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THE TORQUE AND FLUX RIPPLE MINIMIZATIOIN USING SVM-DTC METHOD

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Abstract: This paper presents a simulation of Direct Torque control (DTC) Method of Induction Motor using Space Vector Modulation (SVM) technique. Direct Torque Control is the control strategy used for high performance torque control of Induction Motor. DTC scheme of Induction Motor presents in this paper, which features in low torque ripple and low flux ripple by means of Space Vector Modulation (SVM). The performance is explained using simulation in MATLAB environment. Results of the simulation show improvements in flux and torque.

Keywords*:* Direct Torque Control scheme, Space Vector Modulation, Induction Motor, Flux and Torque Ripple

I. INTRODUCTION

Over the past years DC machines were widely used for variable speed drives application. Decoupled control of flux and torque can be achieved by field and armature control method respectively. DC machines have advantages like high starting torque, simple control. The biggest disadvantages of DC machines are the presence of commutator and brushes [1]. Today these drives are not much used because of various advantages of ac drives over DC drives. In industry, electric motor plays a very important role. It is a main part or the heart of the system. Today the performance of the system is considered in terms of efficiency, accuracy and smoothness of operation. Induction motor are widely used in industries and also widely used in high-performance drive. It is also used in commercial and domestic application of variable speed drives. It is robust in nature and also the absence of the commutator and brushes. The cost of the motor is very low. It has simple mechanical structure; more reliable and also low maintenance is required [1].

Scalar Control or v/f control method is very popular for induction motor drives. It is very simple method to implement. It only requires magnitude of the quantity. In this method, torque and flux are neither directly nor indirectly controlled. Also the flux variation is sluggish due to coupling. Control is provided by a frequency and voltage reference generator to get a constant volts per hertz output. Because of that it gives limited speed accuracy and poor torque response. It is normally used without speed feedback [3].The main features of Direct Torque Control (DTC) method are as follows [7]:

- Direct control of flux and torque.
- Indirect control of stator currents and voltages.
- Approximately sinusoidal stator fluxes and stator currents.
- High dynamic performance.
- Inverter switching frequency depends on width of flux and torque hysteresis bands.

The advantages of this method are as follows [7]:
- Absence of co-ordinate transformation.
- Doesn’t suffer from parameter variation.
- No PWM modulator is required.
- No PI controller is required.
- No separate voltage modular block is required.

- Absence of voltage decoupling circuits.
- Minimum torque response time.

II. DIRECT TORQUE CONTROL SCHEME

The new control technique for induction motor drive was introduced by I. Takahashi as a Direct Torque Control (DTC) [2] and by M. Depenbrock as a direct Self Control (DSC). Using DTC, there is a possibility to obtain good dynamic control of torque without mechanical transducers on the machine shaft. The basic functional blocks used to implement the DTC scheme in an induction motor is shown in Fig. 2[6]. Three phase AC supply is given to the diode bridge rectifier which produces a DC voltage. A high value dc link capacitor is used to reduce the ripple content in the DC voltage. The filtered DC is the power supply to the inverter switches. The IGBT inverter switches are controlled by the direct torque control algorithm. The output of the inverter is connected to the stator terminals of induction motor.

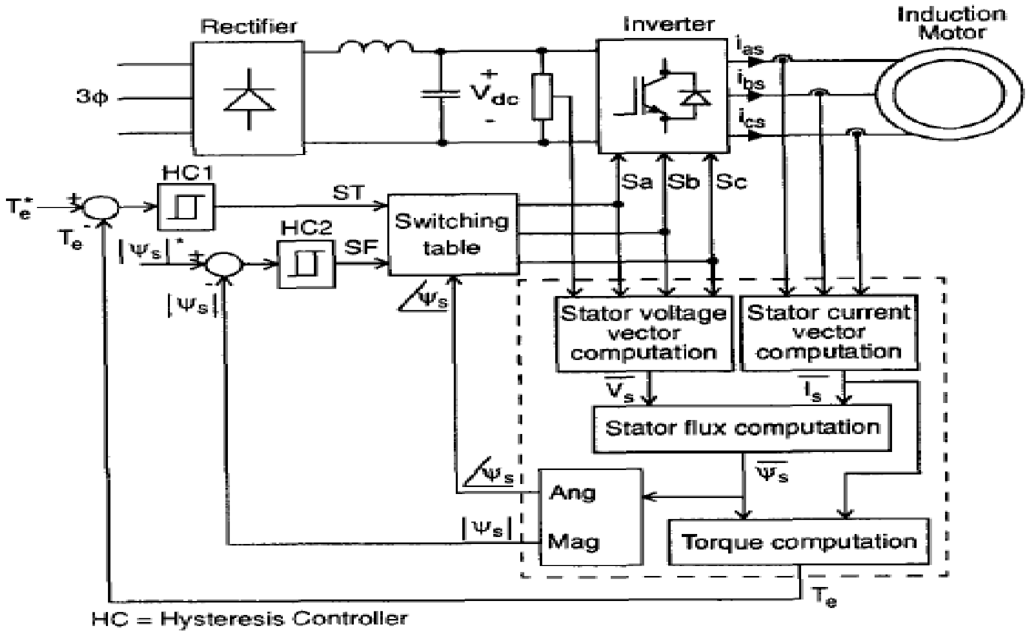

Figure 1: Direct Torque Control of Induction Motor. [1]

a. Flux and torque estimation

The feedback flux and torque are calculated from the machine terminal voltages and currents. The computation block also calculates the sector number in which the flux vector lies.

The stator flux of IM in stationary reference frame is written as [1]:

$$\Phi_s = \int (V_s - R_s i_s)\, dt \qquad (1)$$

The flux vector can be obtained from the stator flux components. By using the flux components, current components and IM number of poles, the electromagnetic torque can be calculated by,

$$T_e = \frac{3}{2}\frac{p}{2}(\varphi_d i_q - \varphi_q i_d) \qquad (2)$$

b. Torque and flux controller

The instantaneous values of flux and torque are calculated from stator variables by using flux and torque estimator. The command stator flux and torque magnitudes are compared with their respective estimated values and the errors are processed by the hysteresis band controllers. The flux loop controller has two levels of digital output according to following equations.

Stator flux error $\Delta\varphi_s = \varphi_{sref} - \varphi_s$

$|d\varphi_s| = 1$ if $|\varphi_s| \leq |\varphi_{sref}| - |\Delta\varphi_s|$: Flux is to be increased

$|d\varphi_s| = 0$ if $|\varphi_s| \geq |\varphi_{sref}| + |\Delta\varphi_s|$

: Flux is to be decreased

The width of the hysteresis band is$2\Delta\varphi_s$.The actual stator flux is constrained within the hysteresis band and tracks the command flux. The torque control loop has three levels of digital output represented by the following equations.

Torque error $\Delta T_e = T_{eref} - T_e$

$|dT_e| = 1$ if $|T_e| < |T_{eref}| - |T_e|$: Torque to be increased

$|dT_e| = -1$ if $|T_e| < |T_{eref}| - |T_e|$: Torque to be increased

$|dT_e| = 0$ if $|T_{eref}| - |T_e| \leq |T_{eref}| + |T_e|$: not changed

c. switching table

The switching selection block in fig.1 receives the input signals as shown in figure. The look up table for desired control voltage vector is shown in Table 1.

TABLE 1: - FONT SIZES FOR PAPERS

dφ	dT_e	α1	α2	α3	α4	α5	α6
1	1	V_2	V_3	V_4	V_5	V_6	V_1
	0	V_7	V_0	V_7	V_0	V_7	V_0
	-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	V_0	V_7	V_0	V_7	V_0	V_7
	-1	V_5	V_6	V_1	V_2	V_3	V_4

$$-30° < \alpha_1 < 30°$$
$$30° < \alpha_2 < 90°$$
$$90° < \alpha_3 < 150°$$
$$150° < \alpha_4 < 210°$$
$$210° < \alpha_5 < 270°$$
$$270° < \alpha_6 < 330°$$

The flux increment vector corresponding to each of six inverter voltage vectors are shown in fig.2.

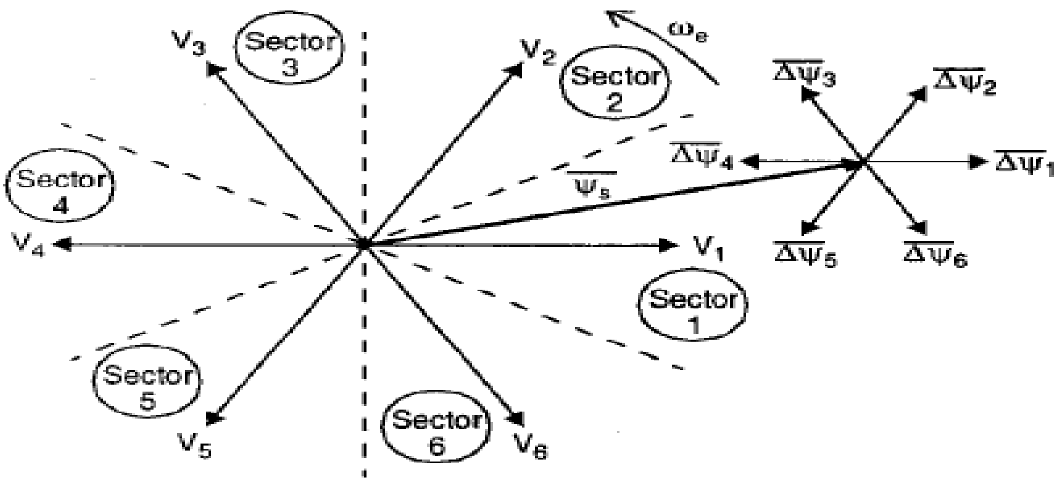

Figure 2: Inverter Voltage vectors and corresponding stator flux variation. [1]

III. SVM-DTC METHOD

Direct flux and torque control with space vector modulation (DTC-SVM) schemes are invented to improve the classical DTC. These strategies operate at a constant switching frequency. In the control structures, space vector modulation (SVM) algorithm is used.

This basic block diagram for DTC-SVM scheme is shown in Fig 3. [25] [26]. In this scheme, flux and torque estimator are used to determine the actual value of the flux and torque. In that scheme instead of the switching table and hysteresis controllers, a PI controller and numeric calculation are used to determine the duration time of voltage vector so the error vector in flux and torque can be fully compensated.

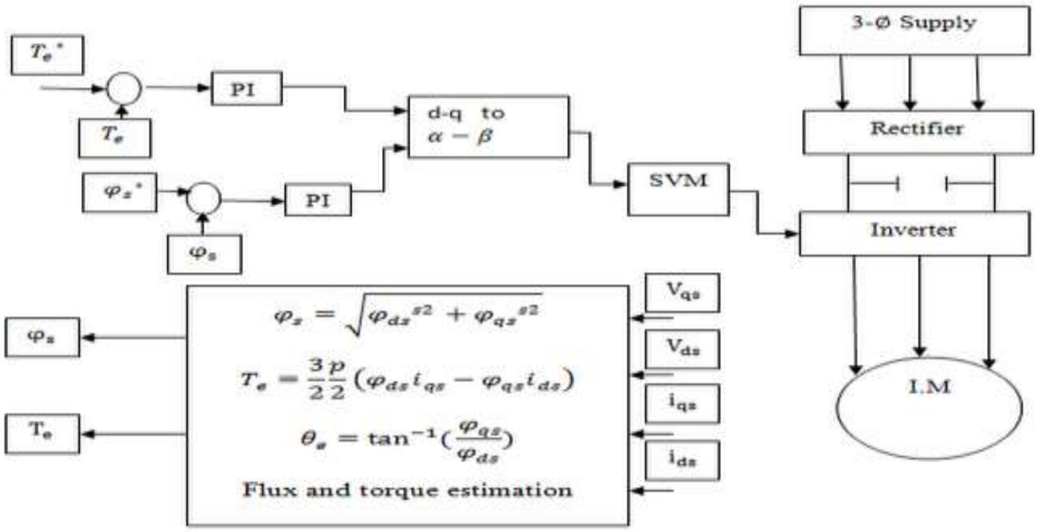

Figure 3: Block diagram of DTC-SVM. [25]

Two proportional integral (PI) type controllers regulate the flux and torque error. These controllers produce the voltage command vector; appropriate space voltage vector can be generated with SVM. The output of the PI flux and torque controllers can be interpreted as a reference voltage component in d-q co-ordinate system. These dc voltage commands are then transformed into stationary frame (α-β) and then command value V_α, V_β are applied to SVM block. This SVM block generates gate signals for the inverter circuit.

A. Principle of Space Vector Modulation

The Space Vector PWM (SVPWM) is operated at a constant switching frequency and is considered to be the better among the different PWM algorithms [28]. The SVPWM represents a better approach to poly phase inverters. The power circuit of a three-phase VSI is shown in Fig 4. Each switch in the inverter leg is composed of two back-to-back connected semiconductor devices. One of these two is a controllable device and other one is a diode for protection. In inverter two switch of same leg is complementary [28].

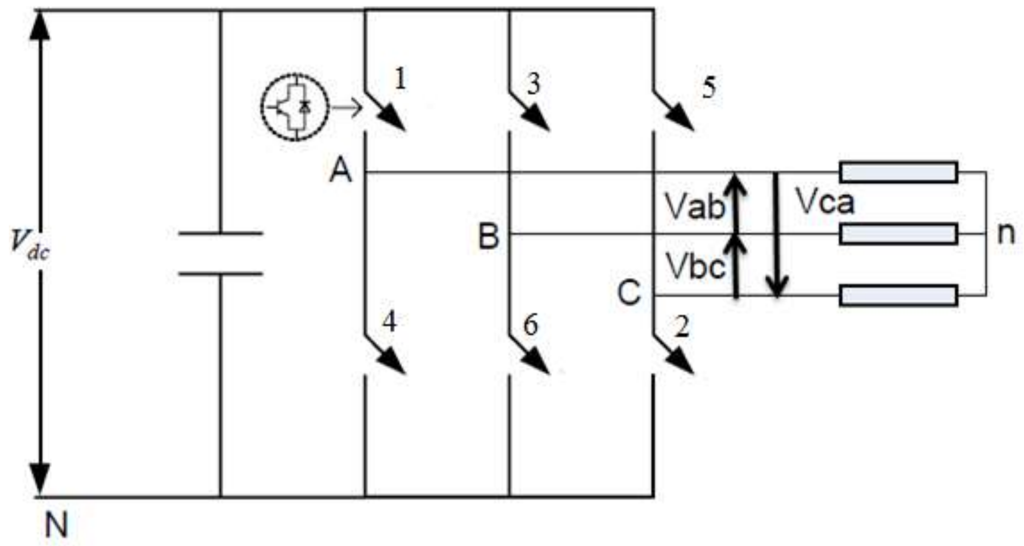

Figure 4: Three Phase VSI.

Three phase inverter have eight possible combinations; two of them are a null value because all terminals are connected to same potential either at ground or at V_{cc}. The remaining six combinations give non-zero voltage and all are represented as a state which form hexagon in plane spanning 60° from each other.

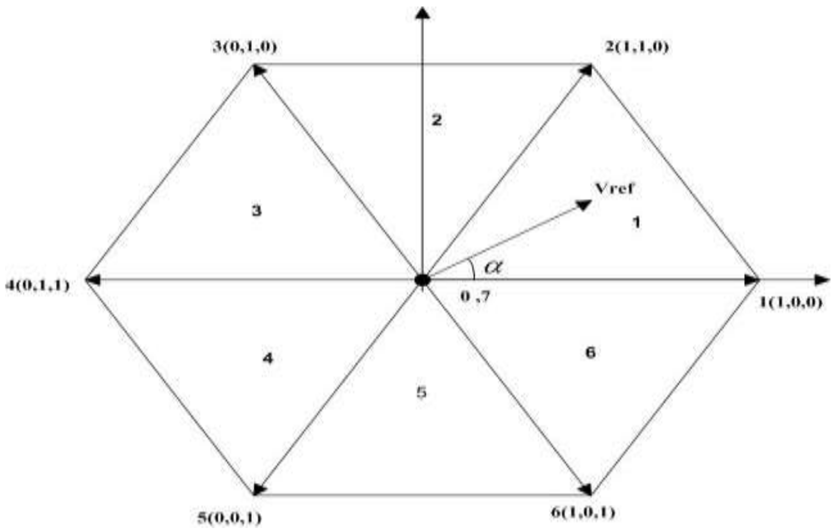

Figure 5: Possible switching combination

In above Fig 5, each state is represented by three numbered coordinate system which is corresponding to the state of the inverter leg. State 0 represent conduction of lower switch and state 1 represent conduction of upper switch. There is a command vector which rotates at same angular speed of desired frequency. The position of vector gives instantaneous voltage output of the inverter. When vector lies between two active vectors, a vector sum is made in order to obtain desired output voltage given by,

$$V = V_a + V_b + V_o \qquad (3)$$

The reference vector which represents three-phase sinusoidal voltage is generated using SVPWM by switching between two nearest active vectors and zero vectors. Where V_a and V_b are the two nearby active state vector, and V0is a null vector; which become necessary because it helps to control the magnitude of applied voltage by adding time on commutation sequence where energy is not applied to the load[28]. PWM range is divided into linear and over modulation range. The modulation index for PWM inverter is defined by,

$$\mathrm{MI} = \frac{\mathrm{V}^*}{{}^2/_\pi \mathrm{V_{dc}}} \quad (4)$$

Where, V^* = Phase Voltage reference
V_{dc} = input voltage to inverter

In linear modulation range trajectory of reference voltage vector is inside the hexagon. To calculate the time of application of different vector, consider Fig 6, depicting the position of different available space vectors and the reference vector in the first sector. From Fig 6, time for application of active space vector is found by using volt-time balance theory[28].

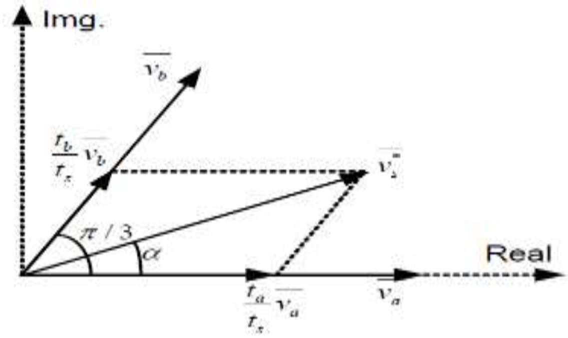

***Figure 5**: Time calculation for application of active and zero vectors.*

$$\int_0^{T_s} V_{ref} = \int_0^{T_a} V_a + \int_{T_a}^{T_a+T_b} V_b + \int_{T_a+T_b}^{T_s} V_0 \quad (5)$$

$$T_s * V_{ref} = T_a * V_a + T_b * V_b \quad (6)$$

$$T_s * V_{ref} \begin{bmatrix}\cos(\alpha)\\ \sin(\alpha)\end{bmatrix} = T_a V_a \begin{bmatrix}1\\0\end{bmatrix} + T_b V_b \begin{bmatrix}\cos(^{\pi}/_3)\\ \sin(^{\pi}/_3)\end{bmatrix} \quad (7)$$

$$T_a = \frac{V_{ref}}{V_a}\frac{\cos(^{\pi}/_3 - \alpha)}{\sin(^{2\pi}/_3)} \quad (8)$$

$$T_b = \frac{V_{ref}}{V_b}\frac{\sin\alpha}{\sin(^{2\pi}/_3)} \quad (9)$$

$$T_o = T_s - (T_a + T_b) \quad (10)$$

Where, $V_a = V_b = {}^2/_3 V_{dc}$

Equation 8 to 10 gives time duration for application of active and zero vectors in first sector. Similarly for other sector application time of active vector given by volt-time balance theory is as per equation 11 to 13.

$$T_a = T_s \frac{V_{ref}}{V_a}\frac{\sin(n\,^{\pi}/_3 - \alpha)}{\sin(^{2\pi}/_3)} \quad (11)$$

$$T_b = T_s \frac{V_{ref}}{V_b}\frac{\sin(\alpha - (n-1)\,^{\pi}/_3)}{\sin(^{2\pi}/_3)} \quad (12)$$

$$T_o = T_s - (T_a + T_b) \quad (13)$$

Where, n=sector in which reference vector rotate.

To obtain optimum harmonics performance and for fixed switching frequency from SVPWM, each leg change its state only once in a single switching period. To achieve half wave symmetry switching period is divide into 7 parts and at starting zero vector is applied for 1/4th of the zero vector time. Then zero vectors are followed by two active vectors in half cycle and next half cycle is mirror image of the first half.

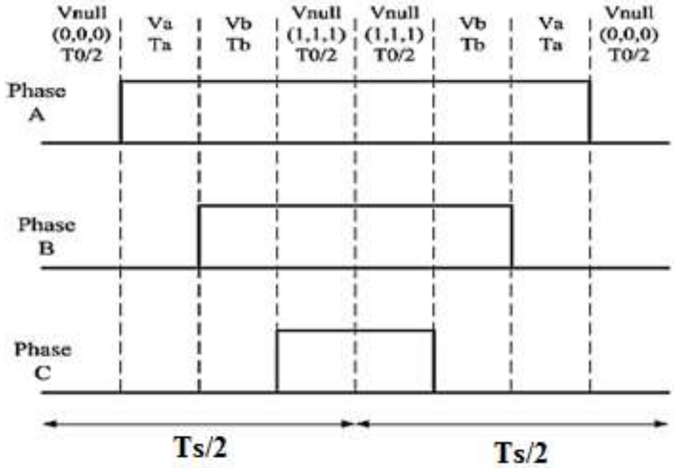

Figure 6: **Space vector position for one switching period in sector 1**

For sinusoidal reference space vector, maximum output voltage magnitude is largest circle that can be inscribed within the hexagon. This circle is tangential to mid points of lines joining the ends of the active space vector.

IV. SIMULATION RESULTS

The flux and torque ripple minimization using SVM-DTC Method is done using simulation in MATLAB.

A simulink model for SVM-DTC is shown in Fig 7,

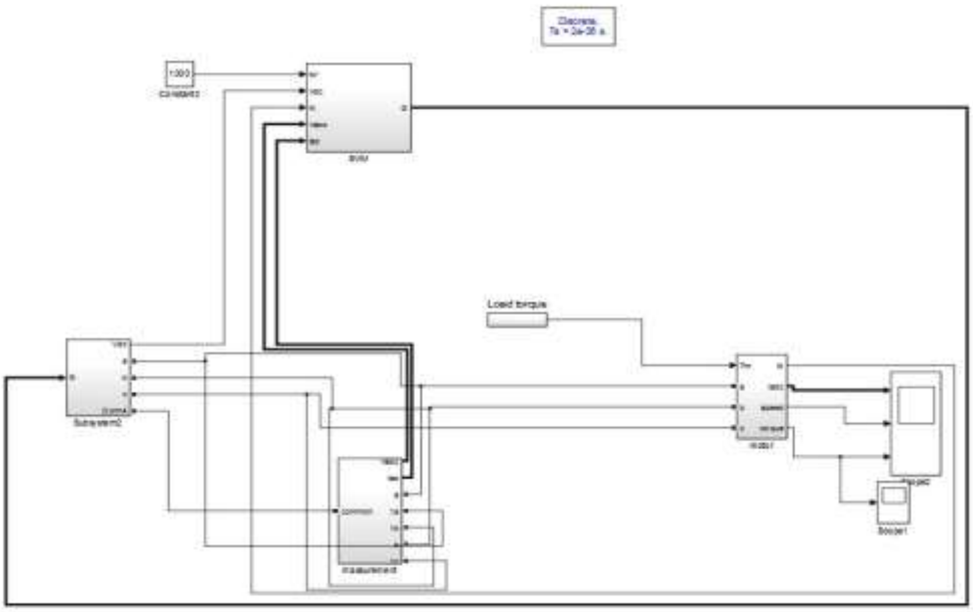

Figure 7: Simulink Diagram of SVM-DTC

From this model, we get the desired output of minimum ripple of torque and flux waveform. The output waveform for this is shown in Fig 8 and 9.

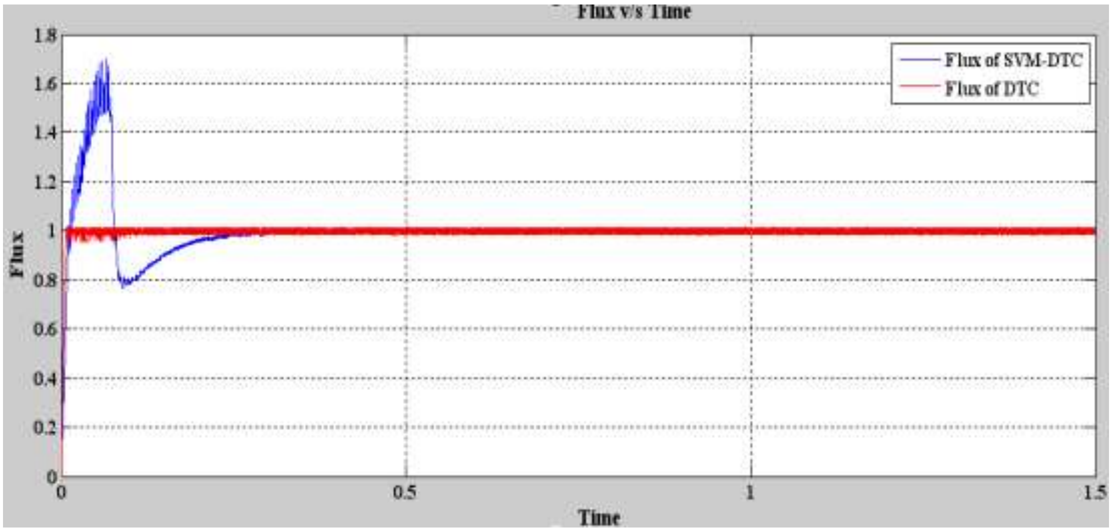

Figure 8: Flux waveforms of DTC and SVM-DTC Methods

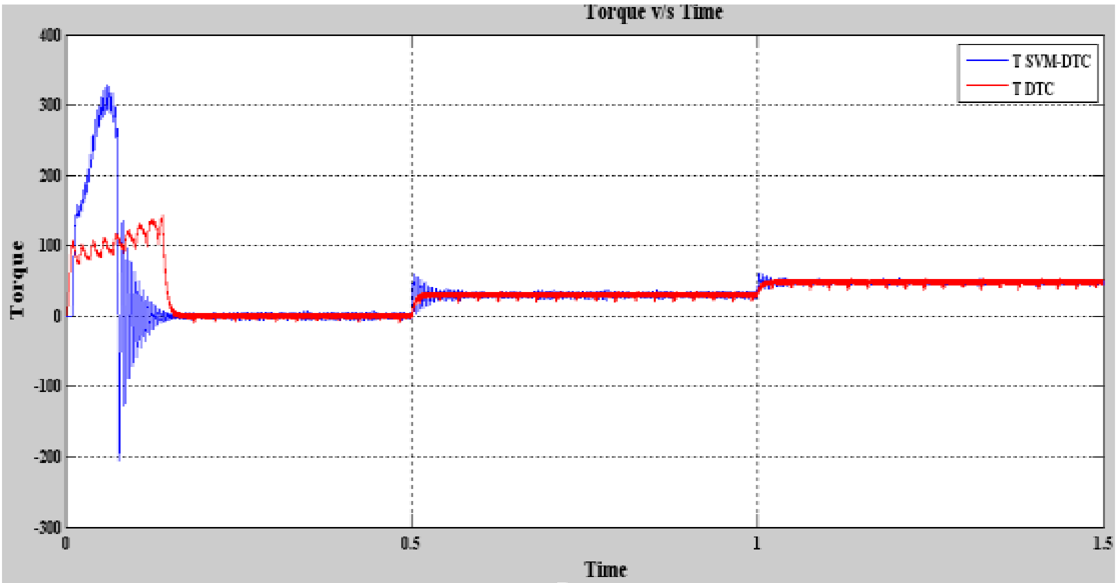

Figure 8: Torque waveforms of DTC and SVM-DTC Methods

V. CONCLUSION

In classical DTC method, speed response is faster. Torque and Flux ripple is present in that method. This torque and flux ripple can be minimized by SVM-DTC method. From the simulation results, we clearly see that flux and torque ripple is greatly minimized.

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