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Performance Improvement of Direct Torque Control Induction Motor Drive Using Space Vector Modulation Technique

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ABSTRACT

DTC is a vector control technique. With DTC stator flux and torque of induction motor can control separately. But during the estimation process some error occurs on the system which degrades the drive performance and also inverter switching frequency get varied. The error occur on the system is due to DC-link voltage, uneven gain of motor, stator resistance variation and incorrect integration. To improve the drive performance by reducing the error due to DC-link and to maintain switching frequency constant SVPWM technique is used here. Using this modulation technique space vector of stator voltage is controlled by providing proper switching sequence for inverter. SVPWM technique utilize the full DC bus voltage because of this harmonic contents are reduced. To maintain switching sequence constant the required DC link voltages for inverter are obtained through PI controller. PI controller reduces the ripple content on controlling parameter. In this paper DTC-IM drive performance are improved by reducing the estimation error with the help of DTC-SVM technique. The system implemented using MATLAB/SIMULINK model.

Keywords

Direct torque control, Induction motor, Space vector pulse width modulation, voltage source inverter

INTRODUCTION

In recent years the uses of induction motor are increased rapidly compare to other motor because of its high reliability, simple construction, robustness, and relative cheapness. Today's industry requires a highly efficient motor with low maintenance, great accuracy and smoothness. These requirements of industry are fulfilled by induction motor. Induction motor drive mostly used in the application where variable speed drive is required. For variable frequency operation induction motor is good solution but its control structure is complex. The induction motor control is challenging task due to its high dynamic performance, machine parameter variation, and the difficulties of processing feedback signal in the presence of harmonic. A number of strategies have been developed to address this difficulty. In 1970s, a first vector control technique for induction motor drive as a field oriented control method is introduced. In FOC method the motor decoupling and linearization replace with co-ordinate transformation of motor. In the middle of 1980's I. Takahashi present a new control strategy called as direct torque control technique and M. Depenbrock as direct self control technique. DTC method introduced 14 year after FOC technique. FOC method does not provide exact decoupling for torque and flux control while DTC provide very fast dynamic response to torque control compare to FOC. FOC is very sensitive to rotor time constant. In case of DTC, required parameter is only stator resistance. FOC method require current controller, coordinate transformation, PWM modulator and in direct FOC rotor flux estimator and in indirect FOC mechanical speed is required. DTC structure is simple and it does not require coordinate transformation, separate voltage modulator and current control loop.

In conventional DTC, hysteresis controller is used which provide good switching operation for inverter. Due to torque and stator flux hysteresis band controller ripple are produced in torque and stator current. This DTC scheme has some disadvantages. Variable switching frequency is one of the main disadvantages of this method. Recently a new control technique has been developed from classical DTC method called as space vector modulated direct torque control for induction motor drives. SVM technique is based on representation of three phase voltage as a space vector in a sector of inverter. The main advantages of DTC-SVM technique over classical DTC are constant switching frequency operation. These methods DTC- SVM are the main subject of this paper.

1. MATHEMATICAL MODELING OF INDUCTION MOTOR

Some assumption are made for induction motor model,

1. The induction motor is considered in steady state condition.
2. The voltage is sinusoidal.
3. The induction motor is symmetrical.
4. The presented harmonics is only fundamental.
5. The higher harmonics of air gap mmf is neglected.
6. The magnetic saturation, eddy current loss, iron loss is neglected.
7. The resistance and reactance of a coil is taken to be a constant.

By considering the above assumption, the instantaneous stator phase voltages of induction motor is given as,

$$\mathrm{Va} = \mathrm{IaRa} + \frac{d\Psi a}{d}$$

$$\mathrm{Vb} = \mathrm{IbRb} + \frac{d\Psi b}{d}$$

$$\mathrm{Vc} = \mathrm{IcRc} + \frac{d\Psi c}{d}$$

Here vector is selected for stator flux. The stator flux is easy to obtain by using terminal voltage and current. The stator flux is given as,

$$\psi s = \int (\mathrm{Vs} - \mathrm{is.Rs})dt$$

The stator and rotor voltage equations is,

$$\mathrm{Vs} = \frac{d\Psi s}{d} + \mathrm{Rs.Is}$$

$$0 = \frac{d\Psi s}{d} - j\omega.\Psi r + \mathrm{Rr.ir}$$

The voltage magnitude of rotor voltage is taken as zero because rotor is short circuited.

1.1. Axis Transformation

With concept of two axis theory, time varying parameters of motor are mutually perpendicular direct (d) and quadrature (q) axis. This can be done with the help of axis transformation from three phase to two phase. Many models were presented by many researchers and find more reliable and accurate. In -q axis plane speed of the rotation can be arbitrary even though, they favored three reference frames as follows,

a) The stationary reference frame when the d-q axes do not rotate
b) The synchronously rotating reference frame when the d-q axes rotate at synchronous speed
c) The rotor reference frame when the d-q axes rotate at rotor speed.

The direct and quadrature flux linkage in term of inductances of motor is given as,

$$\psi sd = \mathrm{Ls.}\ i_s d + \mathrm{Lm.}\ i_r d$$

$$\psi sq = \mathrm{Ls.}\ i_s q + \mathrm{Lm.}\ i_r q$$

Ls, Lm are a self and mutual inductance of motor. The stator and rotor direct and quadrature axis current are defined in the stationery reference frame fixed to stator and they can vary arbitrarily with time.

To eliminate the machine time varying inductances the change of variable is used. The change of variable transformed from three phase stationery circuit element to arbitrary reference frame,

$$\mathrm{fqd0s} = \mathrm{ks.fabcs}$$

$$[\mathrm{fqd0s}]^{T} = [\,\mathrm{fqs}\;\;\mathrm{fds}\;\;\mathrm{f0s}\,]$$

$$[\mathrm{fabcs}]^{T} = [\,\mathrm{fas}\;\;\mathrm{fbs}\;\;\mathrm{fcs}\,]$$

$$\mathrm{ks} = \frac{2}{3}\begin{bmatrix} \cos\theta & \cos(\theta-120) & \cos(\theta+120) \\ \sin\theta & \sin(\theta-120) & \sin(\theta+120) \\ 0.5 & 0.5 & 0.5 \end{bmatrix}$$

In stationary reference frame θ = 0

$$\mathrm{ks} = \frac{2}{3}\begin{bmatrix} \cos 0 & \cos(0-\frac{2\pi}{3}) & \cos(0+\frac{2\pi}{3}) \\ \sin 0 & \sin(0-\frac{2\pi}{3}) & \sin(0+\frac{2\pi}{3}) \\ \frac{1}{2} & \frac{1}{2} & \frac{1}{2} \end{bmatrix}$$

$$\mathrm{ks} = \frac{2}{3}\begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \\ \frac{1}{2} & \frac{1}{2} & \frac{1}{2} \end{bmatrix}$$

The direct and quadrature phase variable obtain from three phase quantity is,

$$\begin{bmatrix} f \\ f \end{bmatrix} = \frac{2}{3}\begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & \frac{\sqrt{3}}{2} \end{bmatrix}\begin{bmatrix} f \\ f \\ f \end{bmatrix}$$

The factor 2/3 is a constant of transformation.

The motor equations are calculated in dynamic model for designing torque control drives.

$$T = \frac{3}{2}\frac{P}{2}[\psi \;\; .ic \;\; - \;\psi \;\; .ic \;\;]$$

The electromagnetic torque within machine is a multiplication of stator flux and current. The above equation is electromagnetic torque of induction motor which can be controlled using DTC –SVM technique.

2. Direct Torque Control With Space Vector Modulation (DTC -SVM)

In this paper DTC –SVM scheme is used to control the induction motor torque and flux. The drawback of conventional DTC is fixed by using this scheme. Direct flux and torque control with space vector modulation (DTC-SVM) schemes are proposed in order to improve the conventional DTC. With this scheme inverter switching frequency maintain constant and also it required very low sampling frequency. In DTC-SVM scheme PI controller give the demanded voltage vector then these vectors acquire SVM algorithm. In conventional DTC system voltage vector obtain through instantaneous values and gives direct control signal

to inverter. The control signal for conventional DTC based on instantaneous value where as DTC SVM scheme based on average value.

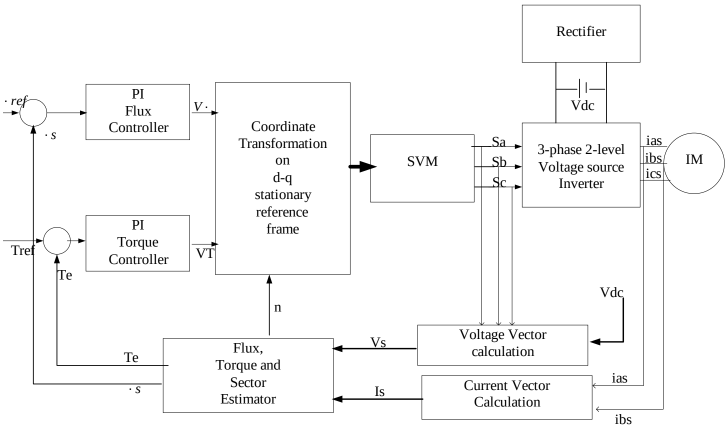

Figure 1. DTC-SVM model for Induction motor drive

The functional blocks of DTC-SVM scheme are shown in fig. Here estimator estimates the actual value of flux and torque. In DTC-SVM scheme instead of hysteresis controller and lookup table, PI controller is used. The two PI controllers is used to reduce the error due to flux and torque values. Controllers provide the voltage vectors, this vector then realized by SVM scheme to generate exact space vector with fixed switching frequency.

The output of the PI flux and torque controllers can be interpreted as the reference stator voltage components in d-q co-ordinate system. These dc voltage commands are then transformed into stationary frame (d-q), the command values are delivered to SVM block. The SVM block performs the space vector modulation of Vs to obtain the gate drive pulses for the inverter circuit. Close loop speed controller can be obtain by using PI controller whose output gives the torque reference and the input to the speed controller is the difference between the reference speed and actual speed.

2.1. Estimator

Estimator estimates the parameter which has to control such as flux and torque. Control parameters are directly calculated through motor voltage model. These parameters are directly taken through the motor hence use of tachometer or encoders are reduced. Estimator also provides the sextant n where flux vector is located on stationary reference plane. The motor voltage model provides information regarding stator voltage, current and stator resistance which is then fed to estimator to calculate stator flux and electromagnetic torque. The stator flux estimator based on the voltage model is obtained from the stator voltage equation given by,

$$\mathrm{Vs} = \frac{\mathrm{d\psi s}}{\mathrm{d}} + \mathrm{Rs.Is}$$

$$\frac{\mathrm{d\psi s}}{\mathrm{d}} = \mathrm{Vs} - \mathrm{RsIs}$$

The stator flux is,

$$\mathrm{\psi s} = \int(\mathrm{Vs} - \mathrm{is.Rs})\mathrm{dt}$$

$$\mathrm{\psi ds} = \int(\mathrm{Vds} - \mathrm{ids.Rs})\mathrm{dt}$$

$$\mathrm{\psi qs} = \int(\mathrm{Vqs} - \mathrm{iqs.Rs})\mathrm{dt}$$

$$\mathrm{\psi s} = \mathrm{\psi ds} + \mathrm{j\psi qs}$$

The stator flux vector magnitude and phase are given by,

$$|\mathrm{\psi s}| = \sqrt{\mathrm{\psi ds}^2 + \mathrm{\psi qs}^2}$$

$$\delta = \tan^{-1}\frac{\psi q}{\psi d}$$

Electromagnetic torque is a product of stator flux and current it is given by,

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$$T = \frac{3}{2}\frac{P}{2}[\psi \quad .i\iota \quad - \psi \quad .i\iota \quad]$$

2.2. PI controller

The transfer function of PI controller is,

$$G(s) = \frac{V(s)}{E(s)} = Kp\frac{1+s'}{s'}$$

G(s), V(s), E(s) is a transfer function of PI controller, output voltage and input voltage of controller. Kp is a controller gain, Ti is a controller integrating time.

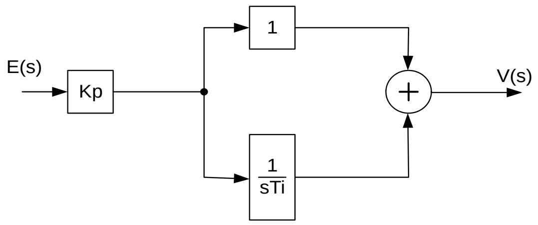

Figure 2. Block diagram of PI controller

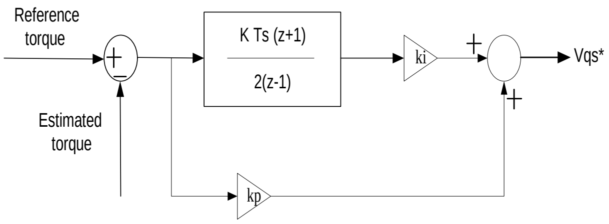

Figure 3. Torque PI controller design

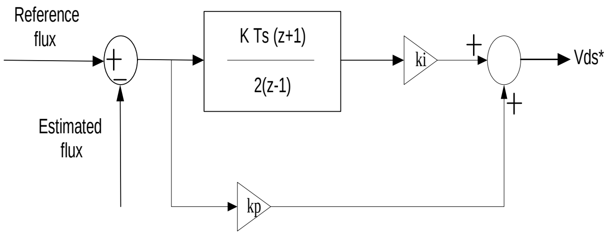

Figure 4. Flux PI controller design

The output of PI controller is in voltage form. PI controller is used to control the output voltage to obtain the required value of current so that torque can be control. The estimated quantity is subtracted from the reference quantity and its error status is given to PI controller. The output of torque PI controller is a q- axis stator voltage and the output of flux PI controller is a d- axis stator voltage.

3. SVPWM TECHNIQUE

SVPWM Principle:- Space vector modulation technique is one of the pulse with modulation technique which gives the vector approach for three phase inverter. SVPWM technique utilizes full DC bus voltage so that it provides higher voltage to motor. The two level three phase inverter produce eight voltage vectors from these two are zero vector. Because of this zero vector sine wave modulated perfectly with minimum harmonic distortion. The main aim of this technique is to provide distortion less sine wave with high fundamental component and minimum harmonics.

Space vector concept originated from rotating field of induction motor which is used to regulate the inverter output voltage. In the modulation technique the three phase quantities can be transformed into their equivalent two-phase quantity in stationary reference frame. From these two-phase components, the magnitude and angle of reference vector can be found and used for modulating the inverter output.

3.1. 3-Phase to 2-Phase Conversion

3 phase sinusoidal voltage signal are,

$$Va = Vm \sin \omega t$$
$$Vb = Vm \sin(\omega t - 2\pi/3)$$
$$Vc = Vm \sin(\omega t + 2\pi/3)$$

When these three phase voltages are applied to the induction motor it produces a rotating flux in the air gap of the motor. This rotating resultant flux can be represented as a single rotating voltage vector. The conversion of these three phase quantity into two phase by using clark's transformation.

$$V \ = V \ \cos 0° + V \ \cos 120° + V \ \cos 240°$$
$$V \ = V \ - \frac{V}{2} - \frac{V}{2}$$
$$V \ = V \ \cos 270° + V \ \cos 30° + V \ \cos 150°$$
$$V \ = 0 + \frac{\sqrt{3}V}{2} - \frac{\sqrt{3}V}{2}$$
$$\begin{bmatrix} V \\ V \end{bmatrix} = \frac{2}{3}\begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & \frac{-\sqrt{3}}{2} \end{bmatrix}\begin{bmatrix} V \\ V \\ V \end{bmatrix}$$

3.2. Magnitude and angle calculation

The magnitude and angle of reference space vector can be obtained through clark's transformation.

$$V \ = V \ + jV$$
$$V \ = 2/3(\,Va \ + \ aVb \ + \ a2Vc)$$

Where, $a = e^{j2\pi/3}$ and $a^2 = e^{-j2\pi/3}$

$$Vd + jVq = \frac{2}{3}(\,Va - 0.5\,Vb - 0.5\,Vc) + \qquad j\,\frac{2}{3}(\frac{\sqrt{3}}{2}Vb - \frac{\sqrt{3}}{2}\,Vc)$$

By equating real and imaginary terms,

$$V \ = \frac{2}{3}(\,V \ - 0.5\,V \ - 0.5\,V \ )$$
$$V \ = \frac{2}{3}(\frac{\sqrt{3}}{2}V \ - \frac{\sqrt{3}}{2}\,V \ )$$

In matrix form,

$$\begin{bmatrix} V \\ V \end{bmatrix} = \frac{2}{3}\begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & \frac{-\sqrt{3}}{2} \end{bmatrix}\begin{bmatrix} V \\ V \\ V \end{bmatrix}$$

The magnitude Vs and angle δ of stator voltage of motor is,

$$|Vref| = \sqrt{Vd^2 + Vq^2}$$

$$\delta = \tan^{-1}\frac{V}{V}$$

3.3. Sector selection

Table1. Identification of Vref position with respect to angle

Angle δ	Position of V in sector
0^{c}- 60^{c}	1
60^{c}- 120^{c}	2
120^{c}- 180^{c}	3
180^{c}- 240^{c}	4
240^{c}- 300^{c}	5
300^{c}- 360^{c}	6

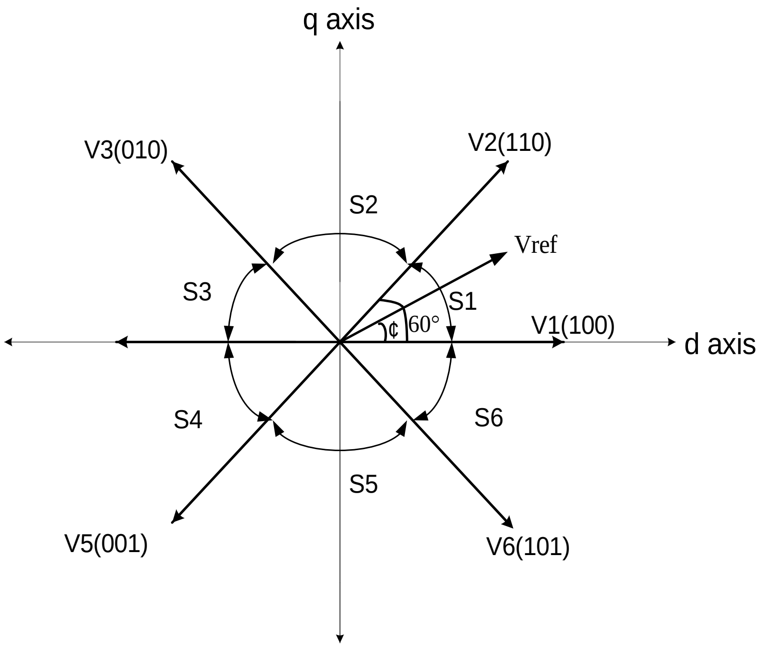

Figure 5. Reference voltage vector in particular sector

The vector diagram of voltage source inverter is divided into six sectors. Eight vector lie on six sectors on which two are zero vector placed at the origin and six are active vector rotate on the space. Angle between corresponding vector of given sector is 60°. The reference vector rotates anticlockwise with respect to speed of the motor.

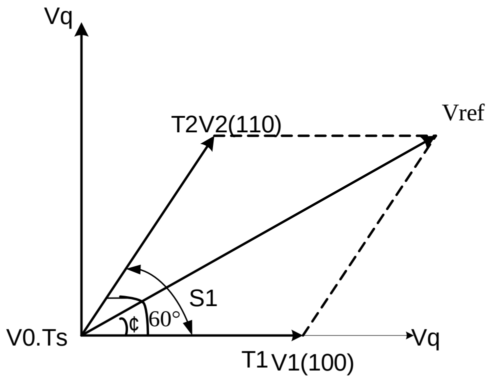

Figure 6. Sample reference voltage vector on first sector

Apply volt sec balance equation for the calculation of time duration for each space vector on the sector. Volt sec equation for sector one,

$$\mathrm{Vref.Ts} = \mathrm{V2\ T2 + V2\ T2 + V0\ T0 + V7\ T7}$$

V0 and V7 are the zero voltage.

$$\mathrm{Vref.Ts} = \mathrm{V2\ T2 + V2\ T2 + V0\ T0}$$

Volt sec balance equation along d-axis,

$$V1.T1 + (V2\ \cos 60).T2 = (V \quad \cos\delta).T$$

Volt sec balance equation along q-axis,

$$0 + (V2\ \sin 60).T2 = (V \quad \sin\delta).T$$

$$\mathrm{T2} = \frac{\mathrm{Vref}\cos\delta\,.\,\mathrm{Ts}}{\mathrm{V2}\ \ \sin 60.}$$

The max phase voltage in SVPWM Is,

$$\mathrm{Vmax} = \mathrm{Vref} = \frac{\mathrm{Vdc}}{\sqrt{3}}$$

Modulation index for space vector modulation,

$$\mathrm{M} = \frac{\mathrm{Vref}}{\frac{2}{\pi}.\mathrm{Vdc}}$$

Put it into equation of T2,

$$T2 = \frac{2\sqrt{3}.M\,.si\quad .T}{\pi}$$

Put the value of T2 in equation of T1,

$$\mathrm{T1} = \frac{2\sqrt{3}.\mathrm{M.Ts.sin}(60 - \delta)}{\pi}$$

The equation of T1, T2 are same for all modulation technique. In SVPWM technique zero vector are placed during sampling period of active vector hence along with T1, T2 sample time calculated for zero vector. T1, T2 is a time calculation of active vector V1, V2. Now calculation of time period for zero vectors is,

$$\mathrm{T0{,}7} = \mathrm{Ts} - (\mathrm{T1} + \mathrm{T2}$$

Vref is a reference vector placed on sector 1 and its sampling time is Ts. The reference voltage vector is calculated by using active voltage vector on which sample lies and zero vectors for different time over sample time. If the zero vectors placed symmetrically then its sample time is,

$$\mathrm{T0} = \mathrm{T7} = \frac{\mathrm{Ts} - \mathrm{T1} - \mathrm{T2}}{2}$$

The time calculation of sector 1 is same for all sectors. If k is a sector no. 1-6 then time calculation for sector 1, 3, 5 is,

$$\mathrm{T1} = \frac{2\sqrt{3}.\mathrm{M.Ts.sin}(\mathrm{K}.60 - \delta)}{\pi}$$

$$\mathrm{T2} = \frac{2\sqrt{3}.\mathrm{M}\,.\sin\,(\delta - ((\mathrm{k}-1)\,60).\mathrm{Ts}}{\pi}$$

Time calculation for sector 2, 4, 6 are

$$T1 = \frac{2\sqrt{3}.M\,.si\quad (\delta - ((k-1)\,60).T}{\pi}$$

$$T2 = \frac{2\sqrt{3}.M.T\ \ .\sin(K.60 - \delta)}{\pi}$$

After calculation of sampling time on the sector of each vector, it is easy to calculate the modulating signal by using different switching sequence. Here symmetrical switching sequence is used. The switching sequence is used in such a way that it should reduce the switching frequency. The switching frequency is reduces if switch position change from 1 to 0 or 0 to 1in next sampling period.

From this equation we can obtain the magnitude and angle of stator voltage reference vector. Angle δ can be change as position of reference voltage vector changes. Here each voltage vector placed 60^{c} apart from each other. Reference vector placed between corresponding two voltage vectors hence its position changes as sector changes.

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The switching sequence for sector 1,

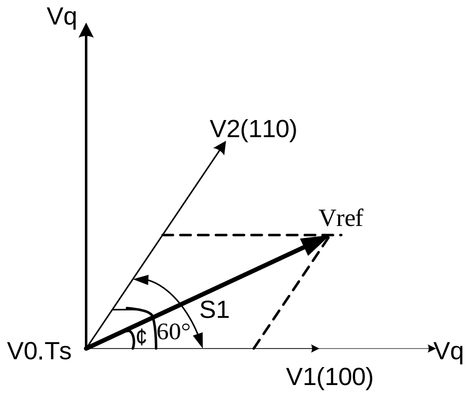

Figure 7. Reference vector on sector 1

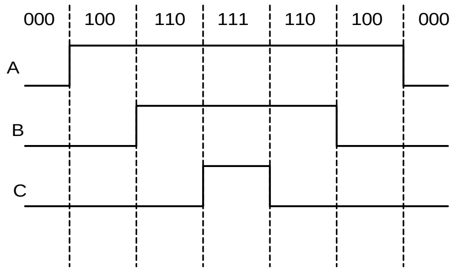

Figure 8. Switching sequence for sector 1

$$V \quad \rightarrow V1 \rightarrow V2 \rightarrow V7 \rightarrow V2 \rightarrow V1 \rightarrow V0$$

Using this switching strategy switching losses can be reduces. These also maintain the constant switching frequency. The SVM technique increases the choice of voltage vector selection by varying the switching position from 0 to 1 or 1 to 0. It is possible to apply any voltage during teach switching period. Here symmetrical switching strategy is preferred.

3.4 Flow chart of SVM algorithm

Here in DTC –SVM technique at start three phase quantities is converted into two phase quantity on stationary reference frame. From these two phase quantity magnitude and phase angle is calculated on the same reference frame. Using this angle the position of reference voltage vector on particular sector can be finding.

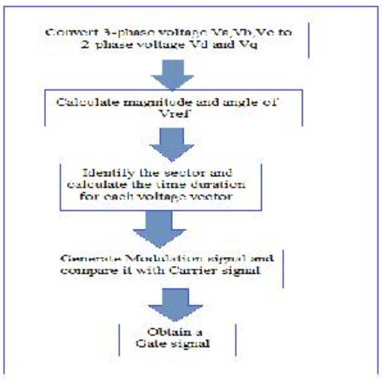

Figure9. SVPWM algorithm

All these information the modulating signal for VSI generated and compare with carrier signal. From this comparison gate signal is obtain which further fed to the VSI.

4. Voltage Source Inverter Configuration

Two level three phase voltage source inverter is used on DTC model consist of six switches. Switching states of lower switches are opposite to the upper one. Each leg consists of two switches. One switch on each leg conducts at a time. When one switch is conducting another switch must be open to prevent short circuit of the supply. Possible vector configurations for two level three phase inverter are 2^3 =8. Hence total eight voltage vector obtained on which six are active vector (V1 to V6) and two are zero vectors (V0, V7). These vectors commanded through the switching table. By considering the advantages of semiconductor switches in this model IGBT switches are used. An 180^o mode of operation is used in this configuration each switch conducts at an interval of 180^o. The switching signal applied and removed on each switch at a 60^{o}of interval. In this mode three switches remain on at any instant of time.

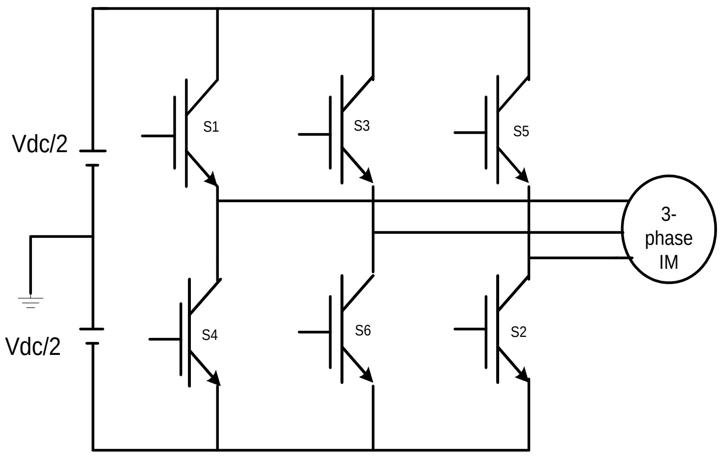

Figure 10. Three phase voltage source inverter configuration

4.1. Switching state of inverter

Below fig shows the switching state for VSI. On which in one switching state only one switch change their position from 1 to 0 or 0 to 1 to reduced the switching losses. First, second and third binary digit shows the state of a, b, c voltage. Indication 1 shows the upper switches is on and lower off. Indication 0 shows the lower switch is on and upper is off. The logical state for these eight switches is given in table.

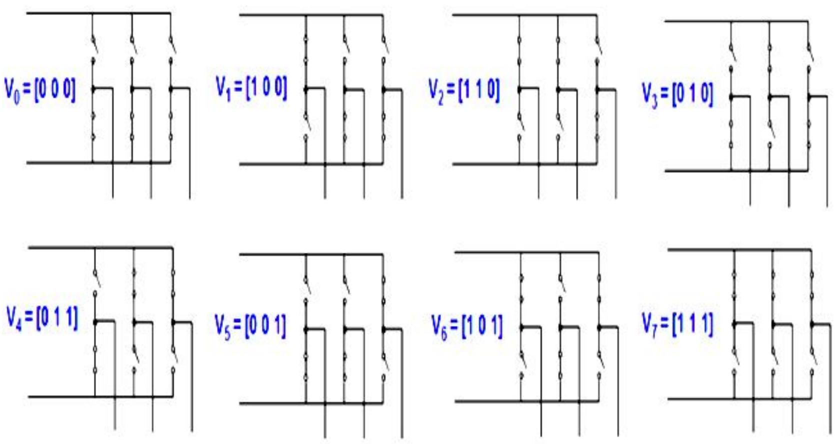

Figure 11. Inverter voltage vectors (V0 to V7)

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The output voltage of VSI in term of space vector is given as,

$$V1 = \frac{2}{3}\, Vdc.\, e^{(j0)} = \frac{2}{3}\, Vdc\angle\, 0°,$$

$$V2 = \frac{2}{3}\, Vdc.\, e^{(j\frac{\pi}{3})} = \frac{2}{3}\, Vdc\angle\, 60°,$$

$$V3 = \frac{2}{3}\, Vdc.\, e^{(j\frac{2\pi}{3})} = \frac{2}{3}\, Vdc\angle\, 120°,$$

$$V4 = \frac{2}{3}\, Vdc.\, e^{(j\frac{3\pi}{3})} = \frac{2}{3}\, Vdc\angle\, 180°,$$

$$V5 = \frac{2}{3}\, Vdc.\, e^{(j\frac{4\pi}{3})} = \frac{2}{3}\, Vdc\angle\, 240°,$$

$$V6 = \frac{2}{3}\, Vdc.\, e^{(j\frac{5\pi}{3})} = \frac{2}{3}\, Vdc\angle\, 360°$$

Table2. The standard 8 voltage vectors and the logic states

	V0	V1	V2	V3	V4	V5	V6	V7
A	0	1	1	0	0	0	1	1
B	0	0	1	1	1	0	0	1
C	0	0	0	0	1	1	1	1

Where,
Vdc - Dc input voltage of inverter,
V1-V6 - Active voltage vectors,
V0-V7 - Zero voltage vector.

5. DIRECT FLUX CONTROL

The stator voltage equation of induction motor can be written as

$$\frac{d\psi s}{d} = Vs - RsIs$$

By rearranging equation the stator flux in stationary frame can be written as,

$$\Psi s = \int Vs - i_s .\, R_s$$

The stator resistance voltage drop are neglected to fix the stator flux vector direction along the selected voltage vector. Over a small period of time, stator flux can be written as

$$\Delta\Psi s = Vs.\, \Delta t$$

Which means that stator flux Ψs, can be change by applying stator voltage vector Vs for a time interval Δt. As time increments stator flux vector changes incrementally. The rotation of flux vector on sector is shown in figure 6. Stator flux vector is integral of stator voltage space vector. For increase the flux the voltage vector must be outward from the centre of rotor and to reduce flux the voltage vector must be directed towards the

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centre of rotor. To control the stator flux vector, the magnitude and direction of rotation of the stator flux must be known.

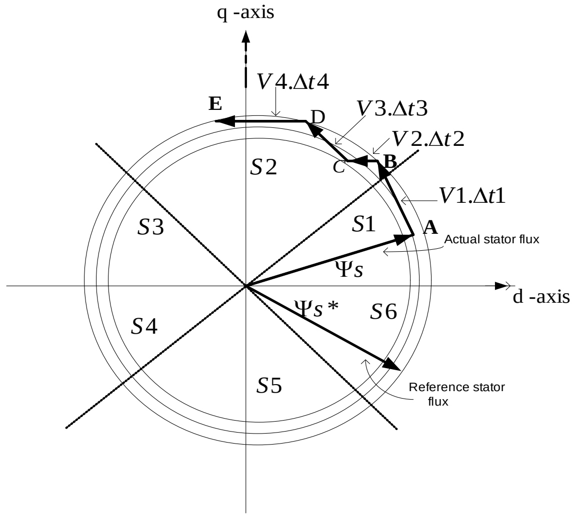

Figure 12. Trajectory of stator flux

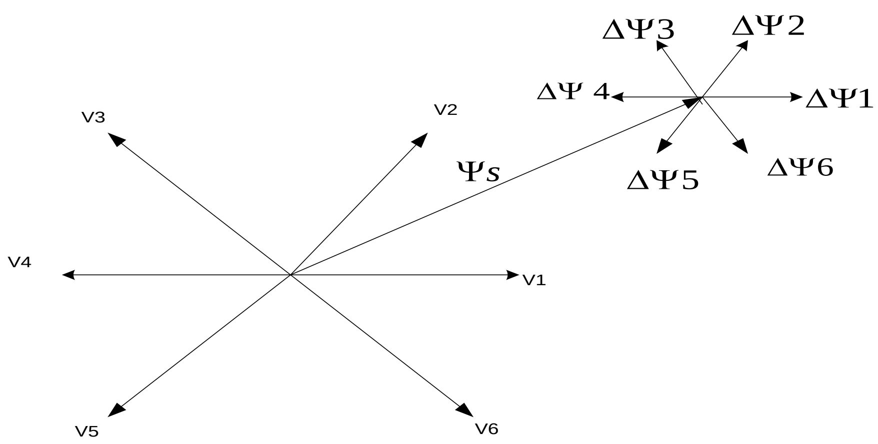

Figure 13. Stator flux variation in time Δt

6. Results

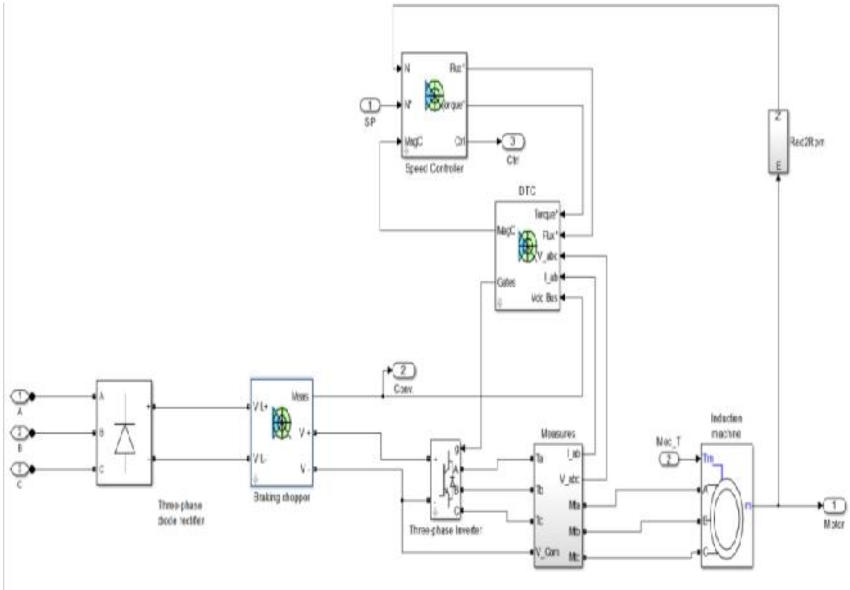

Figure 14. Simulink model for Close loop DTC model

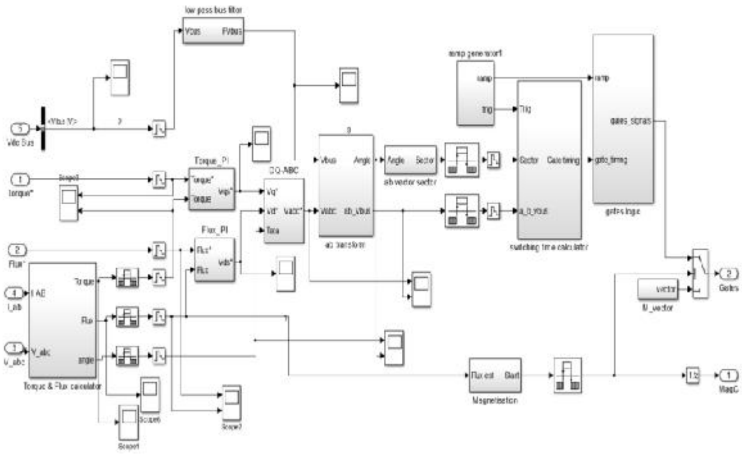

Figure 15. Structure of SVM scheme based direct torque controller

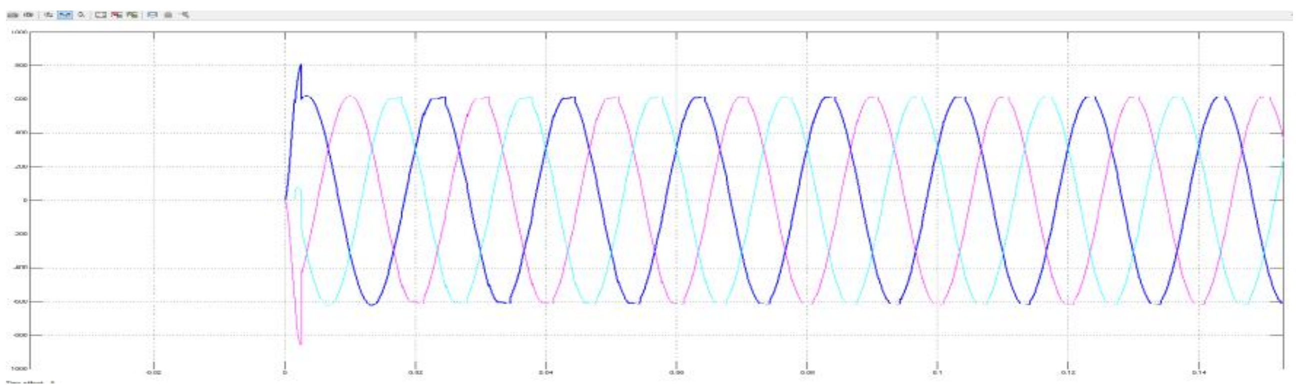

Figure 16. -3 phase Supply voltage

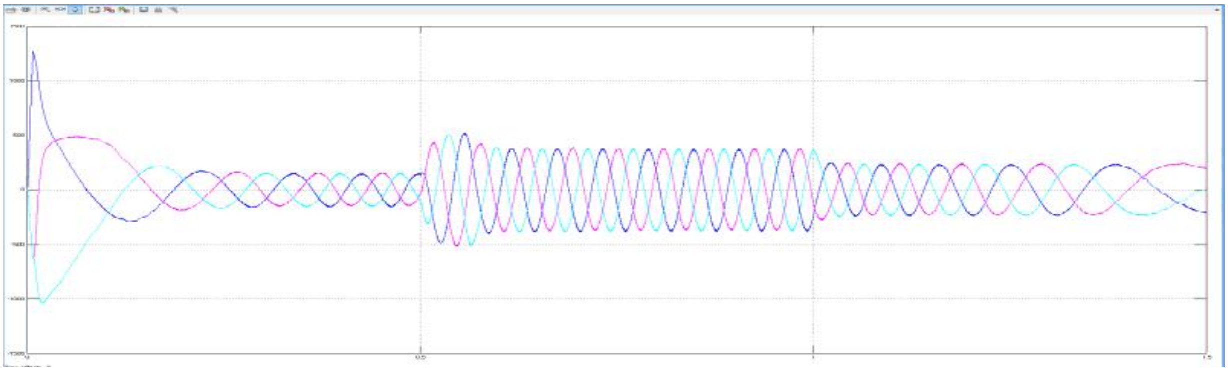

Figure 17. Three phase Stator current from DTC- SVM

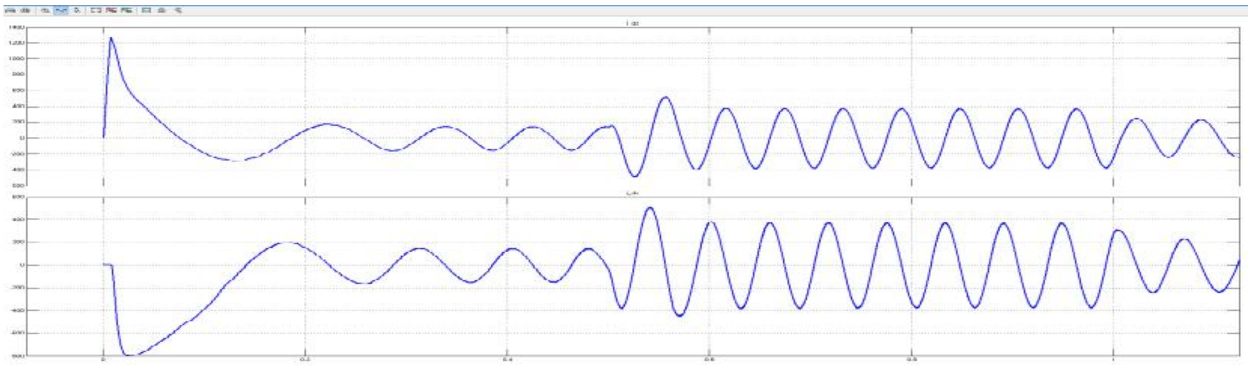

Figure 18. Estimated q-d axis stator current obtained from modified DTC

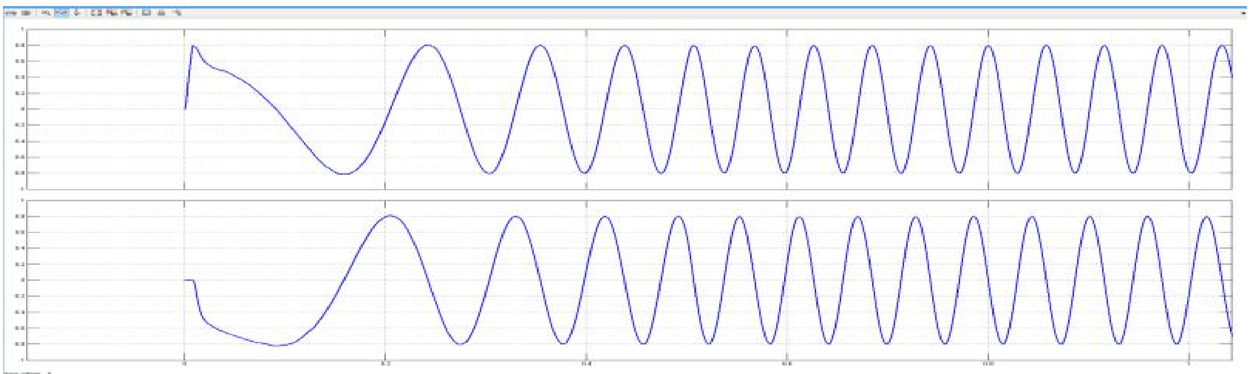

Figure 19. Estimated q-d axis stator flux obtained from DTC-SVM

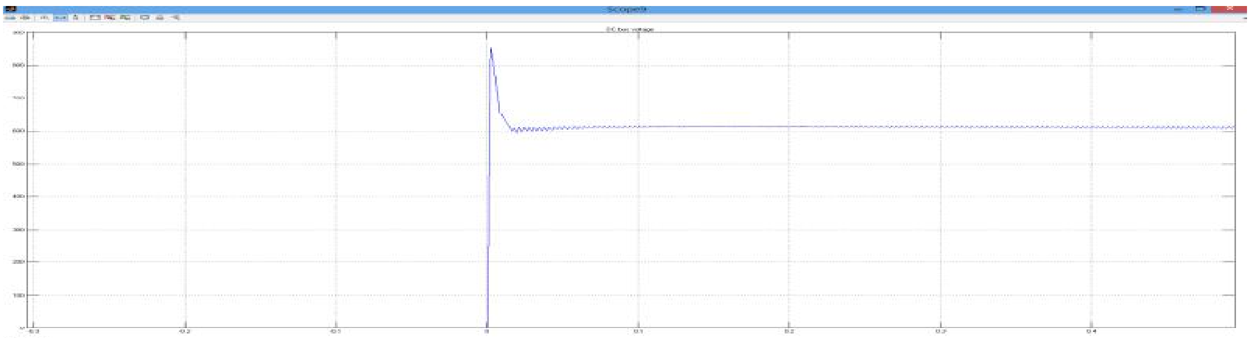

Figure 20. DC bus voltage waveform from modified DTC

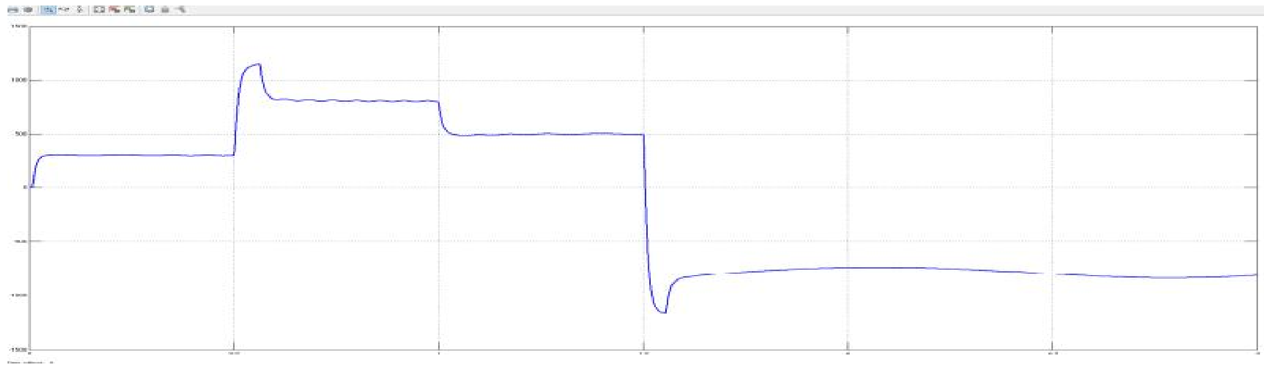

Figure 21. Reference Torque

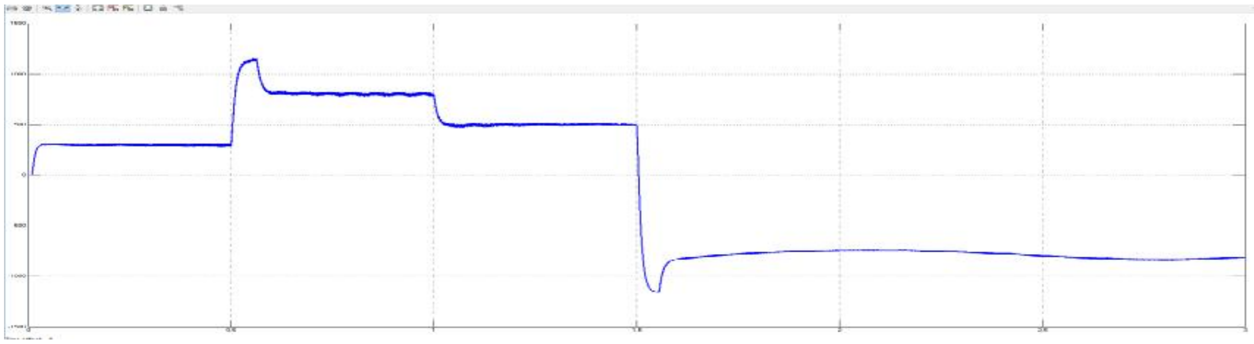

Figure 22. Estimated electromagnetic torque from DTC-SVM

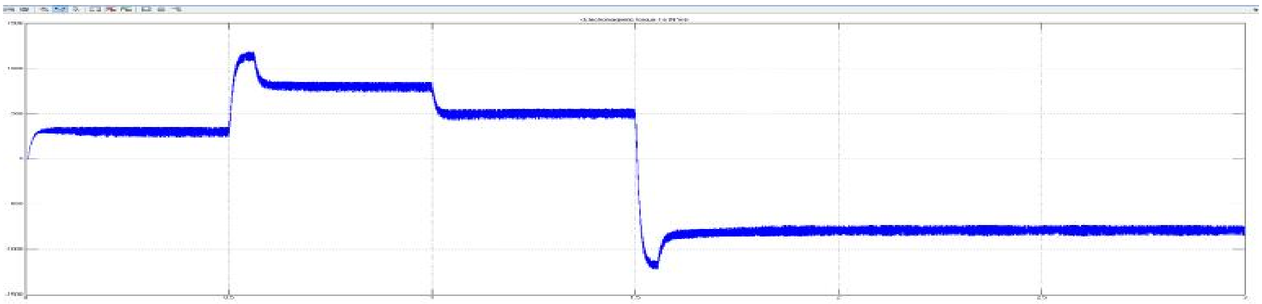

Figure 23. Estimated electromagnetic torque from conventional DTC

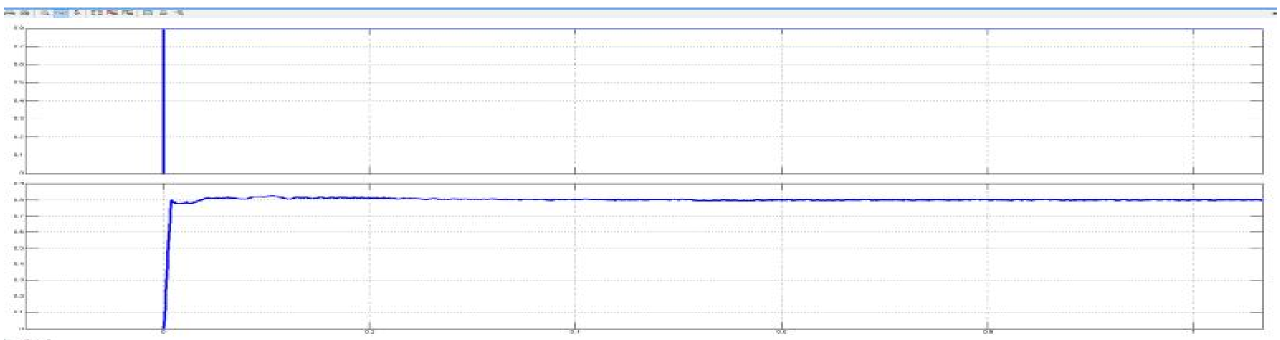

Figure 24. Reference flux and estimated torque with modified DTC

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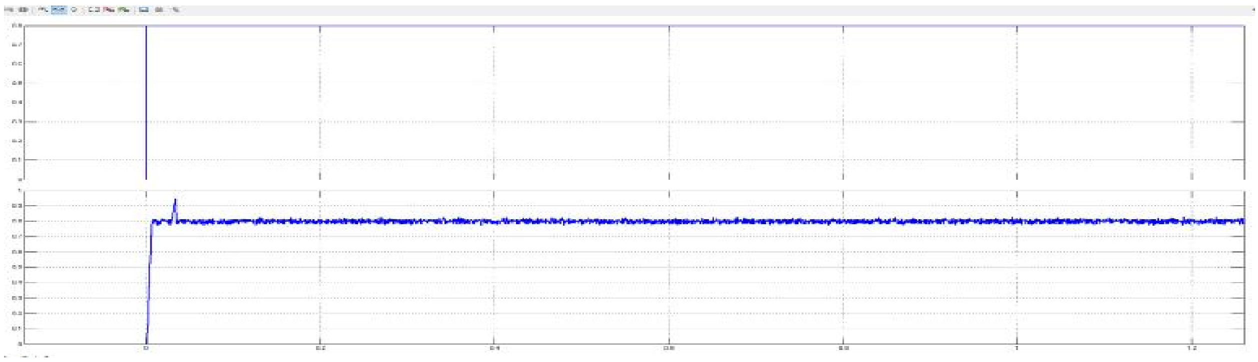


Figure 25. Reference flux and estimated torque with classical DTC

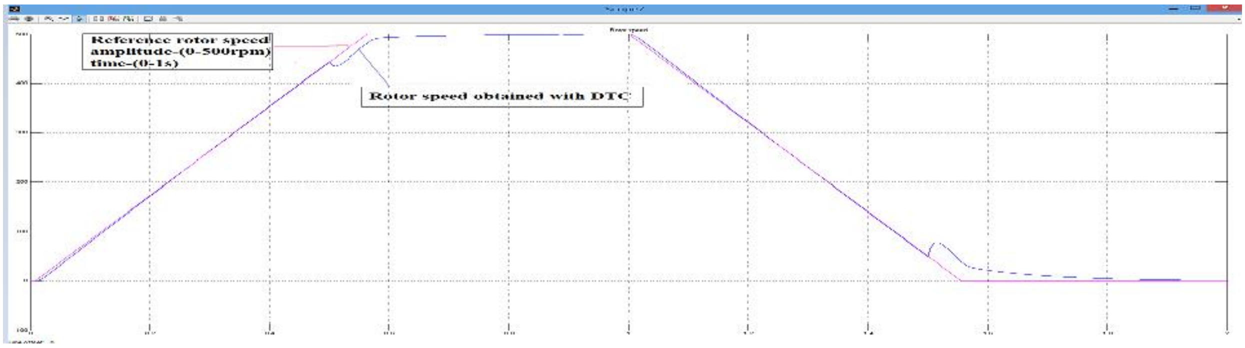
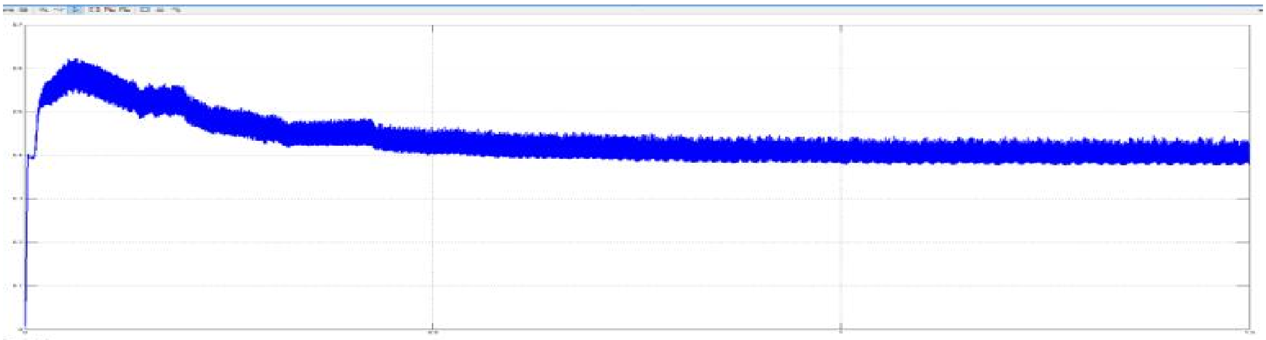
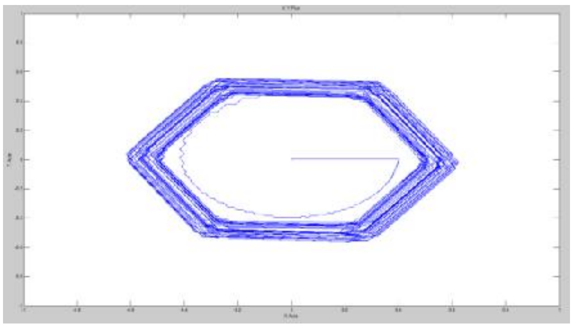


Figure 26. Rotor speed waveform

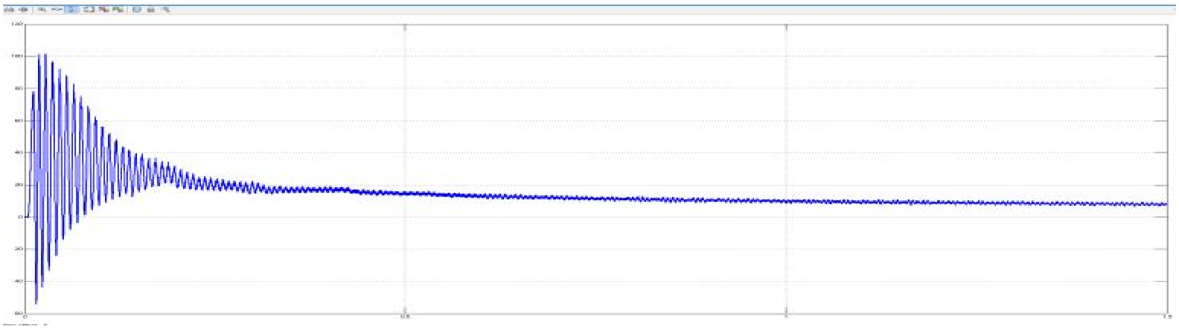
Flux variation:-



(a)



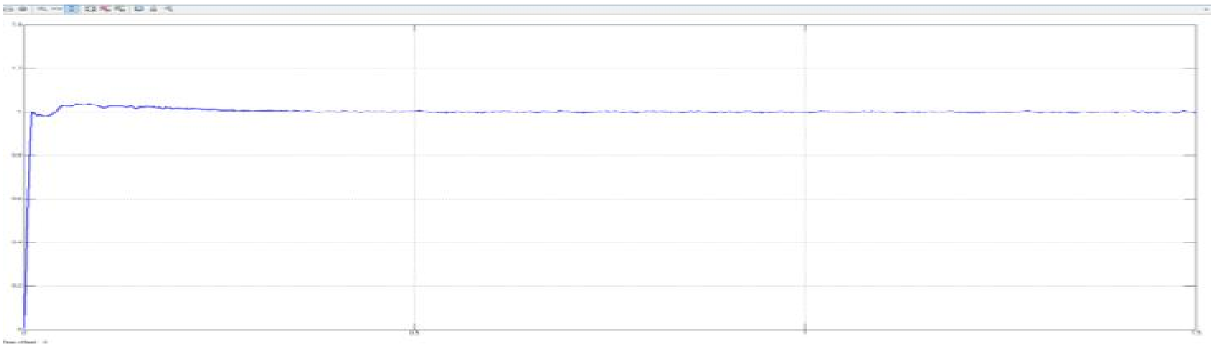
(b)



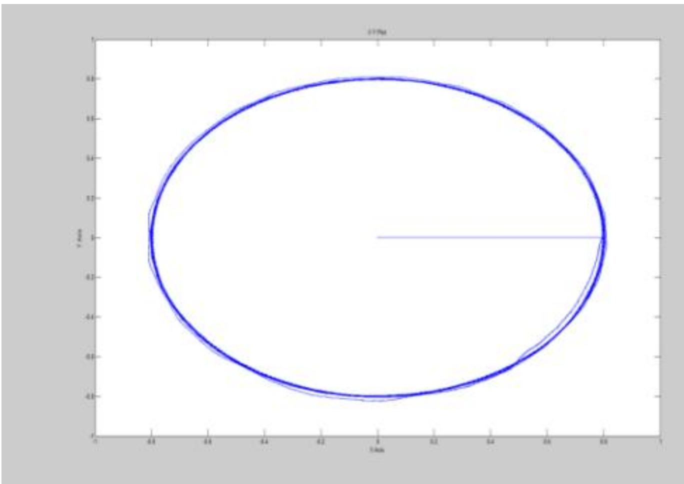
(c)

Figure 27. Effects of a decrease stator flux on the (a) estimated flux magnitude (b) estimated flux trajectory and (c) torque.

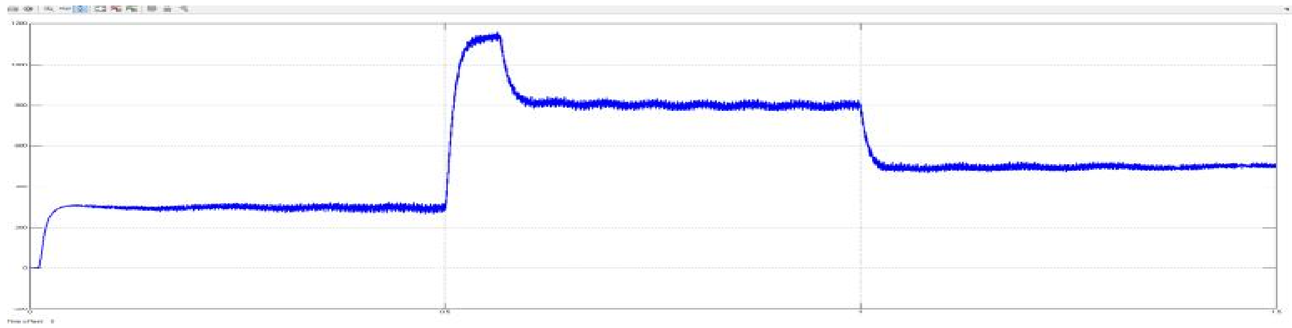
Increase in Flux:-



(a)



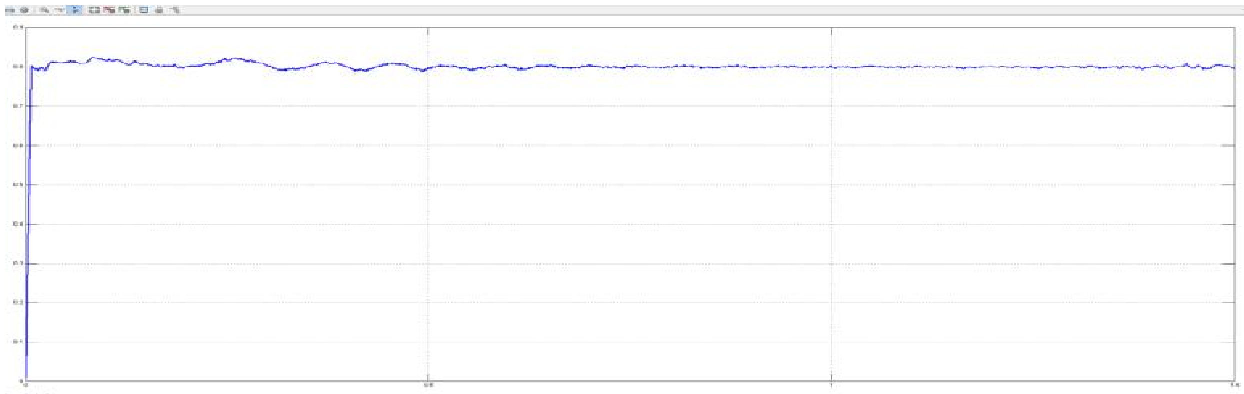
(b)



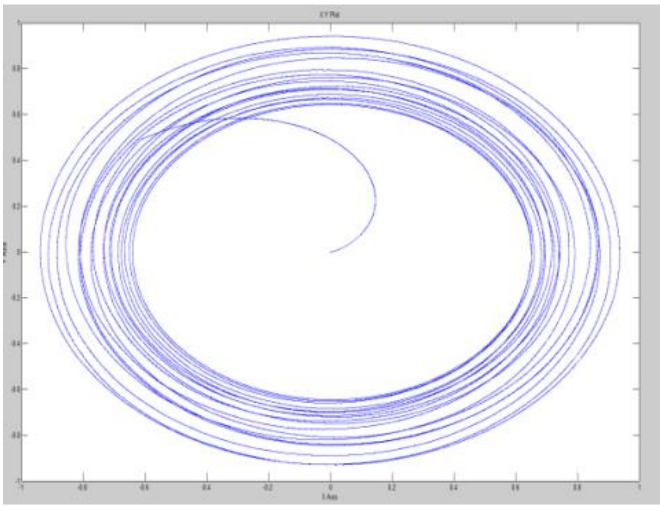
(c)

Figure 28. Effects of a increase stator flux on the (a) estimated flux magnitude (b) estimated flux trajectory and (c) torque.

Resistance Variation-



(a)



(b)

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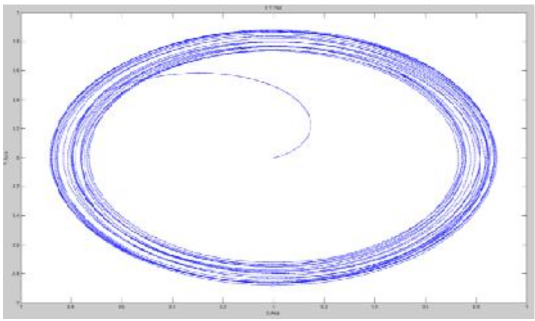
(c)

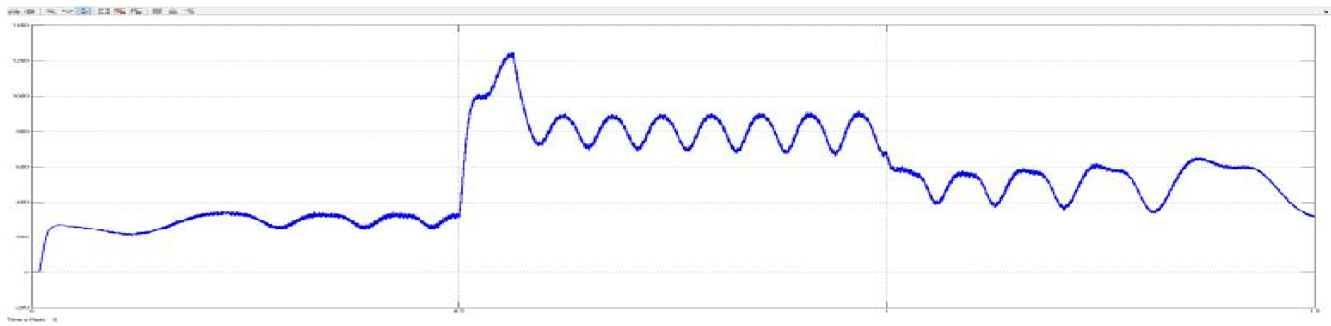
Figure 29. Effects of a decrease stator resistance on the (a) stator flux magnitude (b) Stator flux trajectory and (c) torque.

Increase in Resistance:-

(a)



(b)



(c)

Figure 30. Effects of a increase stator resistance on the (a) stator flux magnitude (b) Stator flux trajectory and (c) torque

CONCLUSION

This paper has given DTC strategies for SVPWM inverter- fed IM motor drives. The MATLAB simulink model shows the DTC implementation with SVPWM technique. By using SVPWM technique switching frequency maintain constant and also it reduces the torque ripple. DTC-SVM schemes improve the dynamic performance of drive also it provides better control at low speed operation with reliable start up.

During induction motor operation stator resistance does not maintain constant because of motor heating. It degrades the drive performance. In this paper the effect of change in stator resistance on motor estimated parameter are shown using simulink results. Also small change in stator flux produces large torque ripple and also it affect the estimated quantity. Hence stator flux must be within the range of 0.8 to 1 wb. The effect changes in stator flux on estimated variable are also shown with simulink result using DTC-SVM technique.

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Nomenclature

Vdc – Dc link voltage

d Ψs - Demand value of stator flux

dTe – Demand value of electromagnetic torque

S1-S6 – Sector number

V0-V7 – Null or Zero voltage vector

V1-V6 -Active voltage vector

Vd, Vq – d-q axis voltage vector

Va,Vb,Vc – Phase to neutral voltage of a,b,c phase.

Vs – Stator voltage

Ψs – Stator flux

RsIs - Stator resistance drop

δ – Position of reference voltage vector

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