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Control of Induction Motor Fed with Inverter Using Direct Torque Control - Space Vector Modulation Technique

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Abstract— In the industries induction motors are widely used, because they are reliable, rugged and cheap. Induction motor drive requires suitable converters to produce the required speed and torque without ripples. In this paper direct torque control (DTC) scheme of induction motor (IM) and its comparative study using (DTC-SVM) technique under varying dynamic conditions are discussed. Direct Torque Control is a restraint technique used to obtain high performance torque control. The rule is based on simultaneously decoupling of stator flux and electromagnetic torque. The DTC-SVM can be implemented using closed loop torque control system, for minimization of torque ripple. In this case estimation of the stator and rotor flux is needed. Thus, all the parameters of the induction motor must be recognized. Multilevel inverter has developed recently as a very important alternative option in the field of medium-voltage, high-power control and also for improving the THD (total harmonic distortion) by reducing the harmonics. In this paper a Simulink model is developed by using the DTC - SVM technique for controlling the speed of induction motor and verified using MATLAB.

Keywords— Direct Torque Control (DTC), Multilevel Drives, Space Vector Modulation (SVPWM), Induction Motor (IM) Control.

I. INTRODUCTION

In the industries Induction Motors (IMs) are widely employed in domestic applications as well as commercial applications they are simple in structure, cheap and easy to maintain. Since induction motor demands, well control performance parameter (precise and quick flux and torque response, torque is high at low speed, wide speed range and for Induction motor the drive control system is needed). DC motor is able to give these desired performance parameters, but maintenance of DC motor is difficult and cost of DC motor is high.

Field Oriented Control (FOC) scheme was proved successfully In 1970s, for controlling of an induction motor (torque and speed control). With the help of field oriented control scheme decoupling of two components of stator currents i.e (flux and torque producing elements) is produced same as DC machines, for providing independent torque control of the induction machine. Hence with the help of field oriented control strategy its proved that AC machine is more superior to the DC machine. The main problem faced by FOC scheme is its complexity in its implementation, due to the reference frame transformation and dependency on machine parameters.

After that direct torque control (DTC) was introduced. DTC method needs only the stator resistance to calculate the torque and stator flux. Electromagnetic flux and torque are independently controlled in DTC technique by selecting optimum witching modes of the inverter. The selection of optimum switching modes of inverter is require to determine the flux linkage and electromagnetic torque error within the flux and torque hysteresis bands. The DTC scheme has two comparators with specified bandwidth, torque and flux estimation block, switching table and voltage source inverter. The DTC control method has some advantages and disadvantages. Some of the advantages are due to lower parameter dependency, which makes the system more robust and easy to implement. The disadvantages are torque and current distortion during the change of the sector, at low speed its difficult to control flux and torque, switching frequency is variable, it requires high sampling frequency for digital implementation of hysteresis controllers, torque ripple is high. The torque ripple creates noise and vibrations, which is causing errors in motor drives and EMI (electromagnetic interfirance) is produced due to associated current ripples.

In order to overcome disadvantages of the DTC (direct torque control) technique a new control technique called (DTC-SVM) Direct Torque Control – Space Vector Modulation has been developed recently. The DTC-SVM technique operates with constant switching frequency. The structure of DTC-SVM technique is based on the same fundamentals as DTC technique. The basic difference between DTC technique and DTC-SVM technique is pulse width modulation technique. In DTC technique conventional PWM technique is used but in DTC-SVM technique we use Space Vector Modulation (SVPWM). The paper also present the comparitive analysis of the dynamic behavior of machine which is better in case of DTC-SVM technique as compare to DTC technique and also has a simple structure.

II. PRINCIPLE OF DIRECT TORQUE CONTROL

In the past, for only small demanding applications we were used AC drive, irrespective of the advantages of AC machine over DC machine, at that time the cost of high switching frequency inverters was quite competitive [4]. With the improvement and developments in the area of power electronics, due to vector control technique which use digital signal processing (DSP) and fast microprocessors, it is possible to use induction motors at the place of DC motors, now decoupling of two components of stator currents i.e (flux and torque producing elements) is produced same as DC machines.

First time direct torque control (DTC) method was introduced by German and Japanese researchers [5], which allows direct and independent control of electromagnetic torque and flux, by selecting an optimal switching vector, so we can get fast torque response, low harmonic losses and low inverter switching frequency. Fig. 1 shows the block diagram of a DTC controller. The instantaneous values of torque T_e and flux φ_s are estimated from the stator variables by torque and flux estimator. Magnitude of desired stator flux φ_s^* and torque T_e^* is compared with their respective estimated values of instantaneous torque and flux and the errors are further processed by the hysteresis band controllers. With the help of DTC technique, it is possible to obtain direct control of electromagnetic torque and flux, indirect control of current and voltage, sinusoidal waves of current and flux, low torque ripple, better torque dynamics and hysteresis band-dependent switching frequency of the inverter [5].

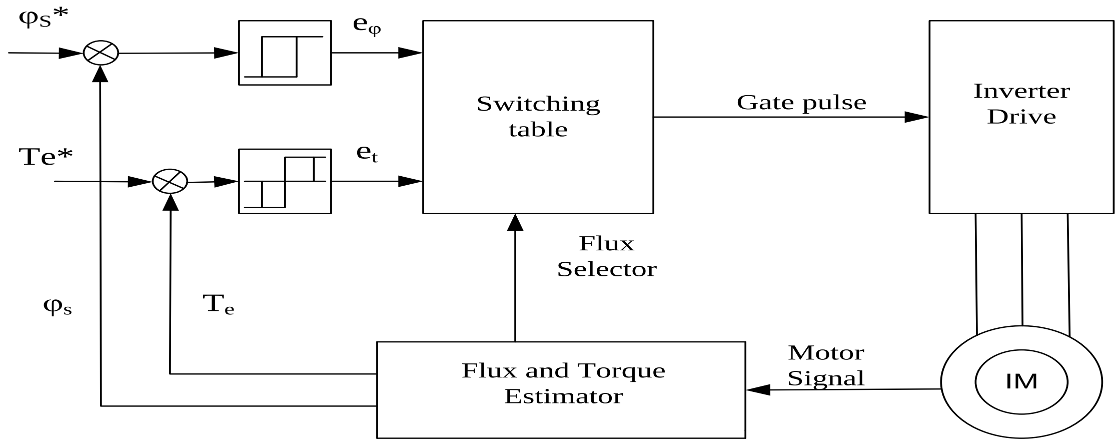

Figure 1. Block diagram of conventional DTC control system.

Although its basic advantages are there are no need of co-ordinate transformation (which are necessary in all vector control drives), modulation specific block is not needed. Still, this technique has some problems at low speed values and during start up, such as high influence of motor parameters and difficulty in startup current control, as well as the need of flux and speed estimation block and variable switching frequency [6]. When we include speed estimator or observer in the arrangement, it is possible to get gains in bigger mechanical endurance and reduction in hardware complexity, decreasing the maintenance needs. Simultaneously the motor-load inertia immunity and noise are increased.

2.1. Torque and Flux estimation

The feedback flux is determined by the machine terminal current and voltages. Sector number in the flux vector lines are calculated by the estimator block. The phase voltage and current are stationary reference, are given as

$$V_{s\text{-}alpha} = V_a \quad \text{and} \quad V_{s\text{-}beta} = \frac{-1}{\sqrt{3}}(V_a + 2V_b) \qquad (1)$$

$$I_{s\text{-}alpha} = I_a \quad \text{and} \quad I_{s\text{-}beta} = \frac{-1}{\sqrt{3}}(I_a + 2I_b) \qquad (2)$$

The two components of stator flux, current producing ($\varphi_{s\text{-}alpha}$) and torque producing ($\varphi_{s\text{-}beta}$) are given by

$$\varphi_{s\text{-}alpha} = \int (V_{s\text{-}alpha} - R_s I_{s\text{-}alpha})dt \qquad (3)$$

$$\varphi_{s\text{-}beta} = \int (V_{s\text{-}beta} - R_s I_{s\text{-}beta})dt \qquad (4)$$

The magnitude of the stator flux can be calculated by equation no (5).

$$\varphi_s = (\varphi_{s\text{-}alpha}^2 + \varphi_{s\text{-}beta}^2)^{1/2} \qquad (5)$$

By using the current and flux components, and the number of poles of IM, the electromagnetic torque can be calculated.

$$T_e = \frac{3}{2}\frac{P}{2}(\varphi_{s\text{-}alpha} I_{s\text{-}beta} - \varphi_{s\text{-}beta} I_{s\text{-}alpha}) \qquad (6)$$

2.2. Torque and Flux Observer

The instantaneous values of torque and flux are estimated from the stator variables by torque and flux estimator. Magnitude of desired stator flux φ^* and torque T_e^* is compared with their respective estimated values of instantaneous torque and flux and the errors signals E_T and E_φ are further processed by the hysteresis band controllers. The output of flux loop controller is H_φ, has two degrees of digital output according to following equations.

H_φ = 1 for $E_\varphi > +HB_\varphi$ (7)
H_φ = -1 for $E_\varphi > -HB_\varphi$ (8)
Where the total hysteresis bandwidth of the controller is $2HB_\varphi$. The output of torque control loop is H_T, has three-levels of digital output given by the following equations.

H_T = 1 for $E_T > +HB_T$ (9)
H_T = -1 for $E_T > -HB_T$ (10)
H_T = 0 for $-HB_T < E_T < +HB_T$ (11)

The input signals H_φ , H_T and sector number S (k) are used to generate the desired control voltage vector by using look-up table. This is shown below.

Table -1

H_φ	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_6	V_1	V_2
	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

By applying stator voltage vector V_s, for time interval Δt, we can change the value of flux incrementally. The value of stator voltage vector V_s and time interval Δt are calculate by neglecting the stator resistance R_s of the induction motor, which is shown in equation (12) and (13) respectively.

$$V_s = \frac{d}{dt}(\varphi_s) \quad (12)$$

$$\Delta \varphi_s = V_s \cdot \Delta t \quad (13)$$

The flux increment vector respective to each of six voltage vectors of inverter is shown by fig. 2. The flux may be decreased by V_3, V_4 and V_5 vectors and it may be increased by V_1, V_2 and V_6 vectors. In same manner torque is decreased by V_1, V_5 and V_6 vectors and it is increased by V_2, V_3 and V_4 vectors.

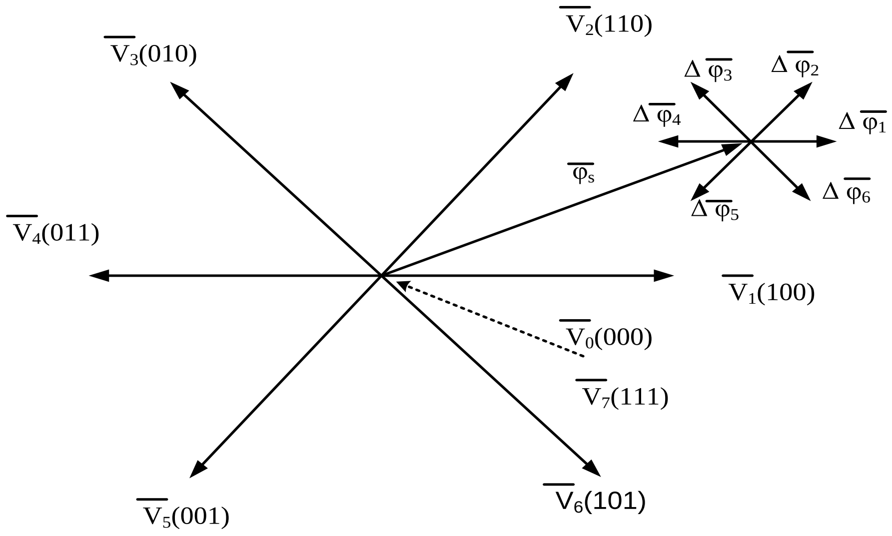

Figure 2. Inverter voltage vector and respective stator flux variation.

III. DTC TECHNIQUE USING SPACE VECTOR MODULATION

In the DTC technique an induction motor model is used to predict the voltage required to obtain a desired output torque [10]. With the help of only voltage and current measurements, it is possible to calculate the instantaneous value of stator flux and output torque. To calculate the voltage required to drive the torque and flux to the desired values within a fixed time interval an induction motor model is used.

This calculated value of voltage is then arranged using Space Vector Modulation (SVM). Equations (5) and (6) are used to calculate the stator flux vector φ_s, and the torque produced by the motor T_e. When the present output torque and the stator flux magnitude are known, the change required in order to obtain the demanded values by the end of the present switching period can be determined. Fig. 3 shows this, the voltage required to drive the error in the flux and torque to zero is calculated directly. The calculated value of voltage is then arranged by Space Vector Modulation [11]. If the inverter is not able to generating the desired voltage than the voltage vector which will drive the flux and torque, towards the demand value is selected and held for the whole cycle.

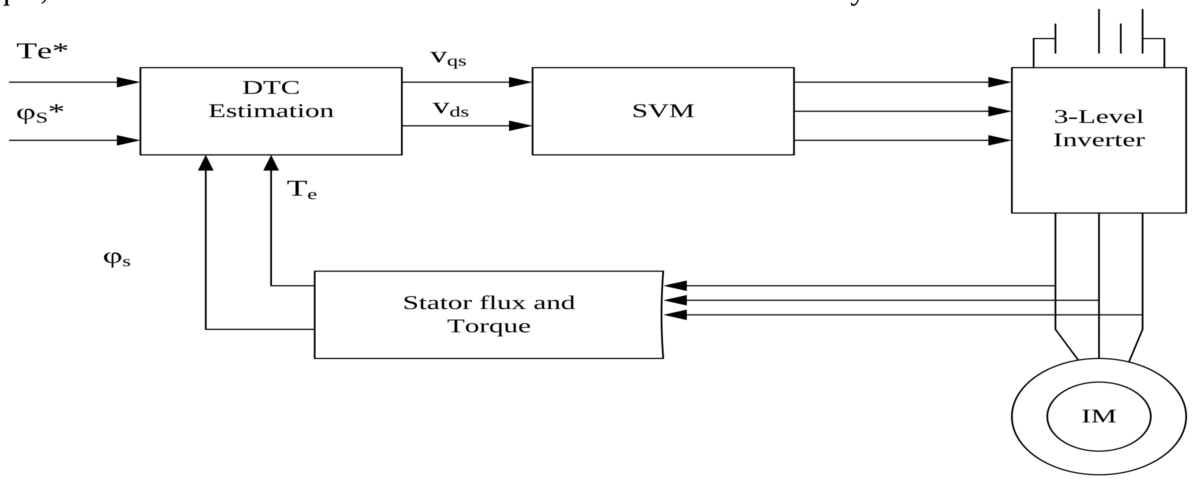

Figure 3. Block diagram of DTC-SVM Technique.

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3.1 Space vector pulse width modulation

Now days Space Vector Modulation (SVM) has become more popular and important PWM technique, for Voltage Source Inverters (VSI) fed to AC motors. It has been developed to reduce the harmonic distortion in the output currents and voltages applied to the phases of an AC machine, in order to get more efficient use of supply voltage. By modulating the switching time of space vectors in each of the six sectors we can generate a reference vector in SVM technique, Fig.4 shows that. The space voltage vector is generated by two active vectors, and a null vector.

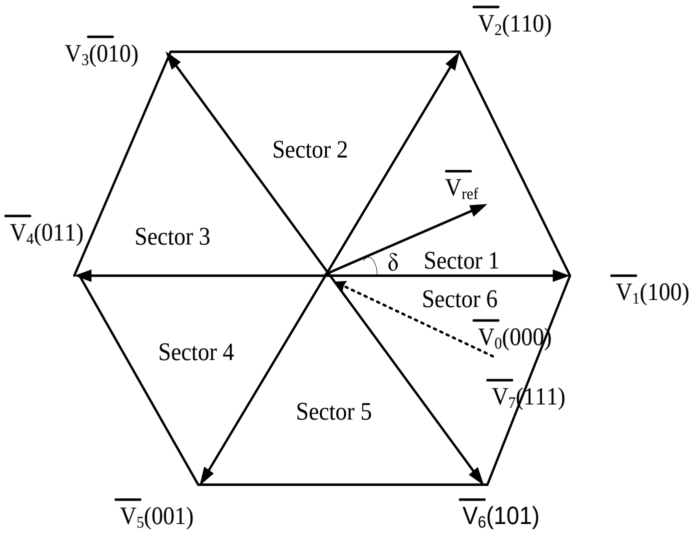

Figure 4. Switching Vector and Sectors

Space vector PWM can be used by the following steps:

- Estimation of space vector magnitude and angle. With the help of following equations

$V_s = (V_\alpha^2 + V_\beta^2)^{1/2}$ (14)

Angle is calculated as, $\delta = \tan^{-1}\frac{V_\beta}{V_\alpha}$ (15)

- Estimation of time interval

In fig. 4 (a) reference space vector V_s is at present in sector one, which is generated as a combination of three active vector V_1 and V_2 and zero vector (V_0/V_7). T_1, T_2 and T_0 is time duration for vector V_1, V_2 and V_0 respectively.

When applying volt-sec balance , we will get these equations-

$V_sT_z = V_1T_1 + V_2T_2 + V_0T_0$ (16)

$V_s \cos\delta\, T_z = \frac{2}{3} V_{dc} T_1 + \frac{2}{3} V_{dc} \cos\frac{\pi}{3} T_2$ (17)

$V_s \sin\delta\, T_z = \frac{2}{3} V_{dc} \sin\frac{\pi}{3} T_2$ (18)

By solving the equations (15) and (16), time T_1, T_2 is obtained as

$T_1 = T_z\, a \frac{\sin(\frac{\pi}{3} - \delta)}{\sin(\frac{\pi}{3})}$ And $T_2 = T_z\, a \frac{\sin(\delta)}{\sin(\frac{\pi}{3})}$ (19)

$T_0 = T_z - (T_1 + T_2)$

Where T_z denotes half the switching period T_s and $a = \frac{V_s}{\frac{2}{3}V_{dc}}$

IV. SIMULATION MODEL OF DTC-SVM TECHNIQUE

The simulation model of DTC-SVM technique is made on MATLAB. The error signal of torque and flux is used to decide the inverter switching pulses, which are obtained from the switching table. The flux position is also calculated with the help of torque and flux estimator. Motor parameters such as phase current and phase voltage are used to estimate the instantaneous value of torque and flux. Simulink model of torque and flux estimator shown in fig. 5, And over all Simulink models of DTC-SVM is shown in fig. 6.

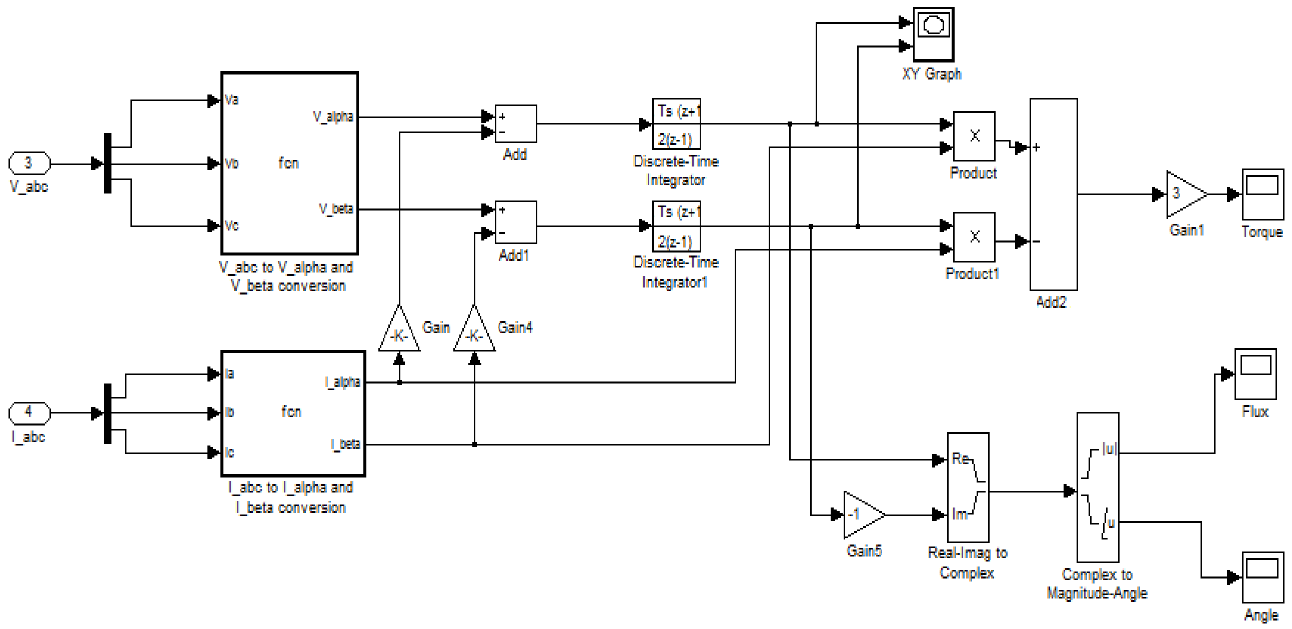

Figure. 5 Torque and Flux Estimator Block

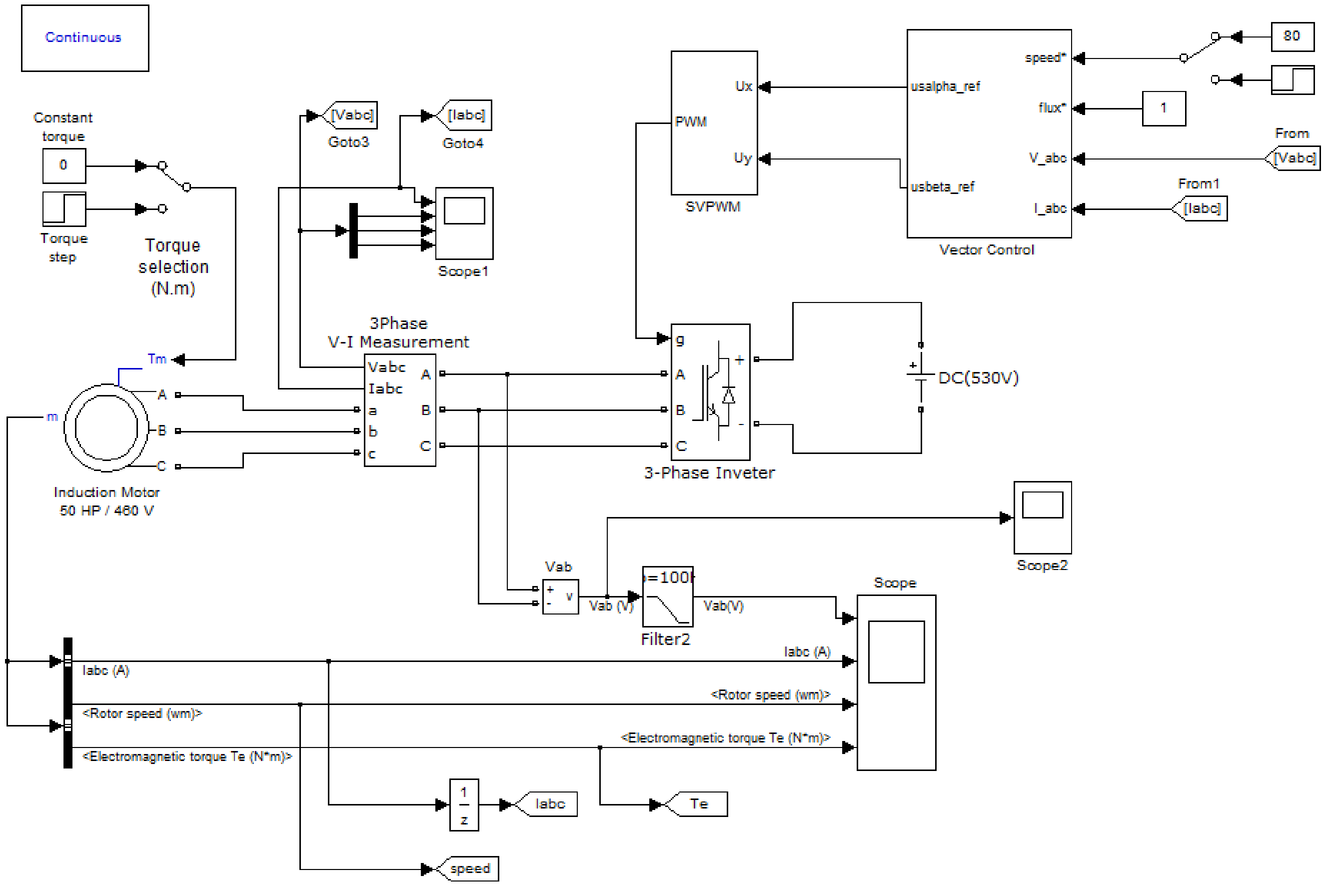

Figure 6. Simulink Model of DTC-SVM Technique

4.1 Testing parameters and results

Table-2 shows the parameters which are used to simulate the DTC-SVM model. The first step in simulation model testing is to test the operation of the induction motor. This block is a highly modular model.

Table -2

Power	50HP
Supply voltage	460V
Frequency	50Hz
Stator Resistance, R_s	0.087ohm
Rotor Resistance, R_r	0.228ohm
Stator self Inductance, L_{ls}	29.9Mh
Rotor self Inductance, L_{lr}	35.5Mh
Mutual Inductance, L_m	34.7mH
Moment of Intertia, J	1.662kg.m^2

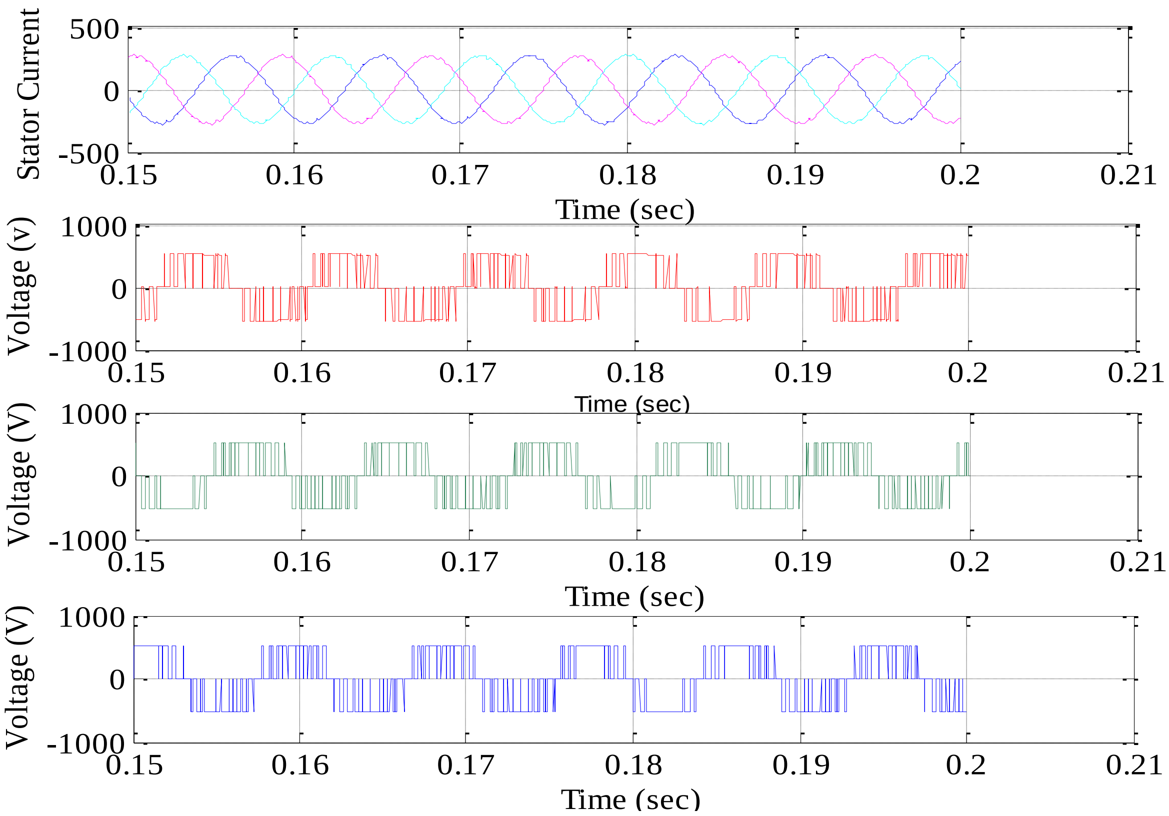

Figure 7. Output waveforms of phase current and phase voltage of inverter.

Fig. 7 shows the output waveforms of phase current and phase voltage of inverter which are fed to induction motor.

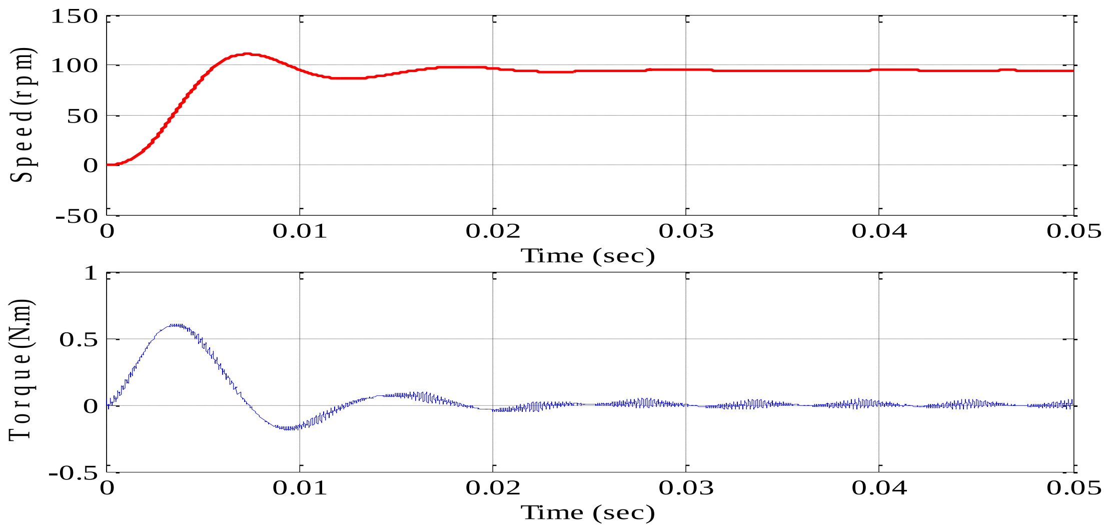

Figure 8. Output waveforms of Torque and Speed for DTC technique

Fig. 8 shows the output waveforms of torque and speed of induction motor by using DTC technique. First waveform is for speed of induction motor and second for Torque. These output waveforms has more ripple as compare to fig. 9 waveform which is obtained by DTC-SVM technique.

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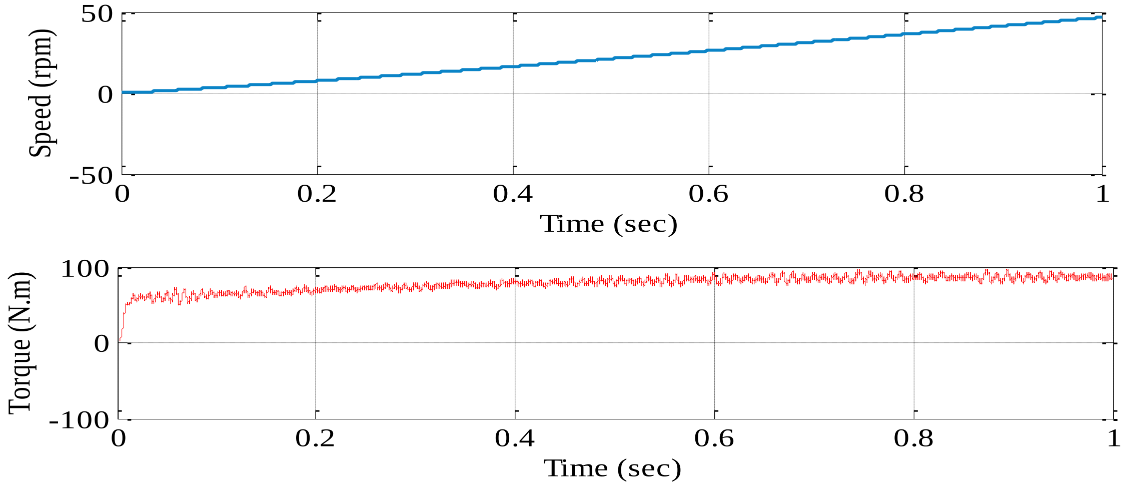

Figure 9. Output torque and Speed Waveforms of DTC-SVM

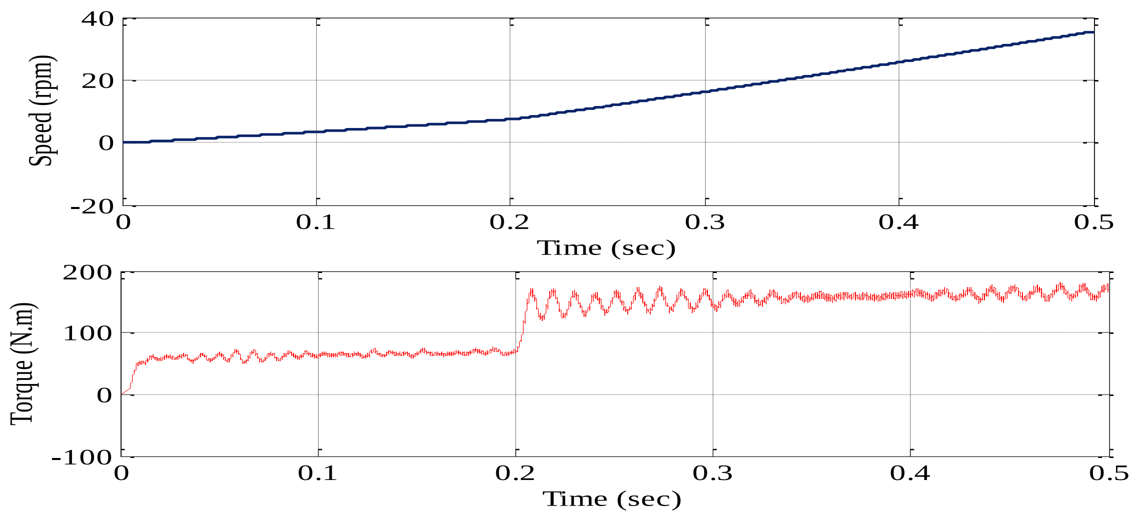

Figure 10. Output Torque and Speed Waveforms of DTC-SVM

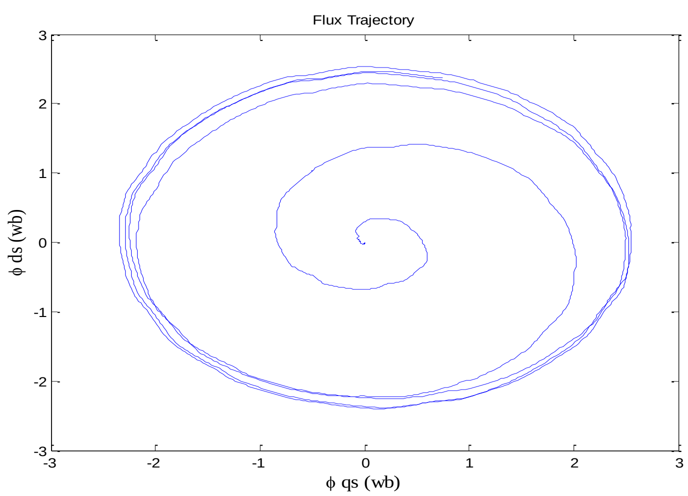

Figure 11. Flux trajectory.

A large amount of high frequency ripples is present in the torque waveform in case of DTC technique and it is also present in current waveform. It is clear from the simulation result that the ripples present in current and torque waveforms are reduced by DTC-SVM technique.

V. CONCLUSION

According to the results which are obtained from Simulink models, the following conclusions may be drawn:

❖ DTC controlling schemes are preferred over other schemes for high dynamic applications, but on the other hand, it shows higher torque and current ripple. This disadvantage can be partially overcome by using the SVM technique in the DTC scheme.
❖ The DTC-SVM controls are easy to implement, due to DTC-SVM it is possible to use cheap DSP boards to implement a sophisticated controller.
❖ DTC based Controlling schemes can achieve better torque responses compare to other schemes in terms of maximum overshoot and settling time.

The modular model used in this work to simulate the induction motor, gives the user of the model access to all internal variables which makes for deep insight in the machine operation and flexibility. It can be used to simulate induction motors, as well as generators also without any modification.

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