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Space Vector Approach for Direct Torque Control Induction Motor drive

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Abstract— *DTC is a vector control technique. With DTC stator flux and torque of induction motor can control separately. But during the estimation process some error occurs on the system which degrades the drive performance and also inverter switching frequency get varied. The error occur on the system is due to DC-link voltage. To improve the drive performance by reducing the error due to DC-link and to maintain switching frequency constant SVPWM technique is used here. Using this modulation technique space vector of stator voltage is controlled by providing proper switching sequence for inverter. SVPWM technique utilize the full DC bus voltage because of this harmonic contents are reduced. To maintain switching sequence constant the required DC link voltages for inverter are obtained through PI controller. PI controller reduces the ripple content on controlling parameter. In this paper DTC-IM drive performance are improved by reducing the estimation error with the help of DTC-SVM technique. The system implemented using MATLAB/SIMULINK model.*

Keywords— *Direct torque control (DTC), induction motor (IM) drives, space vector pulse width modulation (SVPWM), voltage source inverter (VSI).*

I. INTRODUCTION

In early 70s a first vector control technique introduced by K. Hasse as Indirect field oriented control (FOC) and F. Blaschke Direct FOC. In case of FOC method the motor co-ordinate transformation is used instead of the motor decoupling and linearization. In the80's I. Takahashi present a new control strategy called as direct torque control technique and M. Depenbrock as direct self control technique. The decoupled control for flux and torque while DTC provide very fast dynamic response to torque control compare to FOC. FOC # is very sensitive to rotor time constant. In case of DTC, required parameter is only stator resistance. FOC method require current controller, coordinate transformation, PWM modulator and in direct FOC rotor flux estimator and in indirect FOC mechanical speed is required. DTC structure is simple and it does not require coordinate transformation, separate voltage modulator and current control loop. The main advantages of DTC over FOC are requirement of less machine parameter, simpler implementation and quicker dynamic torque response. DTC controls the torque and speed of the motor, which is directly based on the electromagnetic state of the motor.

In this paper the DTC-SVM scheme is proposed for induction motor drive. DTC-SVM scheme gives good dynamic control of flux and torque. The main advantage of DTC-SVM strategy is to operate in constant switching frequency. Constant switching reduces torque ripple substantially. In constant switching DTC, a switching lookup table is used for optimum selection of voltage vector on corresponding state of inverter. The lookup table design to achieve special requirement of induction motor drive on industry such as low speed, high speed and starting. New DTC-SVM scheme replace switching table by space vector modulation and linear PI controller instead of hysteresis band controller.

The control signals in DTC-SVM method are based on average value where as the switching signal for the inverter switching is calculated by space vector modulation algorithm. Actually controller calculates the demanded voltage vector and after that it acquires SVM technique. This is the main difference between classical DTC and DTC-SVM control method.

II. DTC BACKGROUND

The basic principle of DTC is to control electromagnetic torque and stator flux of induction motor by selecting voltage vector using modulation technique. The stator reference frame is used here. Using tangential and radial vector flux and torque can be control independently. The space vector of stator voltage can be change by selecting switching sequence of inverter. This space vector then realized by SVPWM technique. For small change in flux value there is large change obtain on electromagnetic torque of motor.

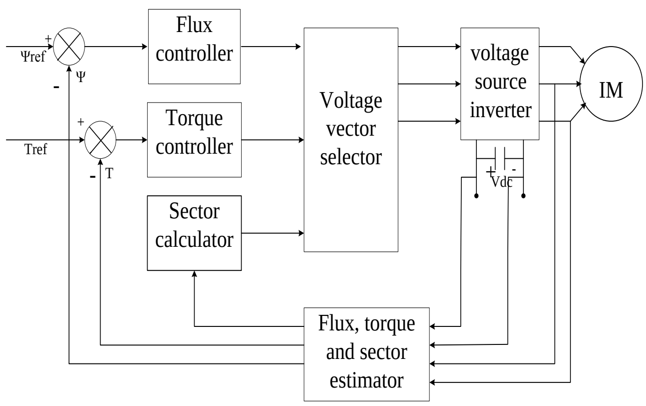

Fig. 1. Block diagram of DTC.

A. *Mathematical model of Induction motor*

Stator and rotor voltage equation of induction motor is

$$Vs = \frac{d\Psi s}{dt} + Rs.Is$$

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$$0 = \frac{d\Psi s}{dt} - j\omega.\Psi r + Rr.ir$$

This mathematical description is based on space vector notation.

Instantaneous stator phase voltage values can be written as,

$$Va = IaRa + \frac{d\Psi a}{dt}$$

$$Vb = IbRb + \frac{d\Psi b}{dt}$$

$$Vc = IcRc + \frac{d\Psi c}{dt}$$

The space vector method is generally used to describe the model of the induction motor. A three phase quantities of motor such as voltage, current or flux linkage can be replaced by one resulting space vector of voltage, current or flux linkage.

For given a set of three-phase voltages, a space vector can be defined by

$$\overrightarrow{V(t)} = \frac{2}{3}[Va(t)e^{j0} + Vb(t)\, e^{j\frac{2\pi}{3}} + Vc(t)e^{j\frac{4\pi}{3}}]$$

Where Va(t), Vb(t), and Vc(t) are three sinusoidal voltages of the same amplitude and frequency but with 120^0 phase shifts.

B. Voltage Source Inverter

Two level three phase voltage source inverter is used on DTC model consist of six switches. Switching states of lower switches are opposite to the upper one. Each leg consists of two switches. One switch on each leg conducts at a time. When one switch is conducting another switch must be open to prevent short circuit of the supply. Possible vector configurations for two level three phase inverter are 2^3 =8. Hence total eight voltage vector obtained on which six are active vector (V1 to V6) and two are zero vectors (V0, V7). These vectors commanded through the switching table. By considering the advantages of semiconductor switches in this model IGBT switches are used. A 120^o mode of operation is used in this configuration where each switch conducts at an interval of 120^o. The switching signal applied and removed on each switch at a 60^o of interval.

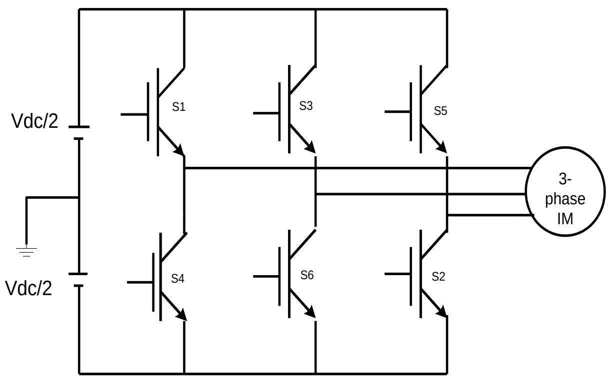

Fig. 2. Three phase voltage source inverter.

Table I. The standard 8 voltage vectors and the logic states.

	V0	V1	V2	V3	V4	V5	V6	V7
A	0	1	1	0	0	0	1	1
B	0	0	1	1	1	0	0	1
C	0	0	0	0	1	1	1	1

C. SVPWM Technique

Space Vector Modulation (SVM) is a vector orientation of pulse width modulation (PWM) technique for three phase inverter. SVPWM technique uses full DC bus voltage hence its output are more sinusoidal with lower harmonic distortion. Also this technique provides variable output voltage so that required voltage for motor can obtained easily. It is a one of the best PWM method for variable frequency drive application.

The space vector concept based on the rotating field of the induction motor, which is used to regulate the inverter output voltage. In SVPWM technique the three phase quantities such as voltage, current can be transformed into their equivalent two-phase quantity in stationary frame. The reference voltage magnitude and phase angle obtained through the two phase quantity. The two phase quantity calculated on d-q axis of reference frame.

The sinusoidal three phase voltage is given by

$$Va = Vm \sin \omega t$$

$$Vb = Vm \sin(\omega t - 2\pi/3)$$

$$Vc = Vm \sin(\omega t + 2\pi/3)$$

This three phase quantity converted into two phase to obtain magnitude of reference vector Vs and angle δ.

The magnitude and angle of space vector can be obtained through clark's transformation.

$$Vref = Vd + j\, Vq$$

$$Vref = 2/3(\,Va + aVb + a2Vc)$$

Where, $a = e^{j2\pi/3}$ and $a^2 = e^{-j2\pi/3}$

$$Vd + jVq = \frac{2}{3}(\,Va - 0.5\,Vb - 0.5\,Vc) + \; j\,\frac{2}{3}(\frac{\sqrt{3}}{2}Vb - \frac{\sqrt{3}}{2}\,Vc)$$

By equating real and imaginary terms

$$Vd = \frac{2}{3}(\,Va - 0.5\,Vb - 0.5\,Vc)$$

$$Vq = \frac{2}{3}(\frac{\sqrt{3}}{2}Vb - \frac{\sqrt{3}}{2}\,Vc)$$

In matrix form,

$$\begin{bmatrix} Vd \\ Vq \end{bmatrix} = \frac{2}{3}\begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & \frac{-\sqrt{3}}{2} \end{bmatrix}\begin{bmatrix} Va \\ Vb \\ Vc \end{bmatrix}$$

The magnitude Vs and angle δ of stator voltage of motor is,

$$|Vref| = \sqrt{Vd^2 + Vq^2}$$

$$\delta = \tan^{-1}\frac{Vq}{Vd}$$

From this equation we can obtain the magnitude and angle of stator voltage reference vector. Angle δ can be change as position of reference voltage vector changes. Here each voltage vector placed 60° apart from each other. Reference vector placed between corresponding two voltage vectors hence its position changes as sector changes.

D. Sector Selection

Table II. Identification of Vref position with respect to angle.

Angle δ	Position of Vref in sector
0° - 60°	1
60° - 120°	2
120° - 180°	3
180° - 240°	4
240° - 300°	5
300° - 360°	6

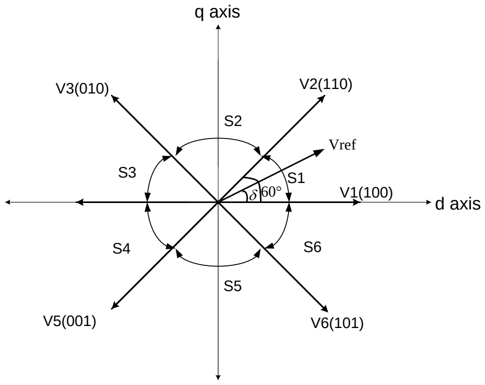

Fig. 3. Reference voltage vector in particular sector.

The vector diagram of voltage source inverter is divided into six sectors. Eight vector lie on six sectors on which two are zero vector placed at the origin and six are active vector rotate on the space. Angle between corresponding vector of given sector is 60^{o}. The reference vector rotates anticlockwise with respect to speed of the motor.

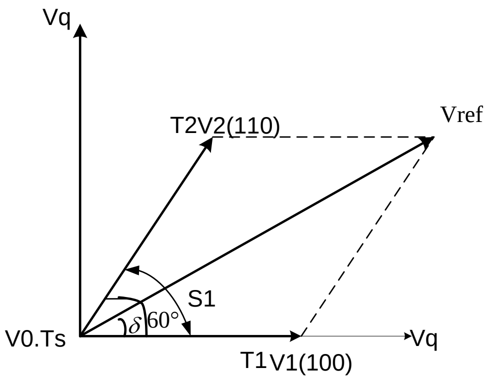

Fig. 4. Sample reference voltage vector on first sector

Apply volt sec balance equation for the calculation of time duration for each space vector on the sector.

Volt sec equation for sector one,

$$\mathrm{Vref.Ts} = \mathrm{V2\,T2} + \mathrm{V2\,T2} + \mathrm{V0\,T0} + \mathrm{V7\,T7}$$

V0 and V7 are the zero voltage.

$$\mathrm{Vref.Ts} = \mathrm{V2\,T2} + \mathrm{V2\,T2} + \mathrm{V0\,T0}$$

Volt sec balance equation along d-axis,

$$V1.T1 + (V2\ \cos 60).T2 = (Vref\ \cos\delta).Ts$$

Volt sec balance equation along q-axis,

$$0 + (V2\ \sin 60).T2 = (Vref\ \sin\delta)\,.Ts$$

$$T2 = \frac{Vref\ cos\delta\ .Ts}{V2\ \ \sin 60.}$$

The max phase voltage in SVPWM Is,

$$Vmax = Vref = \frac{Vdc}{\sqrt{3}}$$

Modulation index for space vector modulation,

$$M = \frac{Vref}{\frac{2}{\pi}.Vdc}$$

Put it into equation of T2,

$$T2 = \frac{2\sqrt{3}.M\ .sin\ \delta\ .Ts}{\pi}$$

Put the value of T2 in equation of T1,

$$T1 = \frac{2\sqrt{3}.M.Ts.\sin(60-\delta)}{\pi}$$

The equation of T1,T2 are same for all modulation technique. In SVPWM technique zero vector are placed during sampling period of active vector hence along with T1, T2 sample time calculated for zero vector.

T1, T2 is a time calculation of active vector V1, V2. Now calculation of time period for zero vector is

$$T0{,}7 = Ts - (T1 + \mathrm{T2})$$

Vref is a reference vector placed on sector 1 and its sampling time is Ts. The reference voltage vector is calculated by using active voltage vector on which sample lies and zero vectors for different time over sample time.

If the zero vectors placed symmetrically then its sample time is

$$T0 = T7 = \frac{Ts - T1 - T2}{2}$$

The time calculation of sector 1 is same for all sectors. If k is a sector no. 1-6 then time calculation for sector 1,3,5 is,

$$T1 = \frac{2\sqrt{3}.M.Ts.\sin(K.60-\delta)}{\pi}$$

$$T2 = \frac{2\sqrt{3}.M\ .sin\ (\delta-((k-1)\ 60).Ts}{\pi}$$

Time calculation for sector 2,4,6 are

$$T1 = \frac{2\sqrt{3}.M\ .sin\ (\delta-((k-1)\ 60).Ts}{\pi}$$

$$T2 = \frac{2\sqrt{3}.M.Ts.\sin(K.60-\delta)}{\pi}$$

After calculation of sampling time on the sector of each vector, it is easy to calculate the modulating signal by using different switching sequence. Here symmetrical switching sequence is used. The switching sequence is used in such a way that it should reduce the switching frequency. The switching frequency is reduces if switch position change from 1 to 0 or 0 to 1in next sampling period.

The switching sequence for first sector is,

$$VO \rightarrow V1 \rightarrow V2 \rightarrow V7 \rightarrow V2 \rightarrow V1 \rightarrow V0$$

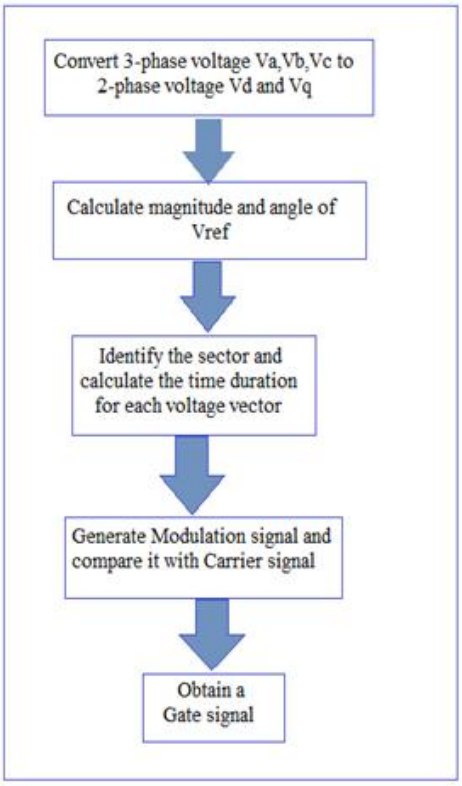

Fig.5. SVPWM algorithm.

III. RESULT AND DISCUSSION

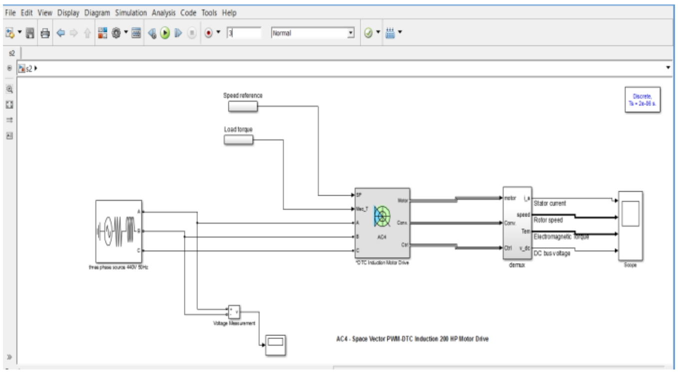

Fig. 6. Simulink model of space vector pulse width modulated DTC induction motor drive.

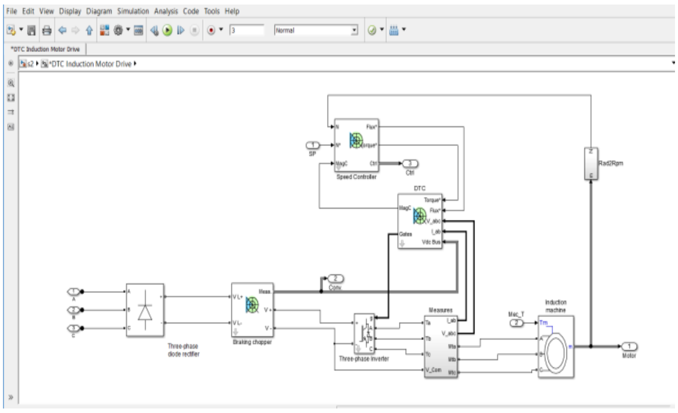

Fig. 7. Subsystem of simulink model of space vector pulse width modulated DTC induction motor drive.

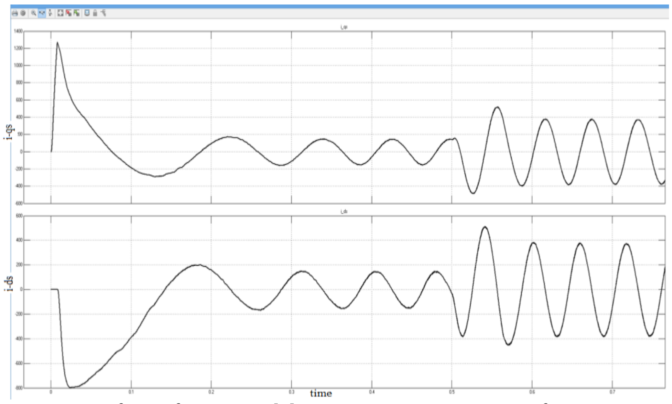

Fig. 8. Waveform of q- axis and d- axis stator current in case of DTC-SVM.

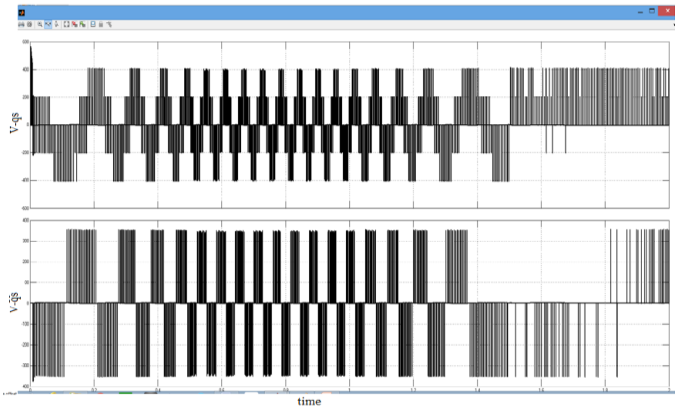

Fig. 9. Waveform of q-axis and d-axis stator voltage.

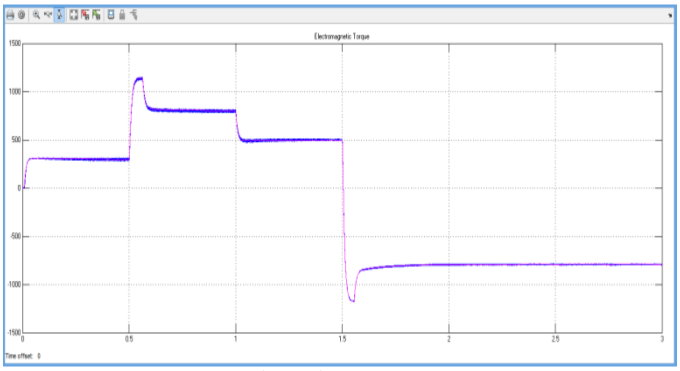

Fig 10. Waveform of electromagnetic torque.

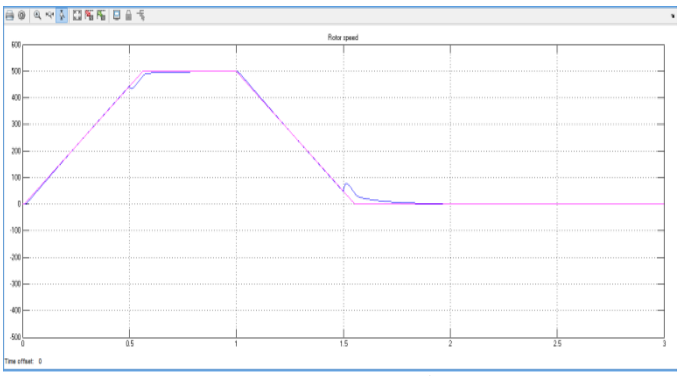

Fig. 11. Rotor speed waveform.

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Fig.10. and Fig.11. shows rotor speed of the machine and electromagnetic torque. This shows that the DTC improve dynamic performance with respect to speed by acquiring change in demand torque. The torque has high initial value in the acceleration zone, increases due to load torque increment then decreases and remains constant in the deceleration zone. Fig.8 shows the electromagnetic torque curve, at first speed increases and then it comes to steady state so that flux is maintained constant to control the torque.

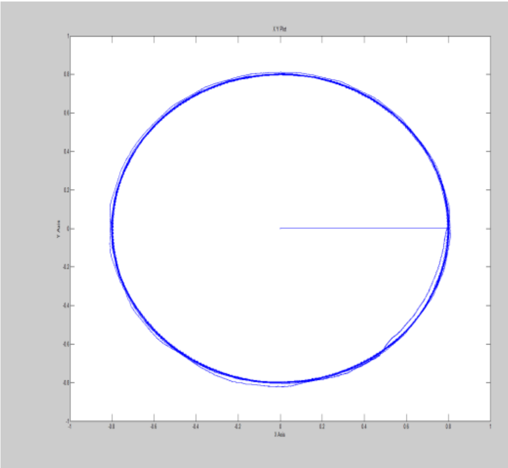
Fig. 12. Stator flux trajectory at gain 1.

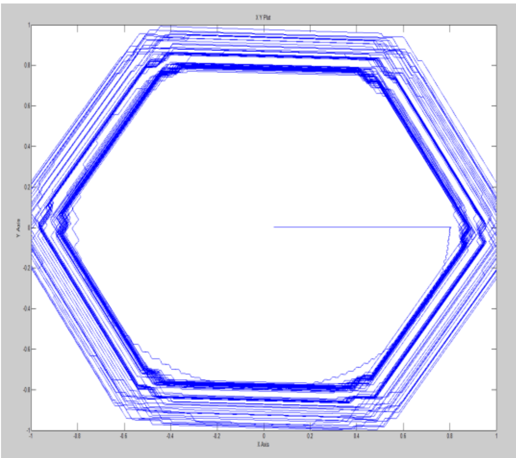
Fig. 13. Stator flux trajectory gain more than 1.

Fig 12 shows the flux trajectory at gain 1. If any error occurs in dc-link voltage the uneven gain produce on motor which results in distortion in stator flux. When motor gain is not match with controller gain then flux trajectory is not maintain circular. Fig. 13 shows the trajectory of flux at uneven gain.

IV. Conclusion

This paper has shows DTC strategies for SVPWM inverter- fed IM motor drives. The MATLAB simulink model shows the DTC implementation with SVPWM technique. By using SVPWM technique switching frequency maintain constant and also it reduces the torque ripple. By using PI controller stator flux orientation maintain constant with gain 1. As gain changes flux locus not maintain uniform. The gains of the motor vary if errors occur on DC-link voltage. Hence to improve DC-bus utilization SVPWM technique is used. DTC-SVM schemes improve the dynamic performance of drive also it provides better control at low speed operation with reliable start up.

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References

[1] Mohand Ouhrouche, Rachid Errouissi, Andrzej M. Trzynadlowski, Kambiz Arab Tehrani, and Ammar Benzaioua, “A Novel Predictive Direct Torque Controller for Induction Motor Drives”, *IEEE transactiom on industrial electronics*, vol. 63,pp. 5221-5223, Aug 2016.

[2] Ibrahim Mohd. Alsofyani, Nik Rumzi Nik Idris, “Lookup-Table-Based DTC of Induction Machines With Improved Flux Regulation and Extended Kalman Filter State Estimator at Low-Speed Operation”, *IEEE transaction on industrial informatics*, vol. 12,pp. 1412-1418, Aug 2016.

[3] Bhoopendra Singh, Shailendra Jain, Sanjeet Dwivedi, “Torque ripple reduction technique with improved flux response for a direct torque control induction motor drive”, *IET Power Electron.*,vol. 6, pp. 326–342, 2012.

[4] Sanila C. M., “Direct Torque Control of Induction Motor with Constant Switching Frequency”, *IEEE International Conference on Power Electronics, Drives and Energy Systems, Bengaluru, India*. Dec 2012.

[5] Y. Zhang, J. Zhu, Z. Zhao, W. Xu, D. Dorrell, “An improved direct torque control for three level inverter fed induction motor sensorless drive”, *IEEE transactions of power electronics*, pp. 1502-1504,2012.

[6] Masood Hajian, Jafar Soltani, “Adaptive Nonlinear Direct Torque Control of Sensorless IM Drives with Efficiency Optimization”, *IEEE transaction on industrial electronics*, vol. 57, pp. 975-978, Mar 2010.

[7] T. Vinay Kumar,S. Shrinivasa Rao, “Switching state algorithm for space vector pulse width modulation”, *Mediterranean conference and exhibition on power generation, transmission, distribution and energy conversion*, pp. 1-5,2010.

[8] Giuseppe Buja and Roberto Menis,“Steady-State Performance Degradation of a DTC IM Drive Under Parameter and Transduction Errors”, *IEEE transaction on industrial electronics*, vol. 55, pp. 1749-1759, 2008.

[9] J.W.Finch and D. Giaouris, “controlled AC electrical drive”, *IEEE transaction of industrial electronics*, vol. 55, pp. 481-484, 2008.

[10] Zhang Xing, Qu Wenlong and Lu Haifeng, “A New Integrator for Voltage Model Flux Estimation in a Digital DTC System”, *IEEE*, 2006.

[11] B.K. Bose, “Modern Power Electronics And AC Drives”, *Prentice Hall India*, 2006.

[12] Jagdish G. Chaudhari,Dr. M. V. Aware, Dr. S. G. Tarnekar, “Improved Direct Torque Control Induction Motor Drive”, *IEEE International Conference power electronics*, 2006.

[13] Liviu Mihalache, “A Flux Estimator for Induction Motor Drives Based on Digital EMF Integration With Pre- and Post- High Pass Filtering” , *IEEE International Conference on applied power electronics*, 2005.

[14] G.S. Buja, and M.P. Kazmierkowski, “DTC of PWM Inverter–Fed AC Motors - A Survey”, *IEEE Transactions on Industrial Electronics*, vol 54, pp. 744–757, 2004.

[15] N.R.N. Idris and A.H.M.Yatim, “Direct torque control induction machine with constant switching frequency and reduced torque ripple”, *IEEE transaction of industrial electronics*, vo.51, pp. 758-760, 2004.