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Comparative Analysis of Speed Control of Induction Motor by DTC over Scalar Control Technique

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ABSTRACT: This paper presents comparative analysis of induction motor speed control by DTC and Scalar control technique. The both Scalar control and direct torque control techniques are proposed. Speed control of induction motor under No-Load and Load conditions by both scalar and DTC control techniques. The basic two-level voltage source inverter is fed to three phase induction motor. SVPWM technique is used to generate switching signals for reference speed signal. The sensor-less speed controlling technique is used in the DTC control technique for speed estimation. The test simulation results are proposed in details verified MATLAB/Simulink.

KEYWORDS: speed control, I.M, scalar, DTC, SVPWM.

I.INTRODUCTION

Three-Phase induction motor had the wide range of applications like as industrial drives, Automotive etc. I.M drive requires variable speed operations based on applications, using of traditional speed controlling techniques will affect the efficiency of operating system. There are number of speed controlling techniques based on applications area [8]. The speed error of the induction motor will depends on the type of speed controlling and PWM techniques using in the system [4].

The Scalar controlling technique is depends on the variation of magnitudes of parameters for speed controlling. The frequently used scalar controlling is v/f control technique. The value of flux can be controlled by varying the voltage magnitude and the torque can be controlled by frequency or slip parameters [2-3]. The speed of induction motor can be controlled using v/f control, which is so simple and easy to control in industrial applications, here the ratio of voltage magnitude to frequency was maintained constant, in order to get the constant flux for producing the required torque over an entire operating range [1].

The scalar control technique has poor performance because of stator impedance drop leads to unstable due to variation in speed (torque) by variation in load conditions. To overcome the disadvantages of scalar control, vector control technique is proposed.

The vector control overcome these problems, here the torque and flux producing current components are decoupled, and the system will adapt to any load disturbances with good dynamic performance [5-6]. In this method, direct torque control is achieved by direct and independent control of the flux linkages and the electromagnetic torque through the selection of optimal inverter switching which gives fast torque response with constant flux.

In this paper comparative analysis had done between scalar control (v/f control) and Direct Torque Control (DTC) techniques. The paper was organized as Section II describes the Dynamic modeling of Three-Phase induction motor. SVPWM technique is mentioned in Section III. Section IV describes scalar control technique; vector control technique is in section V and finally concluded in section VI.

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II.DYNAMIC MODELLING OF INDUCTION MOTOR

Motor dynamic model in stationary frame

Machine model in stationary frame by Stanley equations substituting $\omega_e = 0$. The stator circuit equations are written as:

$$v_{qs}^{s} = R_s i_{qs}^{s} + \frac{d}{dt}\varphi_{qs}^{s} \ldots\ldots\ldots \qquad 1$$

$$v_{ds}^{s} = R_s i_{ds}^{s} + \frac{d}{dt}\varphi_{ds}^{s} \ldots\ldots\ldots \qquad 2$$

$$0 = R_r i_{qr}^{s} + \frac{d}{dt}\varphi_{qr}^{s} - w_r \varphi_{dr}^{s} \ldots\ldots \qquad 3$$

$$0 = R_r i_{dr}^{s} + \frac{d}{dt}\varphi_{dr}^{s} + w_r \varphi_{qr}^{s} \ldots\ldots \qquad 4$$

Where

$\varphi_{qs}^{s}, \varphi_{ds}^{s}$= q axis and d-axis stator flux linkages

$\varphi_{qr}^{s}, \varphi_{dr}^{s}$= q-axis and d-axis rotor flux linkages

R_s, R_r= stator and rotor resistances

w_r= rotor speed and $v_{qr} = v_{dr} = 0$

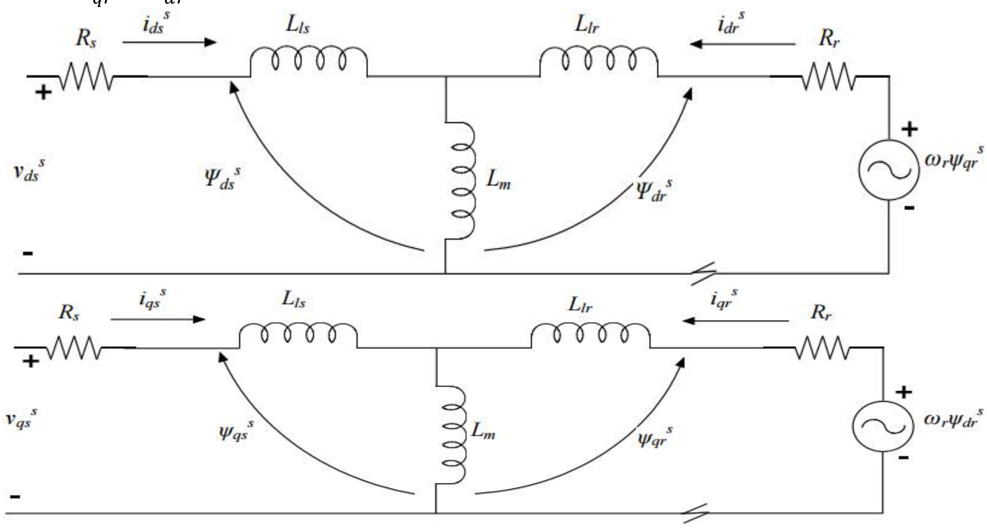

Fig 1: d^s-q^s equivalent circuits

The electromagnetic torque is developed by the interaction of air gap flux and rotor mmf which can be expressed in general vector form as

$$T_e = \frac{3}{2}.\frac{P}{2}\bar{\varphi}_m.T_r \ldots\ldots\ldots \qquad 5$$

The torque equations can be written in stationary frame with corresponding variables as

$$T_e = \frac{3}{2}.\frac{P}{2}\left(\varphi_{dm}^{s} i_{qr}^{s} - \varphi_{qm}^{s} i_{dr}^{s}\right)$$

$$= \frac{3}{2}.\frac{P}{2}\left(\varphi_{dm}^{s} i_{qs}^{s} - \varphi_{qm}^{s} i_{ds}^{s}\right)$$

$$= \frac{3}{2}.\frac{P}{2}\left(\varphi_{ds}^{s} i_{qs}^{s} - \varphi_{qs}^{s} i_{ds}^{s}\right)$$

$$= \frac{3}{2}.\frac{P}{2}L_m\left(i_{dr}^{s} i_{qs}^{s} - i_{qr}^{s} i_{ds}^{s}\right)$$

$$= \frac{3}{2}.\frac{P}{2}\left(\varphi_{dr}^{s} i_{qr}^{s} - \varphi_{qr}^{s} i_{dr}^{s}\right) \ldots\ldots\ldots \qquad 6$$

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III.SVPWM

Theory of Space vector pulse width modulation

When three phase supply is given to the stator of the induction machine, a three phase rotating magnetic field is produced [12]. Due to this field flux, a three phase rotating voltage vector is generated which lags the flux by 90º. This field can also be realized by a logical combination of the inverter switching which is the basic concept of SVPWM [7].

Realization of voltage space phasor

The three phase bridge inverter has eight possible switching states: six active and two zero states. The six switches have a well-defined state ON or OFF in each configurations. At a particular instant, only one switch in each of the three legs is ON. Corresponding to each state of the inverter, there is one voltage space vector. For example for state zero it is V0, for state 1 it is V1 and so on. These switching state vectors have equal magnitude but 60º apart from each other. These vectors can be written in generalized form as follows:

$$V_k = \begin{cases} V_{dc} e^{j\left(k-\frac{1}{3}\right)} & k = 1, 2, \dots, \\ 0 & k = 0, 7 \end{cases} \qquad 6$$

Where k = inverter state number.
Vdc = dc link voltage of the inverter
The inverter state vectors can be drawn as shown in fig.2

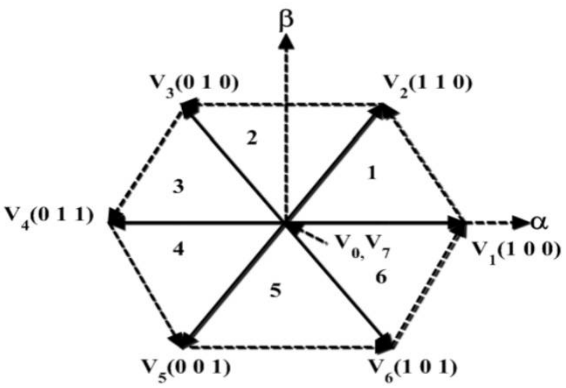

Fig 2: Inverter switching state vectors

The space bounded by two inverter space vectors is called a sector. So the plane is divided into six sectors each spanning 60º. In a balanced three phase system the voltage vectors are 120º apart in space and are represented by rotating vectors, whose projections on the fixed three phase axes are, sinusoidal waves. So they can be represented as three sinusoidal references by a voltage reference space vector Vref*or Vs*. The reference vector is assumed to be rotating in counter-clockwise direction with respect to ds-axis (α-axis) as shown in fig .2 through six sectors.

The reference space vector can be synthesized by a combination of eight state vectors and is constant in magnitude at switching instant t_s in case the switching frequency much higher than the output frequency. In a time average sense thereference vector at that instant can be approximated by two active voltage states of the inverter. For only certain amount of time these states are valid.

$$V_s^* = V_k t_k + V_{k+1} t_{k+1} \quad k = 0, 1, 2, \dots \dots \dots, \qquad 7$$

In SVPWM, it is assumed that the space phasor of stator voltageV_s^*, is moving in α-β plane with constant angular velocity describing approximately a circular path. The basis of SVPWM scheme is to sample the V_s^*at sufficiently high rate, in between the sampling instants the vector is assumed to be constant in magnitude as shown in fig 3.

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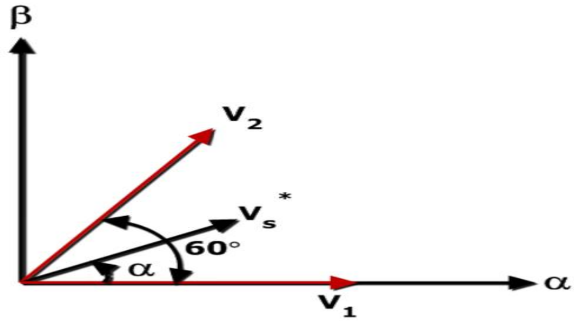

Fig 3: Reference vector in sector 1

In sector 1, the space voltage vector V1 is along α-axis, V_2 makes an angle 60º to V1 and at a particular instant Vs* is making an angle γ w.r.t V1. To generate the reference space vector in sector 1, the switching state vector V_1 is applied for an interval t_1, V_2 for t_2 and the two zero vectors V_0, V_7 for interval t_0, t_7 respectively. So the total sampling interval ts can be written as:

$$t_s = t_1 + t_2 + t_0 + t_7 \dots\dots\dots \qquad 7$$

Resolving Vs* and V_1, V_2 along the α-β axis, and by equating voltage-time integrals we get:

$$|V_s^*|t_s cos\gamma = |V_1|t_1 + |V_2|t_2 \cos\frac{\pi}{3} \dots\dots\dots \qquad 8$$

$$|V_s^*|t_s sin\gamma = |V_2|t_2 \sin\frac{\pi}{3} \dots\dots\dots \qquad 9$$

By the knowledge of t_0, t_1, t_2, t_7, the switching pattern can be determined if the vector is in sector 1. The four time intervals change simultaneously when Vs* goes from one sector to another for a particular modulation index a. The full cycle is completed by six similar sectors with label 1, 2,….6. As Vs* move over to sector 2, the inverter remains in switching state vector V_2 for time interval t_1 and in V_3 for time t_2. For sector 3: V_3 for t_1 and V_4 for t_2 and so on.

Pulse pattern generation

The PWM pattern generation means the generation of gating pulses for the six switches of the inverter, for correct interval so that appropriate switching state vectors are active for the appropriate time intervals as the reference space vector moves over a full cycle.

In order to obtain minimum switching frequency, it is desired that only one phase of the inverter changes state from $+Vdc/2$ to $-Vdc/2$ while changing the switching vectors. So the arrangement of the switching sequence should be such that the transition from one state to the next state is performed by switching only one inverter phase. This is done by switching the inverter legs in a sequence starting from one zero state and ending at another zero state.

The mean values of the phase to center tap voltages (V_{A0}, V_{B0}, and V_{C0}) can be evaluated, averaging over one sampling period ts as follows:

$$\overline{V_{A0}} = \frac{V_{dc}}{2t_s}\left(-\frac{t_0}{2} + t_1 + t_2 + \frac{t_0}{2}\right)$$

$$\overline{V_{B0}} = \frac{V_{dc}}{2t_s}\left(-\frac{t_0}{2} - t_1 + t_2 + \frac{t_0}{2}\right)$$

$$\overline{V_{C0}} = \frac{V_{dc}}{2t_s}\left(-\frac{t_0}{2} - t_1 - t_2 + \frac{t_0}{2}\right) \dots\dots\dots \qquad 10$$

Substituting the values of t1, t2 in above three equations

$$\overline{V_{A0}} = \frac{aV_{dc}}{\sqrt{3}} sin\left(\gamma + \frac{\pi}{3}\right)$$

$$\overline{V_{B0}} = aV_{dc} sin\left(\gamma - \frac{\pi}{6}\right)$$

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$$\overline{V_{C0}} = -\overline{V_{A0}}\ldots\ldots\ldots\ldots \quad 11$$

The mean value of the phase voltages obtained by SVPWM technique has triple harmonics which is eliminated in line voltage. The peak value of the line voltage is 15% more than that in sine PWM at maximum modulation index, so this method of PWM generation gives better utilization of dc bus voltage for inverter.

IV. SCALAR CONTROL

The block diagram for closed loop v/f control by controlling SVPWM technique is shown in Fig. 4. The relation between induced voltage and the flux is

$$v=k*\phi$$

$$\phi=v/f\approx k=\text{constant}$$

Where ϕ is the flux

From the block diagram, the reference speed compared to the actual speed then the PI-control generates the slip command i.e.

$\int w_e dt = w_e t\ldots\ldots\ldots\ldots 12$

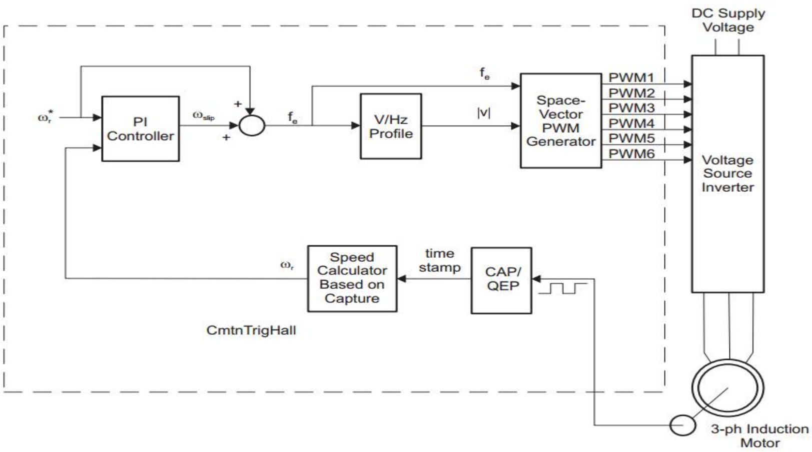

Fig 4: Block diagram for scalar control

From the last equation, it follows that if the ratio V/f remains constant for any change in f, then flux remains constant and the torque becomes independent of the supply frequency. In order to keep ΛM constant, the ratio of Vs/f would also be constant at the different speed. As the speed increases, the stator voltages must, therefore, be proportionally increased in order to keep the constant ratio of Vs/f. However, the frequency (or synchronous speed) is not the real speed because of a slip as a function of the motor load. At no-load torque, the slip is very small, and the speed is nearly the synchronous speed. Thus, the simple open-loop Vs/f (or V/Hz) system cannot precisely control the speed with a presence of load torque. The slip compensation can be simply added in the system with the speed measurement.

Simulation Performance of SCALAR Control

The performance of the scalar control technique for speed control induction motor is validated by MATLAB/Simulink software. Fig 5 shows the simulation circuit of block diagram of scalar control technique shown in fig 4.

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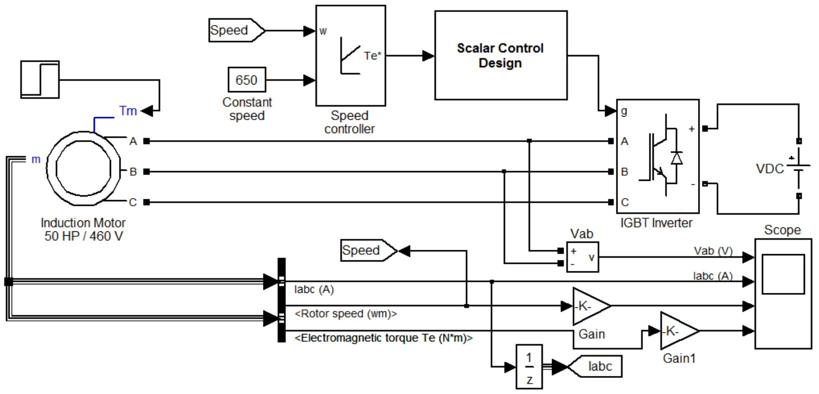

Fig 5: simulation design of speed control of I.M with scalar control

The performance characteristics of the speed control of three-phase induction motor using scalar (v/f) control technique are given in following figures.

Fig 6 shows the line-to-line supply voltage of the induction motor of ab-phase. According to result it shows that operating voltage is near to 800 volts. Fig 7 shows the supplied line current of induction motor. The supply current shows that current is higher during the higher load, the load has been decreased after 2.2s which results decrement in the current value. Fig 8 displays the speed of induction motor under variable load conditions. The estimated speed of 650rpm is getting after 2.2s of settling time. Fig 9 shows the load torque supplied by motor, from wave form it observed that torque is getting decreasing from 3Nm to 2Nm after 2.2s as represented in load torque.

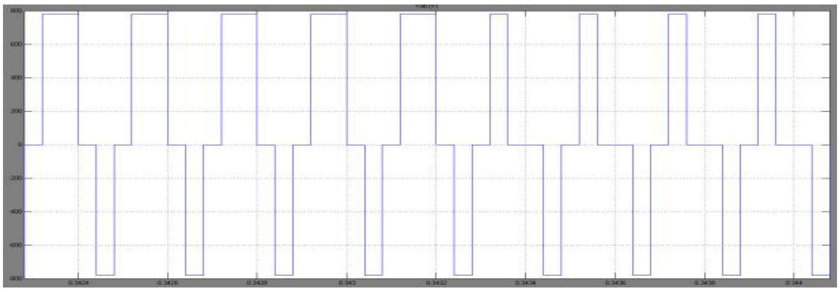

Fig 6: Supply line-to-line voltage of induction motor (~800V).

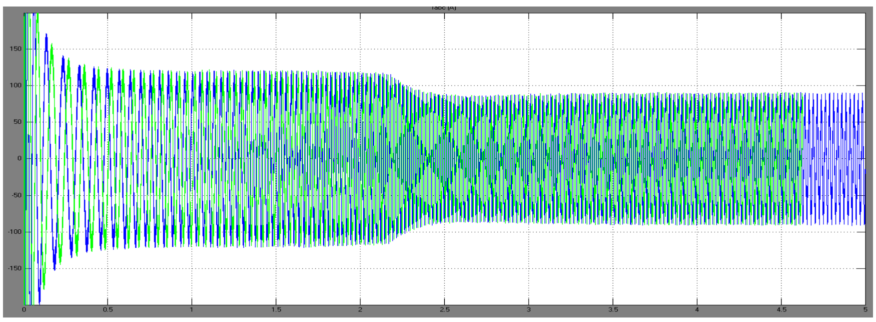

Fig 7: supplied current of induction motor

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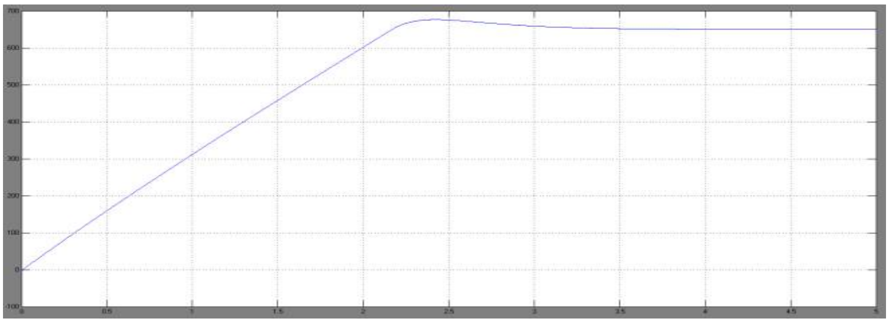

Fig 8: speed variation in the motor

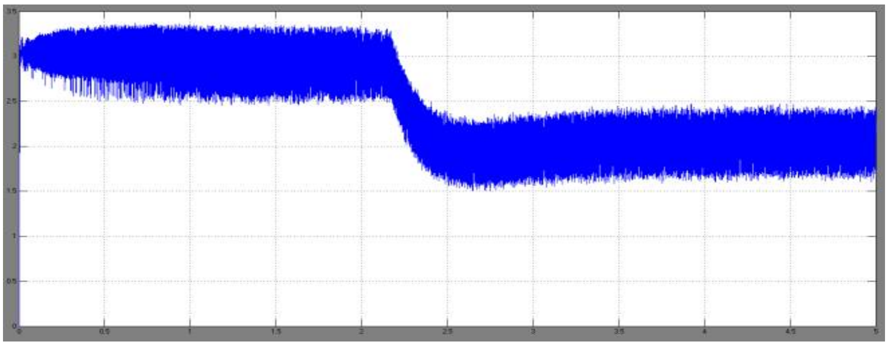

Fig 9: load torque of the induction motor (3 to 2Nm).

V. DIRECT TORQUE CONTROL (DTC)

The block diagram of DTC-SVPWM is shown in Fig. 10. Whereas the speed controller decides the mode of operation either in clockwise or counter clock wise direction. The electromagnetic torque for four-pole induction motor [9-11] is written as.

$$T_e = 3(\psi_{d1} i_{q1} - \psi_{q1} i_{d1}) \ldots\ldots\ldots\ldots 13$$

$$\psi_1 = \sqrt{\psi_{d1}{}^2 + \psi_{q1}{}^2} \ldots\ldots\ldots\ldots\ldots\ldots 14$$

Where ψ_{d1} and ψ_{q1} are the stator flux in d-q axis
Stator flux in d-axis is $\psi_{d1} = \int (v_{d1} - i_{d1} R_1) dt$
Stator flux in q-axis is $\psi_{q1} = \int (v_{q1} - i_{q1} R_1) dt$
The Reference voltage vector 'Vref' can be found from the stator flux of the induction motor as given below

$$v_{ref} = \sqrt{v_{d1}{}^2 + v_{q1}{}^2} \ldots\ldots\ldots\ldots\ldots\ldots 15$$

Where

$$v_{d1} = \Delta\psi_{d1} - R_1 i_{d1}$$
$$v_{q1} = \Delta\psi_{q1} - R_1 i_{q1}$$

Where i_{d1} and i_{q1} are the stator currents of the induction motor in d-q plane

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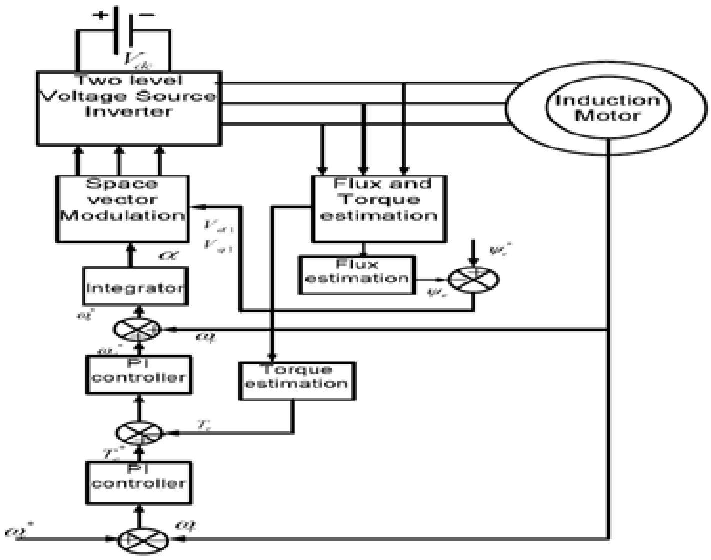

Fig 10: Direct torque control

Direct Torque Control Technique is verified for speed control of induction motor with sensor-less speed measurement technique.
Fig 11 shows the simulation circuit of block diagram of scalar control technique shown in fig10.

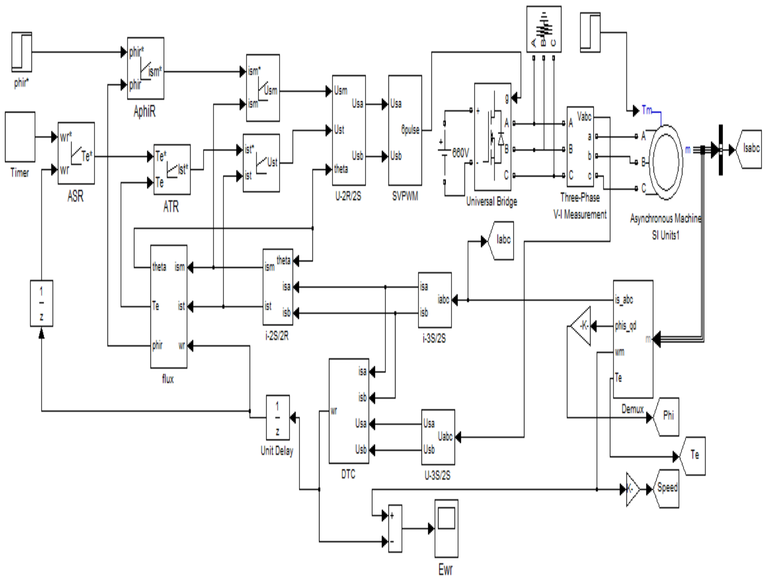

Fig 11: Direct Torque Control Scheme

The simulation performance DTC technique is verified and characteristics are shown in following waveforms. A 5Nm load has been added after the time of 1 sec. Fig 12 shows the speed measurement during continuous time. Supply current is shown in fig 13. The Electromechanical torque is displayed in the fig 14. Fig 15 shows the stator flux distribution in the field winding. Fig 16 shows the speed error of induction motor by DTC scheme.

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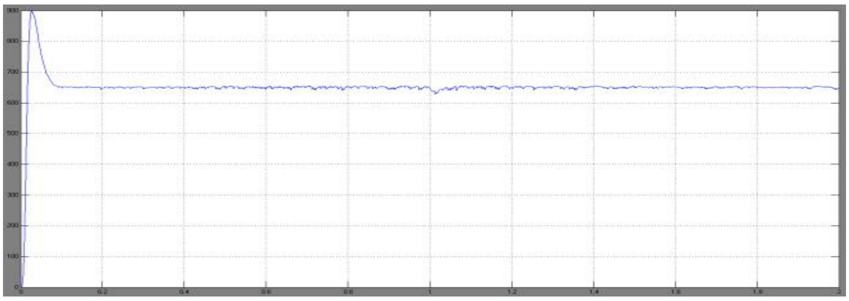

Fig 12: Induction Motor speed under DTC Scheme

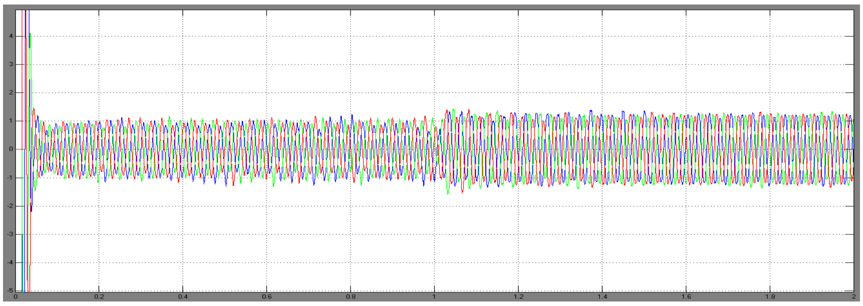

Fig 13: mean value of supply current

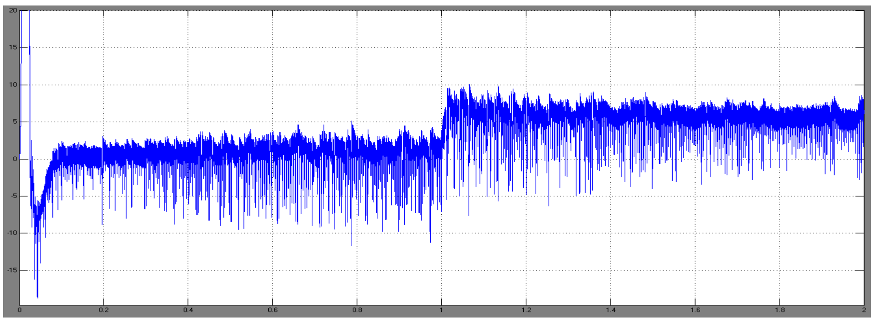

Fig 14: Electro mechanical torque varies from 0Nm to 5Nm after 1Sec.

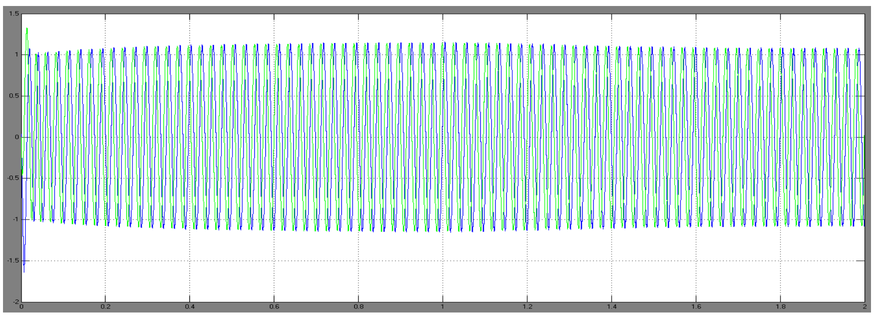

Fig 15: Stator flux distribution in p.u

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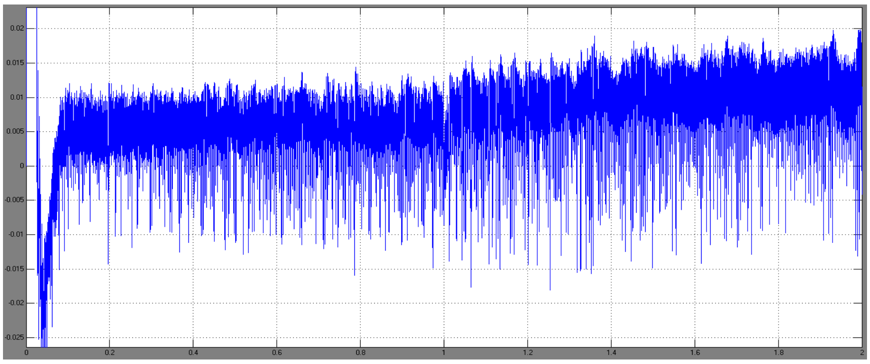

Fig 16: Speed error signal of induction motor (increased when load increased)

VI. CONCLUSION

In this paper analysis of speed controlling techniques scalar and DTC are performed. It is concluded that scalar controlling technique is having the poor performance over DTC scheme. Speed controlling in scalar control is less when compared with the DTC for high rating induction motors like industrial applications. Both control schemes are designed with SVPWM techniques. The DTC scheme is having the linear distribution in stator flux while scalar is nonlinear manner. It's observed that DTC is having advantage in speed control of induction motors compared with Scalar control technique.

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