ISSN 2229-5518

Torque Ripple Comparison Of Direct Torque Control Of Two Level Inverter Fed Three Phase Induction Motor Using SPWM & SVPWM

Sarika E.P, Assistant Professor ,Department Of Electrical & Electronics ,SNIT Adoor

Abstract-This paper proposes torque ripple comparison of Direct Torque Control of induction motor drive system based on conventional hysteresis controller scheme and modified DTC schemes with pulse width modulation (PWM) techniques such as sinusoidal PWM and space vector PWM . Direct Torque Control (DTC) is a control technique used in AC drive systems to obtain high performance torque control. The main principle of DTC is based on simultaneously decoupling the stator flux and electromagnetic torque. DTC drives utilizing conventional hysteresis comparators suffer from high torque ripple and variable switching frequency. The proposed schemes reduces torque ripples and preserve DTC transient merits such as fast torque response. In the work, modeling of two level inverter , modeling of 3 phase induction motor ,DTC schemes with conventional hysteresis controller, modified DTC employing sinusoidal pulse width modulation and space vector modulation controller have been done, analyzed and compared using Matlab/Simulink software.The torque performance of 2 level inverter fed induction motor with both SPWM and SVPWM is then compared. Simulation results show that torque,flux ,stator current waveforms improve when space vector modulation scheme is employed.

Index Terms- Two level inverter , conventional hysteresis controller,Direct Torque Control,Modified Direct torque Control,Sinusoidal PWM, Space vector pwm,Torque ripple.

.

1 Introduction

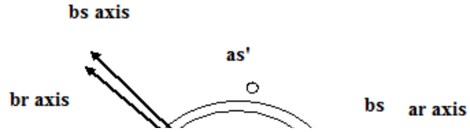
Induction Motors(IMs) are widely used in industrial, commercial and domestic applications as they are simple, rugged, low cost and easy to maintain. Since IMs demands well control performances: precise and fast torque and flux response, large torque at low speed, wide speed range, the drive control system is necessary for IMs. Though DC motor is able to provide desired performance, its maintenance and unsafe in worst environment restricts its use. In 1970s, field oriented control (FOC) "[3]" scheme proved success for torque and speed control of induction motor. Decoupling of two components of stator currents (flux and torque producing components) is achieved as DC machines to provide independent torque control and proves itself superior to the DC machine. But due to dependence of machine parameters, reference frame transformation the scheme is found more complex. Later DTC was introduced. This method requires only the stator resistance parameter to estimate the stator flux and torque. In conventional DTC, electromagnetic torque and flux are independently controlled by selection of optimum inverter switching modes with the help of a lookup table. The selection of optimum inverter switching modes is made to limit the electromagnetic torque and flux linkage errors within the torque and flux hysteresis bands. The basic or conventional DTC "[1]"scheme consists of two comparators with specified bandwidth, lookup table, conventional 2 level inverter model, three phase induction motor model. Some of the disadvantages of conventional DTC schemes are difficult to control flux and torque at low speed, current and torque distortion during the change of the sector, variable switching frequency, high torque ripple etc. The torque ripple causes noise and vibrations and current ripples are in turn responsible for the EMI. The reason of the high current and torque ripple in DTC "[4]"is the presence of hysteresis comparators together with limited number of available voltage vectors. Inorder to improve the output performances, modified SPWM DTC scheme is employed for the inverter.The results show that torque ripple is more reduced when SPWM is employed.

2 BASIC OR CONVENTIONAL DTC

2.1 Basic Principle

The scalar control is based on a relation valid for steady states ,only the magnitude and frequency of voltage, currents, and flux linkage space vectors are controlled. This cannot be applied for transient condition. Therefore, this control is dedicated for application, where high dynamics is not demanded. In search of a simpler and more robust control system a new vector control called direct torque control (DTC) was developed. In this direct control of flux and torque quantities are done without inner current control loops. Generally Electromagnetic torque $T_e = f_s f_r \sin\theta_s$ where f_s, f_r are stator and rotor fluxes and θ_s be the angle between f_s and f_r. Hysteresis controllers are used for flux and torque control which makes this control concept very fast and not complicated. The basic or conventional DTC scheme consists of two comparators with specified bandwidth, lookup table, conventional 2 level inverter model and three phase induction motor model. Three phase induction motor is modeled using dq equations related to voltages and and flux linkages and the inverter model is done using mathematical equations in terms of voltage which are described in sections B & C respectively. The block diagram of basic DTC is given below.

ISSN 2229-5518



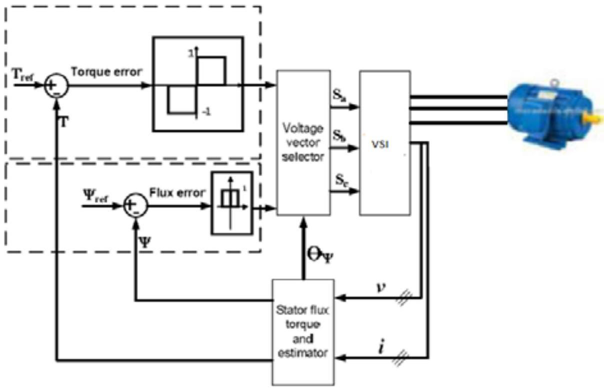


Fig: 1 Schematic Diagram of Conventional DTC

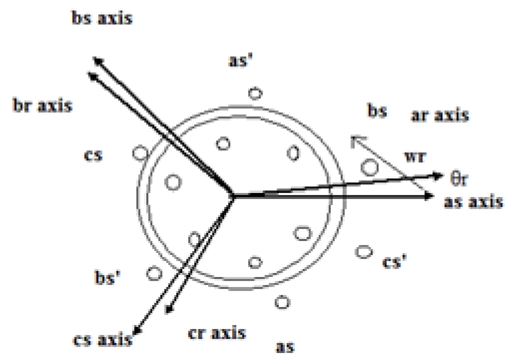


Fig. 2 Winding arrangement of 2 pole 3 phase induction motor

The instantaneous values of flux and torque are calculated from stator variables by using flux and torque estimating equations in the machine model. The reference stator flux f_s* and reference torque T_e * magnitude are compared with their respective estimated values and the errors are processed by the hysteresis band controllers.

The flux controller has two levels of digital output according to following equation.

$H_\Psi=1$ for $E_\Psi > +HB_\Psi$ (1)

$H_\Psi= -1$ for $E_\Psi > -HB_\Psi$ (2)

where $2HB_\Psi$ is the total hysteresis bandwidth of the controller. The actual stator flux is constrained within the hysteresis band and tracks the command flux. The torque controller has two levels of digital output according to following equation.

$H_T=1$ for $E_T > +HB_T$ (3)

$H_T= -1$ for $E_T > -HB_T$ (4)

$H_T= 0$ for $-HB_T < E_T < + HB_T$ (5)

The lookup table for conventional DTC scheme is given below.

TABLE 1
LOOKUP TABLE FOR CONVENTIONAL DTC

H_Ψ	H_T	S(1)	S(2)	S(3)	S(4)	S(5)	S(6)
1	1	V_2	V_3	V_4	V_5	V_6	V_1
	0	V_0	V_7	V_0	V_7	V_0	V_7
	-1	V_6	V_1	V_2	V_3	V_4	V_5
-1	1	V_3	V_4	V_5	V_1	V_2	V_3
	0	V_7	V_0	V_7	V_0	V_7	V_0
	-1	V_5	V_6	V_1	V_2	V_3	V_4

2.2 Modeling of Induction motor

The winding arrangement of a two-pole, three-phase – Y connected induction machine is shown in Fig. 2. The stator windings of which are identical, sinusoidally distributed in space with a phase displacement of 120^0, with equivalent turns and resistance rs

In order to apply generalised machine theory to polyphase induction machines, it is essential to have d,q axis fixed on the stator. Since the 3-phase winding A,B,C on the stator and d,q axes are stationary with respect to each other the transformation matrix from ABC to dq or vice versa should contain constant coefficients.

On expanding the above matrix transformation equation ,

$$i_{ds}= I_m \cos(\omega t+\alpha) \text{ and } iqs=I_m \sin(\omega t+\alpha)$$

This indicates that d,q axes currents are also functions of time and are displaced each other by a phase angle 90^0.That is i_{ds},i_{qs} constitute a two phase system having a frequency equal to the three phase supply frequency.

The electrical and mechanical system equations are given by Vs $= R_s\, i_s + 1/w_o\, (df_s/dt) + w_k\, M(pi/2)\, f_s$ (6)

$Vr = R_r\, i_r + 1/wo\, (df_r/dt) + (w_k - w_m)\, M(pi/2)\, f_r$ (7)

where the variables i, v, and f are 2-dimensional space vectors; for instance i_s ,stator current= $[i_{ds}\ i_{qs}]$, f_s ,stator flux = $[f_{ds}\ \ f_{qs}]$ and so forth, w_k is the speed of the reference frame, wm the rotor speed, and M(pi/2)represents a 90^o space rotator namely M(pi/2) = [0 -1;1 0]

Electromagnetic torque, Te = $2H\, (dw_m/dt) + B_m\, w_m + T_l)$ (8)

Where H=inertia constant

B_m=Viscous coefficient of friction in Nm/rad/sec and

T_l=Load torque in Nm

where Te = f_s (cross) i_s = M(pi/2) f_s (dot) i_s

$= f_{ds}\, i_{qs} - f_{qs}\, i_{ds}$ (9)

$= f_s \times i_s = M(pi/2)\, f_s \,.\, i_s$ (10)

$= i_r \times f_r = L_m\, (i_r \times i_s) = L_m/Lr\, (f_r \times i_s)$ (11)

$= 1/L_m'\, (f_r \times f_s) \quad L_m' = L_m\, c/(1-c) \quad c = 1 - L_m\text{^}2/(L_s\, L_r)$ (12)

2.3 Modeling of Three Phase Inverter

The dc to ac converters are known as inverters, depending on the type of the supply source and the related topology of the power circuit, inverters are classified as voltage source inverters (VSIs) and current source inverters (CSIs). Single-phase VSIs have low-range power applications and three-phase VSIs have medium to high power applications. The main objective of three phase topologies is to provide a three-phase voltage source, where the amplitude, phase and frequency can be controlled. The three-phase inverters are extensively used in mc power flow controllers in rd three-phase inverter sh hing of which depends on

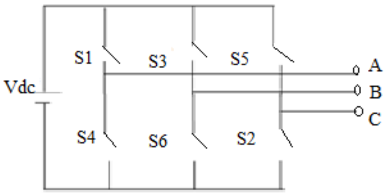


Fig. 3 Basic Three Phase inverter

The inverter has eight switch states as given in the below table. In order to satisfy KCL and KVL, both of the switches in the same leg cannot be turned ON at the same time, as it would short the input voltage violating the KVL. Thus the nature of the two switches in the same leg is complementary.

$$S_{11}+S_{12}=1 \quad (13)$$

$$S_{21}+S_{22}=1 \quad (14)$$

$$S_{31}+S_{32}=1 \quad (15)$$

3 MODIFIED DTC

The basic functional blocks used to implement the SVPWM DTC scheme is shown below.

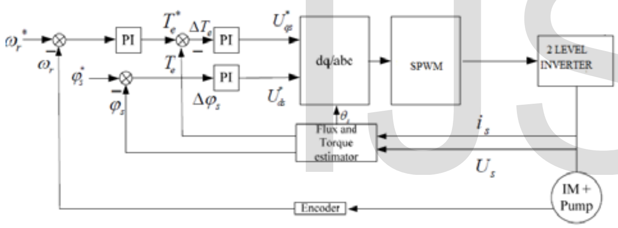


Fig. 4: Block Diagram of SPWM DT C Scheme

3.1 SPWM DTC Scheme

In the proposed system, flux and torque estimating equations are used to determine the actual value of the flux linkage and torque. Instead of the lookup table and hysteresis controllers, two PI controllers and numeric calculations are used to create the voltages corresponding to dq stationary reference frame (U_{ds} & U_{qs}).This corresponding quantities are transformed into abc frame and reference voltage which compensates the error is created which is used for modulating with the carrier. In this way switching signals are generated which is given to the inverter and the inverter output is fed to induction motor terminals.

3.2 SVPWM DTC Scheme

In this system also, flux and torque [4] estimating equations are used to determine the actual value of the flux linkage and torque. Instead of the lookup table and hysteresis controllers, a PI controller and numeric calculation are used to create the voltages corresponding to dq stationary reference frame (U_{ds} & U_{qs}).This quantities are transformed into abc frame and is used for creating reference voltage.Sector selection is done using the value of torque angle θ_s .This reference voltage is used for modulating with the carrier and according to that switching signals are generated which is given to the inverter and the inverter output is fed to induction motor.Since the controllers produce the voltage command vector, appropriate space voltage vector can be generated with SVM and fixed switching frequency can be achieved.

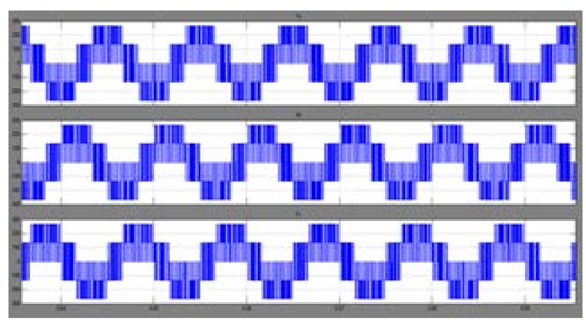
4 SIMULATION RESULTS

The conventional DTC and modified DTC scheme for induction motor with 2 level and three level inverter are simulated using Matlab/Simulink and their results have been compared. The motor parameters are given below.A three phase squirrel cage induction motor with 4 poles is used for simulation work.

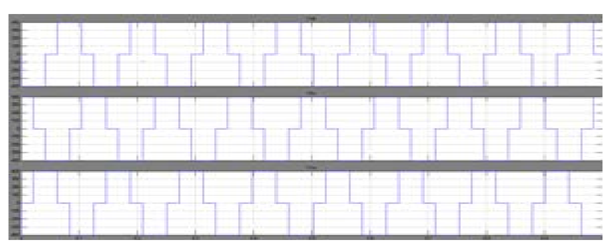
TABLE 2
MOTOR PARAMETERS

Power	3 hp
Type	SCIM
Supply Voltage	400v
Frequency	50 Hz
Stator Resistance	1.77 ohm
Rotor Resistance,	1.34 ohm
Stator self Inductance	13.93mH
Rotor self inductance	12.12mH
Mutual Inductane	369mH
Moment of Inertia	.025
No: of poles	4

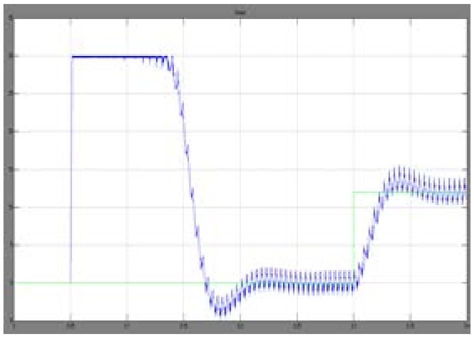
The simulation results are given below.



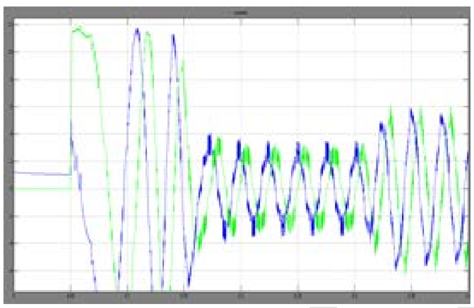
(a)



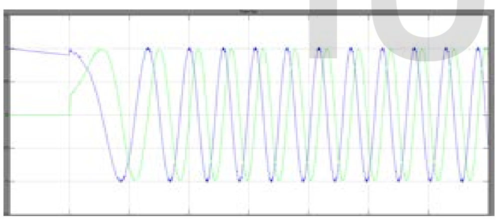
(b)



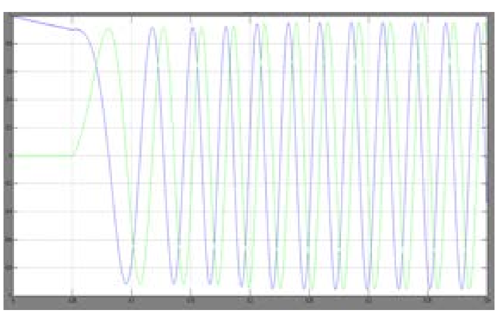
(c)



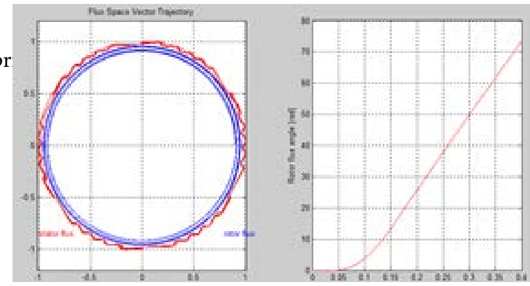
(d)



(e)



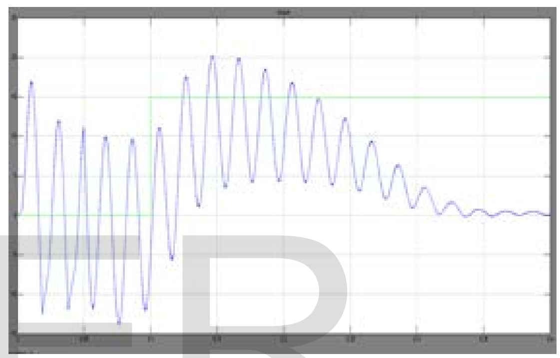
(f)



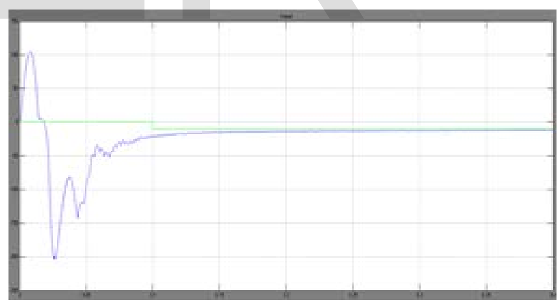
(g)

Fig. 5 Conventional DTC a) inverter phase voltages b) inverter line voltages c) output torque d) stator currents e) stator flux f) rotor flux g) stator and rotor flux trajectory

The output torque waveforms for two level inverter with SPWM and SVPWM are given below.



(a)



(b)

Fig.6 Conventional DTC a) output torque of SPWM DTC scheme b) output torque of SVM DTC scheme

5 CONCLUSION

This project has reviewed Direct Torque Control strategies inverter-fed induction motor drives. The DTC represents a considerable alternative to Field Oriented Control (FOC).Among the DTC strategies ,the drive performance in terms of reduced torque and flux ripples are found in modified DTC schemes when compared to hysteresis-based lookup table DTC. When SVM is incorporated instead of SPWM, the torque ripple and current ripple is found more reduced.

REFERENCES

[1] S. A. Zaid, O. A. Mahgoub, and K. El-Metwally, "Implementation of a new fast direct torque control algorithm for induction motor drives," IET Electr. Power Appl., vol. 4, no. 5, pp. 305-313, May 2010.

[2] G. S. Buja and M. P. Kazmierkowski, "Direct torque control of PWM inverter-fed AC motors-A survey," IEEE Trans. Ind. Electron., vol. 51, no. 4, pp. 744757, Aug.2004.

[3] Casadei, F. Profumo, G. Serra, and A. Tani, "FOC and DTC: Two viable schemes for induction motors torque control", IEEE Trans. Power Electron., vol.17, no. 5, pp. 779787, Sep. 2002

[4] K. B. Lee and J. H. Song, "Torque ripple reduction in DTC of induction motor driven by three-level inverter with low switching frequency," IEEE Trans. Power Electron., vol. 17, no. 2, pp. 255-264, Mar. 2002.

[5] M. Depenbrock, "Direct self-control (DSC) of inverter-fed induction machine,"IEEE Trans. Power Electron., vol. 3, no. 4, pp. 420-429, Oct. 1988

[6] P. C. Krause, O. Wasynczuk, S. D. Sudhoff “Analysis of Electric Machinery and Drive Systems”, IEEE Press, A John Wiley & Sons, Inc. Publication Second Edition, 2002.

[7] P.C. Krause and C. H. Thomas, “Simulation of Symmetrical Induction Machinery”, IEEE Transaction on Power Apparatus and Systems, Vol. 84, November 1965, pp. 1038-1053.

[8] I. Takahashi and T. Noguchi, "A new quick-response and high-efficiency control strategy of an induction motor" IEEE Trans. Ind. Appl., vol. IA- 22,989.