Control of Induction Motor in Forward and Reverse Direction using DTC Technique

K.Lavanya[1], V.Rangavalli[2]
Department of Electrical and Electronics engineering
[1, 2] ANITS

Abstract- *This paper describes the control of induction motor using classical DTC (direct torque control) where the stator flux and torque are controlled directly by selecting the appropriate states of a two level inverter with the help of transient response in torque and stator flux linkages. This paper presents controlling the induction machine in four quadrants DTC has emerged over the last decade to become one possible alternative to the well-known Vector Control of Induction machines as it is a control technique in ac drive system to obtain high dynamic torque performance. The induction motor modelling and implementation of classical DTC control scheme using simulation and also those simulation results are presented in the paper.*

Keywords- DTC, Induction motor modelling, Two level voltage source inverter.

I. INTRODUCTION

AC asynchronous motor, also called as induction motor has become the most widespread electrical motor in use today. These facts are due to the induction motors advantages over the rest of the motors. The main advantage they do not need any mechanical commutator, leading to the fact that they are maintenance free motors. Induction motors also have low weight and inertia, high efficiency and a high overload capability. Therefore, they are cheaper and more robust, and less proves to any failure at high speeds. Furthermore, the motor can work in explosive environments because no sparks are produced. However, mechanical energy is more than often required at producing an infinitely variable induction motor speed drive is to supply the induction motor with the three phase voltages of variable frequency and variable amplitude. A variable frequency is required because the rotor speed depends on the speed of the rotating magnetic field provided by the stator. A variable voltage is required because the motor impedance reduces at low frequencies and consequently the current has to be limited by means of reducing the supply voltages.

II. THEORITICAL ANALYSIS

INDUCTION MOTOR MODELLING:

Dynamic d-q modelling: The following assumptions are made to derive the dynamic model: (i) uniform air gap, (ii) inductance versus rotor position in sinusoidal, (iii) Saturation and parameter changes are neglected. The dynamic performance of an ac machine is somewhat complex because the three-phase rotor windings move with respect to the three-phase stator windings.

Basically, it can be looked on as a transformer with a moving secondary, where the coupling coefficients between the stator and rotor phases change continuously with the change of rotor position correspond to rotor direct and quadrature axes. The machine model can be described by differential equations with time-varying mutual inductances, but such a model tends to be very complex.

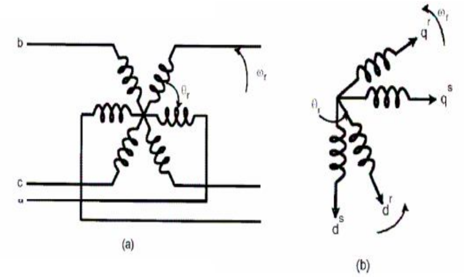

Figure.1 (a) coupling effect in three-phase stator and rotor windings of motor, (b) Equivalent two-phase machine

$$V_{qs}^{s} = \frac{2}{3}V_{as} - \frac{1}{3}V_{bs} - \frac{1}{3}V_{cs} = V_{as}$$

$$V_{ds}^{s} = -\frac{1}{\sqrt{3}}V_{bs} + \frac{1}{\sqrt{3}}V_{cs}$$

$$V_{ds}^{s} = -V_{qs}\sin\theta_e + V_{ds}\cos\theta_e$$

$$V_{qs}^{s} = V_{qs}\cos\theta_e + V_{ds}\sin\theta_e$$

$$\bar{V} = V_{qs}^{s} - jV_{ds}^{s}$$

$$= \left(\frac{2}{3}V_{as} - \frac{1}{3}V_{bs} - \frac{1}{3}V_{cs}\right) - j\left(-\frac{1}{\sqrt{3}}V_{bs} + \frac{1}{\sqrt{3}}V_{cs}\right)$$

$$= \frac{2}{3}\left[V_{as} + aV_{bs} + a^2V_{cs}\right]$$

(Where a=$e^{j2\Pi/3}$ & $a^2 = e^{-j2\Pi/3)}$

III. DIRECT TORQUE CONTROL

In a DTC drive, flux linkage and electromagnetic torque are controlled directly independently by the selection of optimum inverter switching modes. The selection is made to restrict the flux linkages and electromagnetic torque errors within the respective flux and torque hysteresis bands, to obtain fast torque response, low inverter switching frequency and low harmonic losses. The required optimal switching vectors can be selected by using so-called optimum switching-voltage vector look-up table. This can be obtained by simple physical considerations involving the position of the stator-flux linkage space vector, the available switching vectors, and the required torque flux linkage.The magnitude of torque is [2]

$$\overline{T}_e = \frac{3}{2}\left(\frac{P}{2}\right)\frac{L_m}{L_r L_s^{'}}\left|\overline{\psi}_r\right|\left|\overline{\psi}_s\right|\sin\gamma$$

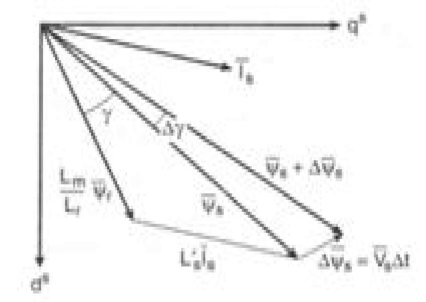

Figure.2 Stator flux, rotor flux, and stator current vectors on d_s-$q_s$plane.

CONTROL STRATEGY OF DTC

The command stator flux $\hat{\psi}_s^*$ and torque T_e^* magnitudes are compared with the respective estimated values and the errors are processed through hysteresis-band controllers. The flux loop controller has two levels of digital outputs according to the following relations:

$$H_\psi = \ 1 \quad \text{for} \quad E_\psi > +HB_\psi$$

$$H_\psi = -1 \quad \text{for} \quad E_\psi < -HB_\psi$$ Where $2HB_\psi$ = total hysteresis - band width controller.

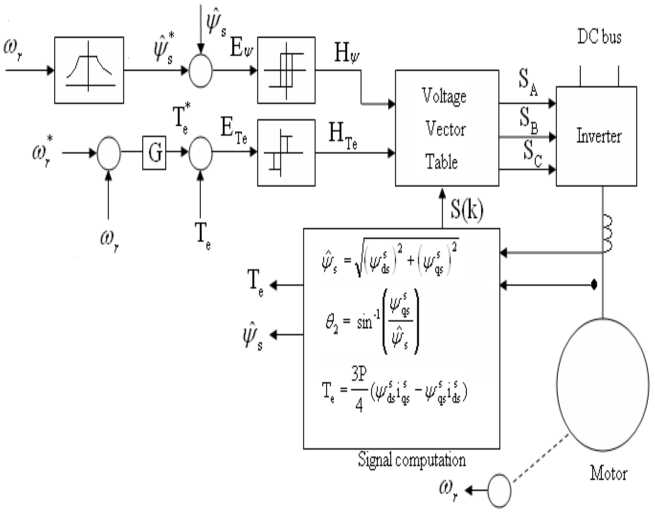

Figure.3 DTC control block diagram

The circular trajectory of the command flux vector $\hat{\psi}_s^*$ with the hysteresis band rotates in an anti-clockwise direction as shown in Figure.3.The actual stator flux $\overline{\psi}_S$ is constrained within the hysteresis band and it tracks the command flux in a zigzag path. The torque control loop has three levels of digital output, which have the following relations:

$$H_{Te} = \ 1 \quad \text{for} \quad E_{Te} > +HB_{Te}$$

$$H_{Te} = -1 \quad \text{for} \quad E_{Te} < -HB_{Te}$$

$$H_{Te} = \ 0 \quad \text{for} \quad -HB_{Te} < E_{Te} < +HB_{Te}$$

The feedback flux and torque are calculated from the machine terminal voltages and currents. The signal computation block also calculates the sector number *S (k)* in which the flux vector ψ_s lies. There are six sectors. The voltage vector table block receives the input signals H_ψ, H_{Te}, and *S(k)*and generates the appropriate control voltage vector (switching states) for the inverter by lookup table .Which means that $\overline{\psi}_S$ can be changed incrementally by applying stator voltage $\overline{V}_s$ for time increment Δt. Table 1 applies the selected voltage vector, which essentially affects both the torque and flux simultaneously. The flux trajectory segments AB, BC, CD and DE by the respective voltage vectors $\overline{V}_3$,$\overline{V}_4$,$\overline{V}_3$, and$\overline{V}_4$ are shown .The total and incremental torque due to $\Delta\overline{\psi}_s$ are explained in Figure 2. Note that the stator flux voltage vectors changes quickly, but the $\overline{\psi}_r$ change is very sluggish due to large time constant T_r.

The average speed of both, however, remains the same in the steady-state condition. Table 5.3.4 summarizes the flux and torque change for applying the voltage vectors.

H_Ψ	H_T	S1	S2	S3	S4	S5	S6
1	1	V2	V3	V4	V5	V6	V1
	0	V0	V7	V0	V7	V0	V7
	-1	V6	V1	V2	V3	V4	V5
-1	1	V3	V4	V5	V6	V1	V2
	0	V7	V0	V7	V0	V7	V0
	-1	V5	V6	V1	V2	V3	V4

Table.1 switching table of voltage vectors [4]

Voltage vector	V1	V2	V3	V4	V5	V6	V0 or V7
Ψ_s	↑	↑	↓	↓	↓	↑	0
T_e	↓	↑	↑	↑	↓	↓	↓

Table.2 Flux and Torque variations [3]

Similarly, torque is increased by the $\overline{V}_2$,$\overline{V}_3$, and $\overline{V}_4$ Vectors, but decreased by the $\overline{V}_1$,$\overline{V}_5$, and $\overline{V}_6$ vectors. The zero vectors short-circuit the machine terminals and keep the flux and torque unaltered. Due to finite resistance drop, the torque and flux will slightly decrease during the short-circuit condition.Consider for example, an operation in sector S (2) , where at point B, the flux is too high and the torque is too low. $H_\psi = -1$

$H_{Te} = +1$

From table, voltage V_4 is applied to the inverter, which will generate the trajectory BC. At point C, $H_\psi = +1$ and $H_{Te} = +1$ and this will generate the V_3 vector from the table. The drive can easily operate in the four quadrants, and speed loop and field-weakening control can be added, if desired. The torque response of the drive is claimed to be comparable with that of a vector-controlled drive.

IV. SIMULINK MODEL OF INDUCTON MOTOR

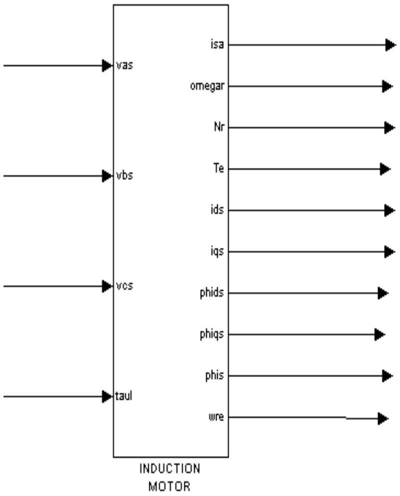

Figure .4 Induction motor block

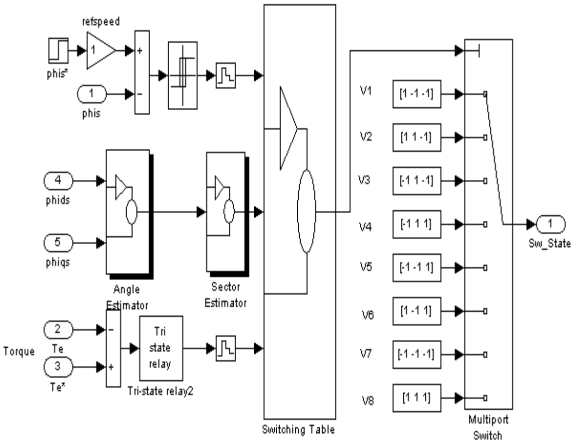

Figure.5 DTC switching block

V. SIMULINK DIAGRAM OF DTC OF INDUCTION MOTOR

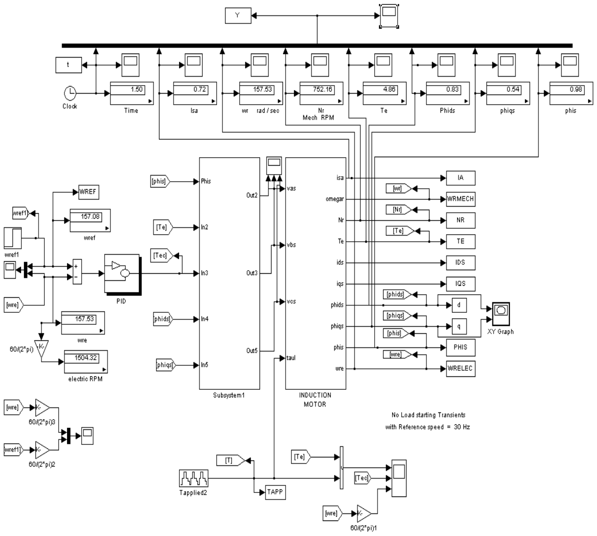

Figure.6 Simulink models for DTC of induction motor

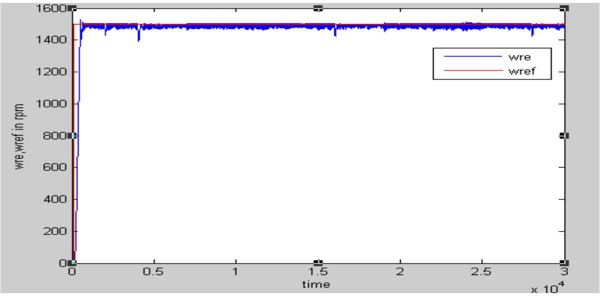

Fig 5.1 Speed response of induction motor when reference speed is maintained constant

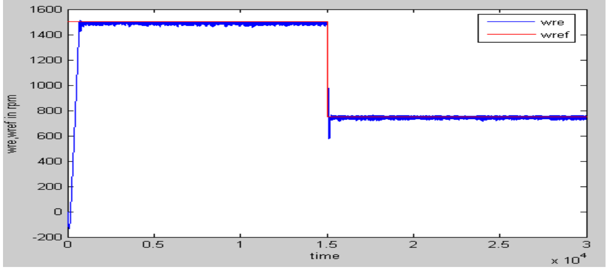

Fig 5.2 speed variation of induction motor at 0 to 1.5 sec

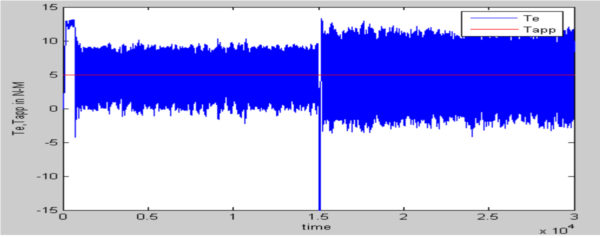

Fig 5.3 Torque response of induction motor when load is constant

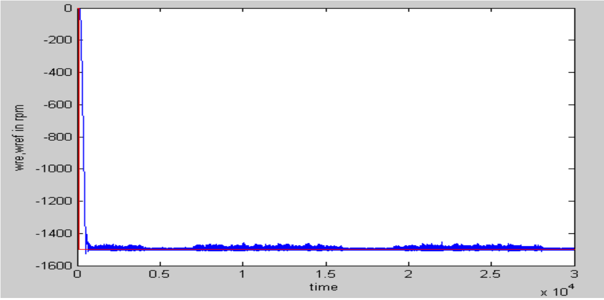

Fig 5.4 speed response of induction motor when speed is reversed

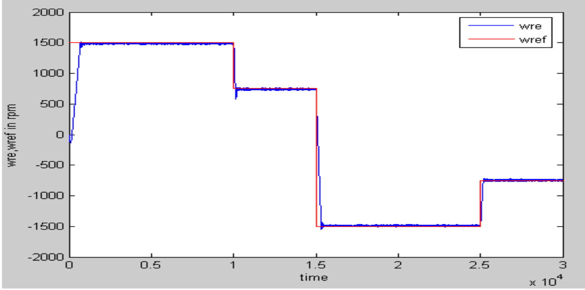

Fig 5.5 speed response of IM when speed is in forward and reverse direction

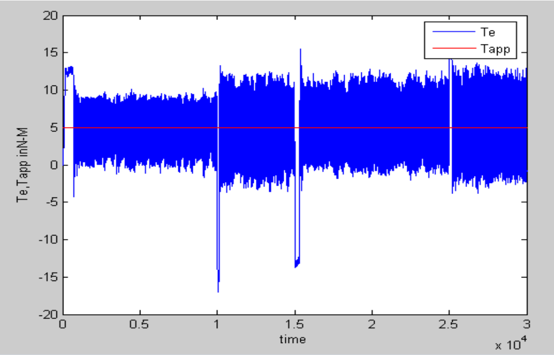

Fig 5.6 Torque response of induction motor when load is constant

VI. CONCLUSION

The simulation results shows that torque and speed responses are very good dynamic torque response for the direct torque control of the induction motor in forward and reverse speed directions. A direct torque control of induction motor is developed in Simulink environment. Its dynamic performances have been subjected to sudden changes in load and reference speed. With DTC scheme employing a voltage source inverter (VSI), it is possible to control directly the stator flux linkage and the electromagnetic torque by optimum selection of inverter switching vectors. The selection of inverter switching vector is made to restrict the flux and torque errors within the respective flux and torque hysteresis bands. This achieves a fast torque response. DTC-SVM strategy realizes minimum ripple free operation for the entire speed range. Consequently, the flux, torque and speed estimation is improved. The switching frequency is constant and controllable. In fact, the better results are due to the increasing of the switching frequency. While for DTC a single voltage vector is applied during one sampling time, for DTC–SVM a sequence of six vectors is applied during the same time. This is the merit of SVM strategy. The DTC-SVM controller does not depend on motor parameters and is relatively robust as was proved by simulation. The developed model is used load can be changed in short interval of time.

The parameters of the induction motor are:

Rotor resistance	6.03 ohm
Stator resistance	6.08 ohm
Stator leakage inductance	489.3 MH
Rotor leakage inductance	489.3 MH
Number of poles	4
Magnetizing inductance	450.3 MH

LIMITATIONS

No matter how comprehensive a system is, there will be few limitations or shortcomings. The variations in the reference speed and load are limited by induction motor parameters. The limitations direct torque control is the torque and flux ripples still exit in the output.

FURTURE SCOPE

All further work is summarized schematically in the following ideas:

- Development of new direct torque control by using fuzzy logic and neural networks to get better performance.
- Development of fuzzy duty ratio controller DTC.
- Study the torque ripples not only with fuzzy logic but also with multilevel inverters.

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AUTHORS

First Author: Received her Master degree in 2010 in Power Electronic from JNTU University (AURORA Eng College), Hyderabad, India, and Bachelor degree in 2005 in Electrical & Electronics Engineering from TPIST, Bobbili, India. She had 6 years teaching experience. She is currently working as an Assistant Professor of Electrical and Electronics Engineering Department at ANITS, Visakhapatnam, India.
Mail id: lavanyagumpena1008@gmail.com

Second Author: Received her Master degree in 2012 in Control systems at Anits, Visakhapatnam, India, and Bachelor degree in 2007 in Electrical & Electronics Engineering from SVP Engg.college, P.M Palem, and India. She is currently working as an Assistant Professor of Electrical and Electronics Engineering Department at ANITS, Visakhapatnam, India.
Mail id: rangavallivasa@gmail.com