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Direct Torque Control of Induction Motor Drive using Space Vector Modulation Technique

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Abstract: **The operation of the induction motor can be analyzed similar to a DC motor through direct torque control method. The axis control with variable speed in low power applications with these technological projections, various command approaches have been developed by the scientific community to master in real time, the flux and the torque of the electrical machines, the direct torque control (DTC) scheme being one of the most recent steps in this direction. This scheme provides excellent properties of regulation without rotational speed feedback. In this control scheme the electromagnetic torque and stator flux magnitude are estimated with only stator voltages and currents and this estimation does not depend on motor parameters except for the stator resistance. Induction motor has been simulated in stationary d-q reference frame and its free acceleration characteristics are drawn. Review has been done to study the recent improvements in DTC scheme which somehow is able to overcome the drawbacks of conventional one. The space vector modulation technique (SVPWM) is applied to inverter control in the vector control based induction motor drive system, thereby dramatically reducing the torque ripple.**

***Keywords*: Induction motor (IM) drives, Direct Torque Control (DTC).**

I. INTRODUCTION

1.1 Induction motor drives

DC drives are advantageous in many aspects as in delivering high starting torque, ease of control and nonlinear performance. But due to the major drawbacks of DC machine such as presence of mechanical commutator and brush assembly, DC machine drives have become obsolete today in industrial applications. The robustness, low cost, the better performance and the ease of maintenance make the asynchronous motor advantageous in many industrial applications or general applications. Squirrel cage induction motors (SCIM) are more widely used than all the rest of the electric motors as they have all the advantages of AC motors and are cheaper in cost as compared to Slip Ring Induction motors; require less maintenance and rugged construction. Because of the absence of slip rings, brushes maintenance duration and cost associated with the wear and tear of brushes are minimized. Due to these advantages, the induction motors have been the execution element of most of the electrical drive system for all related aspects: starting, braking, speed change and speed reversal etc. To reach the best efficiency of induction motor drive (IMD), many new techniques of control has been developed in the last few years. Now-a-days, using modern high switching frequency power converters controlled by microcontrollers, the frequency, phase and magnitude of the input to an AC motor can be changed, hence the motor speed and torque can be controlled. Today, it is possible to deal with the axis control of machine drives with variable speed in low power applications mostly due to joint progress of the power electronics and numerical electronics. The dynamic operation of the induction machine drive system has an important role on the overall performance of the system of which it is a part.

Types of control schemes

There are two important steps to design a control system for electrical drives
1. In order to accomplish the analysis and the evaluation of the system, first the drive system has to be converted into a mathematical model.
2. When external perturbations are present, through an optimal regulator the imposed
Response on the system is obtained.

Classification of control techniques for IM from the view point of the controlled signal
Scalar control: based on relationships valid in steady state, only magnitude and frequency of voltage, current and flux linkage space vectors are controlled, disregards the coupling effect in the machine.
Vector control: based on relations valid in dynamics state, not only magnitude and frequency but also instantaneous position of voltage, current and flux linkage space vector are
controlled. The most popular vector control methods are the Field oriented control (FOC) and
DTC. Scalar controlled drives give somewhat inferior performance, but easy to implement.
Their importance has been diminished recently because of the superior performance of vector
Control drives which is demanded in many applications.

1.2 Direct torque control

This control scheme is considered as the world's most advanced AC Drives control technologies. This is a simple control technique which does not require coordinate transformation, PI regulators, and Pulse width modulator and position encoders. This technique results in direct and independent control of motor torque and flux by selecting optimum inverter switching modes. The electromagnetic torque and stator flux are calculated from the primary motor inputs e.g. stator voltages and currents. The optimum voltage vector selection for the inverter is made so as to restrict the torque and flux errors within the hysteresis bands. The advantages of this control technique are quick torque response in transient operation and also improvement in the steady state efficiency.

II. INDUCTION MACHINE MODEL

The induction machine mathematical model is derived taking stator currents and rotor fluxes as state variables are

$$\frac{d}{dt}\begin{bmatrix} i_s \\ \Psi_r \end{bmatrix} = \begin{bmatrix} A_{11} & A_{12} \\ A_{21} & A_{22} \end{bmatrix}\begin{bmatrix} i_s \\ \Psi_r \end{bmatrix} + \begin{bmatrix} B \\ 0 \end{bmatrix} v_s$$

$A_{11} = \frac{-Rs}{(\sigma Ls)} + (1-\sigma)/\sigma\tau_r\ ) I$

$A_{11} = a_{r11} I$

$A_{12} = Lm / (\sigma\ LsLr)\ (1/\sigma\tau_r\ I - \omega_r\ J)$

$A_{12} = a_{r11} I + a_{i12} J$

$A_{21} = (\frac{Lm}{\tau_r}) I$

$A_{21} = a_{r21} I$

$A_{22} = (\frac{-1}{\tau_r}) I + \omega_r\ J$

$A_{22} = a_{r22} I + a_{i22} J$

$B = \frac{1}{(\sigma Ls)}\begin{bmatrix} I \\ 0 \end{bmatrix}$ C=[I 0]

III. PRINCIPLES OF DTC

The idea of direct torque control (DTC) was to control the stator flux linkage and the torque directly, not via controlling the stator current. This was done by controlling the power switches directly using the output of hysteresis comparator for the torque & the modules of the stator flux linkage and selecting an appropriate voltage from a predefined switching table. Figure1 shows the direct torque control scheme for induction motor drives. The main building blocks are speed PI controller, flux, torque and field angle calculator, torque and flux hysteresis comparators, optimum voltage vector selection table and inverter. The DTC control scheme was done by controlling the power switches directly by switching the eight voltage vector so as to keep the flux and torque within the specified limits of torque and flux hysteresis comparators. Here rotor speed is compared with the reference speed and given to speed controller which has PI controller gives reference torque and a field weakening controller which is for above rated speed operations. The reference flux and torque is compared with calculated torque and flux. The error signals are given to the hysteresis controllers and these signals along with sector value are used to give optimum voltage signals to the inverter based on the designed optimum switching table. The parameters required for the DTC control scheme are stator currents and the armature resistance of the Induction motor.

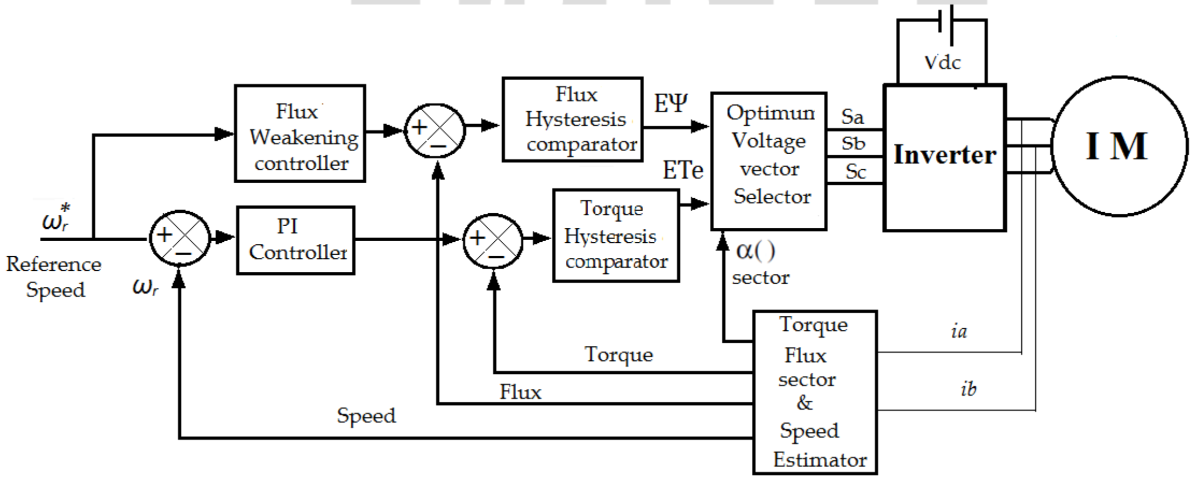

Figure.1 Direct Torque Control Scheme of Induction Motor

1. PI and Filed weakening controllers

The PI controller amplifies speed error ω_{er} and gives reference electromagnetic torque T_e' as the output. The speed error is the difference between the reference speed ω_r' and the measured rotor speed ω_r. The field weakening controller is used when the drive is to operate above the rated speed. Below the rated speed the reference value of the stator flux is considered as

$$\Psi_{sref} = \Psi_k$$

The reference value of the stator flux linkage above rated speed is considered as the function of rotor speed as:
$\Psi_{sref} = \Psi_k(\omega_b/\omega_r)$

Where Ψ_k the rated flux, $\omega_b$is is base speed and ω_r is the rotor speed of the motor.

2. Hysteresis controllers

The electromagnetic torque and estimated stator flux linkage are compared with the reference value. The torque error and flux error are fed to the hysteresis controllers used for selecting appropriate voltage vector according to the switching table

The torque and flux errors are given by

$$e_{Te} = T_{ref} - T_{est}$$

$$e_{\Psi} = \Psi_{sref} - \Psi_{esti}$$

The output of hysteresis controller can be defined as the following set of equations are given below

H_{Te} = 1 for $e_{Te} > +HB_{Te}$
H_{Te} = -1 for $e_{Te} > -HB_{Te}$
H_{Te} = 0 for $-HB_{Te} < e_{Te} < +HB_{Te}$

H_{Ψ} = +1 for $e_{\Psi} > +HB_{\Psi}$
H_{Ψ} = -1 for $e_{\Psi} > -HB_{\Psi}$

3. Flux, torque estimation and sector selection Here electromagnetic torque, stator flux and field angle is calculated using stationary reference frame theory applying in phase values.

The phase voltage and current components after applying transformations are given

$$v'_{ds} = -\frac{1}{\sqrt{3}}(v_{bs}+v_{cs})$$
$$v'_{qs} = -(v_{bs}-v_{cs})$$
$$i'_{ds} = -\frac{1}{\sqrt{3}}(i_{bs}+i_{cs})$$
$$i'_{qs} = -(i_{bs}-i_{cs})$$

The components of the stator flux is shown below

$\Psi_{ds} = \int_0^t (v_{ds} - R_s i_{ds})dt$
$\Psi_{qs} = \int_0^t (v_{qs} - R_s i_{qs})dt$

The stator flux linkage /phase is shown below

$\Psi_s = \sqrt{(\Psi_{ds}^2 + \Psi_{qs}^2)}$

Electromagnetic torque developed by the induction motor can be obtained from the knowledge of stator flux linkage and currents in stationary references (i_{ds}^s and i_{qs}^s) frame as

$$T_e = \frac{3}{2}\left[\frac{P}{2}(\Psi_{qs} i_{ds} - \Psi_{ds} i_{qs})\right]$$

Where, P = number of poles.

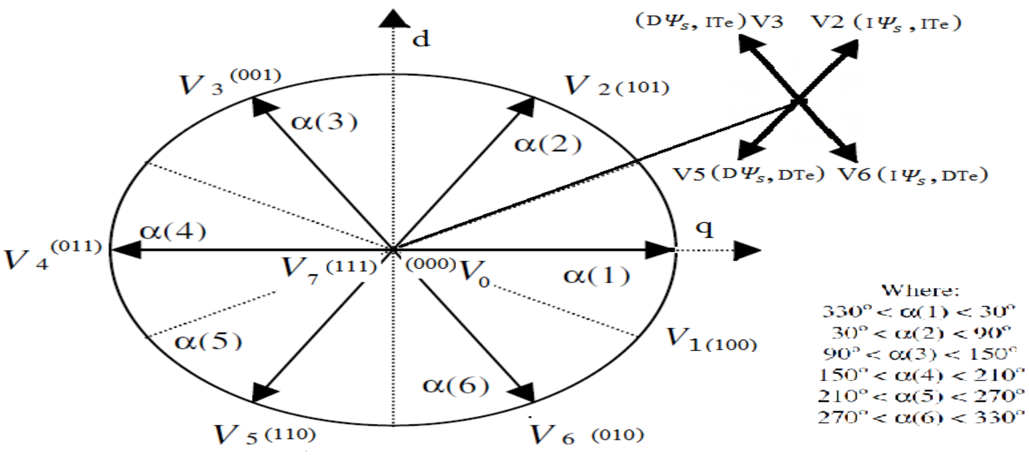

Table. I.

Optimum voltage vector switching table for six sector

H_ψ	H_{Te}	α (1)	α (2)	α (3)	α (4)	α (5)	α (6)
1	1	V_2	V_3	V_4	V_5	V_6	V_1
1	0	V_0	V_7	V_0	V_7	V_0	V_7
1	-1	V_6	V_1	V_2	V_3	V_4	V_5
0	1	V_3	V_4	V_5	V_6	V_1	V_2
0	0	V_7	V_0	V_7	V_0	V_7	V_0
0	-1	V_5	V_6	V_1	V_2	V_3	V_4

IV. SIMULATION RESULTS

The simulation of the DTC for Induction motor is done with MATLAB SIMULINK. Here the signals are sampled at the rate of T=20μs. In this simulation, reference flux is taken as 0.8 wb and electromagnetic torque is limited to 100 N-m. Fig. illustrates the speed response for reference speed of 100 rad/s. The electromagnetic torque and load torque of 10 N-m, motor and the simulated three phase line currents waveforms are depicted in Fig. The stator flux linkage corresponding to the given running condition is shown.

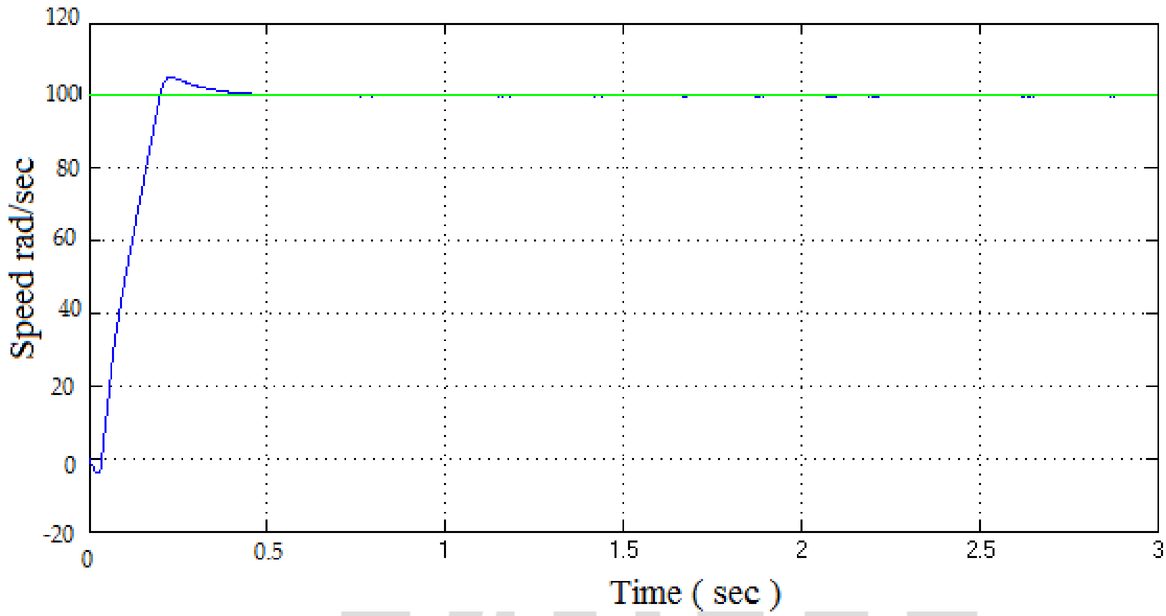

Figure.2 Reference speed and Actual speed

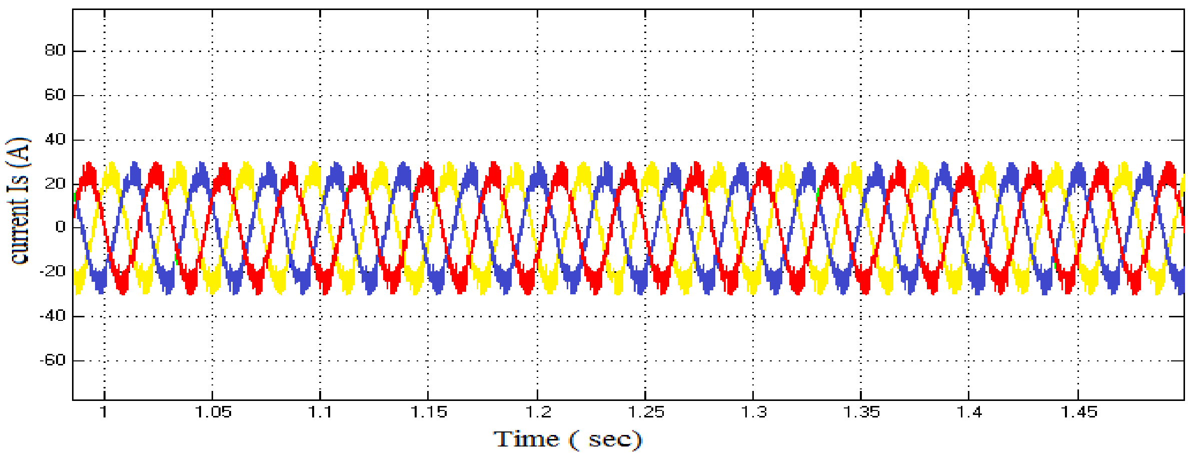

Figure.3 Stator current

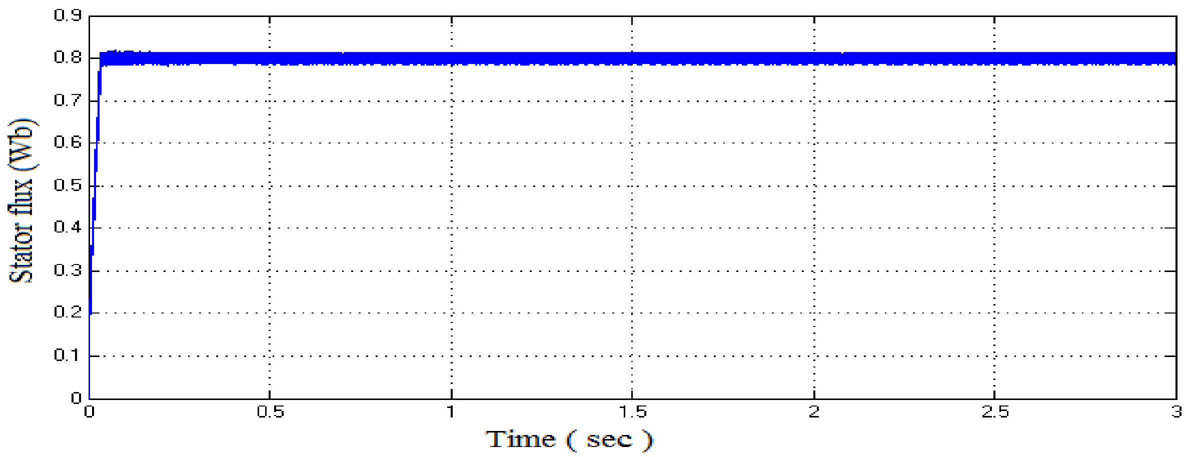

Figure.4 Magnitude of Stator Flux

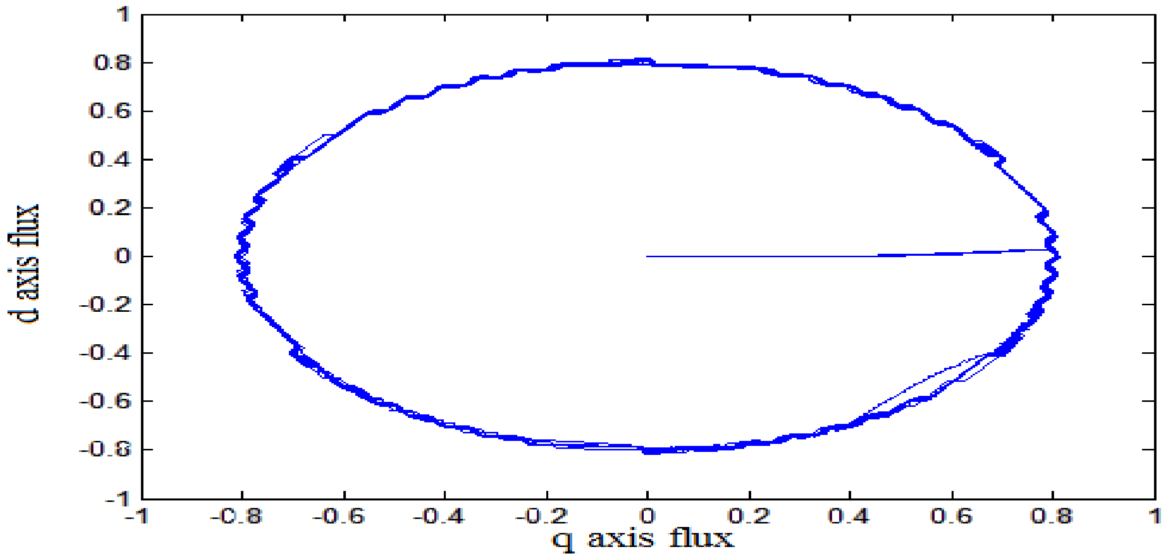

Figure.5 Direct and Quadratic axis flu

V. CONCLUSION

The advanced direct torque control (DTC) is presented in this paper using space vector. The main drawbacks like Torque & current ripples are reduced by dividing the sector into six parts and utilizing all the voltage vectors. The simulation results show considerable amount of reduction in torque ripples. For more advancement twelve sector DTC is used. The twelve sector DTC have good dynamic response & suitable for a kind of application-especially like traction, electric hybrid vehicles etc. Much research is going on to reduce the power consumption during operation, ANN, Fuzzy and genetic concepts are implemented instead of PI regulators and Hysteresis controllers etc to improve the performance.

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