuzzy logic". Conf. Rec. IEEE-PESC Annual Meeting, Atlanta, pp. 396-401, 1995.

[13] Depenbrock, M. "Direct self control (DSC) of inverter–fed induction machine." IEEE Transactions on Power Electronics, vol. 3, no. 4, pp. 420-429, 1988.

[14] Mir, S. and Elbuluk, M. "Precision torque control in inverter fed induction machines using fuzzy logic." Conf. Rec. IEEE-PESC Annual Meeting, Atlanta, pp. 396-401, 1995.

[15] Thomas, G., Halbetler, H. and Deepakraj, M. D. "Control strategies for direct torque control using discrete pulse modulation." IEEE Transactions on Industry Applications, vol. 27, pp. 893-901, 1991.

[16] Takahashi, I and Ohimori, Y. "High-Performance Direct Torque Control of an Induction Motor", IEEE Trans. Industry Applications, Vol. 25, pages 257-264, March 1989.

[17] Perelmuter, V. "Three level inverters with direct torque control." IEEE Proc. on Industry Applications, pp. 1368-1373, 2000.

[18] MATLAB Fuzzy logic toolbox user guide. The MathWorks, Inc, 1999.

[19] S. Mir, D. Zinger and M. Elbuluk, "Fuzzy controller for inverter-fed induction machine," *IEEE Trans. Ind. Appl.*, vol. 30, 1994, no. 1, pp. 78-84.

[20] Y.Xia W.Oghanna " Study on Fuzzy Control of Induction Machine With Direct Torque Control Approach " *,IEEE Catalog Number: 97TH8280- ISIE'97 - GuimarBes, Portugal*
61

[21] A.A.Pujol, "*Improvement in Direct Torque Control of Induction Motors"*, Doctoral Thesis de L'UPC, November 2000

[22] Hui-Hui Xia0, Shan Li, Pei-Lin Wan, Ming-Fu Zhao, "Study on Fuzzy Direct Torque Control System" *Proceedings of the Fourth International Conference on Machine Learning and Cybernetics, Beijing, 4-5 August 2002.*