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Speed Control of BLDC Motor Drive under DTC and Indirect Flux Control Scheme using SVPWM Technique

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Abstract: Brushless dc (BLDC) motor became indispensable in most of the industrial drive applications due to its high efficiency, higher power density, easy maintenance and control, and high torque to inertia ratio. In this paper a sensorless Space Vector Pulse Width Modulation based direct torque and indirect flux control of BLDC has been investigated. Several methods are proposed in the literature to obtain higher torque with better control on current and torque with minimal fluctuations in current /torque. Most of the proposed techniques are complex and they do not take stator flux control in to account, so that high speed operations are not possible with this drive. The proposed sensorless method employs Direct Torque control method for controlling stator flux indirectly and toque directly by varying direct axis current. Space vector pulse width modulation technique used in this paper gives better performance than the conventional PWM and vector control techniques in terms of controlling the variations in direct axis current. The proposed sensorless Direct Torque and indirect flux Control of BLDC motor drive has been simulated in the MATLAB/SIMULINK environment and results are obtained.

Keywords: BLDC Motor, Stator flux control, Direct Torque Control (DTC), Space Vector Pulse Width Modulation (SVPWM).

1. INTRODUCTION

Brushless DC motor is the better option in the present day industrial applications requiring high accuracy, higher efficiency and high power density. Usually BLDC motor is accounted as high pursuance motor which is efficient in generating more amounts of torque over wide speed ranges. BLDC motors give the same performance as a DC motor by exhibiting the some torque-speed characteristics. Additional advantage of BLDC motor over DC motor is related to the usage of brushes. Like DC motor BLDC motor does not require brushes as they are electronically commutated. Commutation is nothing but changing current from one phase to another phase of winding at desired time to create unidirectional torque. The commutation sequences are desired by the rotor position with respective stator windings and the rotor position is detected either by using position sensors or by sensor less techniques

For BLDC motors with trapezoidal shape back emf obtaining low frequency ripple free torque, and instantaneous torque and flux are major considerations. So in order to obtain the control on flux and torque there are different methods that are stated for sensorless control of BLDC they are:

1. Measurement of back EMF
2. Method of Back EMF integration
3. Method of Flux estimation
4. Freewheeling current detection method

The above stated methods have there own advantages and disadvantages and moreover the newer techniques that are evolved made them a bit effective less as some of the techniques needs hardware equipment for sensing purpose.

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This paper presents a simple sensorless indirect flux control and direct torque of BLDC motor, similar to the normal Direct torque control used for sinusoidal alternating current motors where torque generated and flux are regulated at the same time. This method give advantages of fast torque response compared to vector control as lick conventional DTC, and position-sensorless drive. The BLDC motor rotor position is known by calculating stationary reference frame stator flux linkages and winding inductance and stator currents.

The basic property of Direct Torque Control is that to select the voltage vector in relation with the error between reference and calculated torque and flux linkage values. In the proposed scheme, the main control moto is to keep the motor's amplitude of the stator flux and developing torque within particular edges. The inverter is triggered by SVM controllers to switch whenever these limits are exceeded.

2. MODELLING OF BRUSHLESS DC MOTOR

BLDC motors is one of the motor which rotates in synchronism. As its name says synchronism, the magnetic field created by both the stator and rotor rotates with the same speed in air gape of rotor stator. So BLDC motors do not experience any "slip" which is normally observed in induction motors. BLDC motor is built with wire wound stator poles and a permanent magnet rotor.

To achieve proper commutation, brushes and mechanical commutators are used in permanent magnet DC motors. But in case of BLDC motor it uses rotor position and electronic switches in place of mechanical commutators and brushes. So BLDC motor is said to be electronically commutated. The stator of BLDC motor contains winding coils and the rotor with permanent magnets. The stator develops the magnetic field to makes the rotor to rotate. The Hall Effect sensors which are placed 120 electrical degrees apart or different rotor position estimation methods detects the rotor position so as to make proper commutation sequence. Therefore, BLDC motors replace the coils with permanent magnets in armature so it does not require any brushes and commutators as shown in Figure 1. And the schematic diagram for Brushless DC motor is shown in below Figure 2.

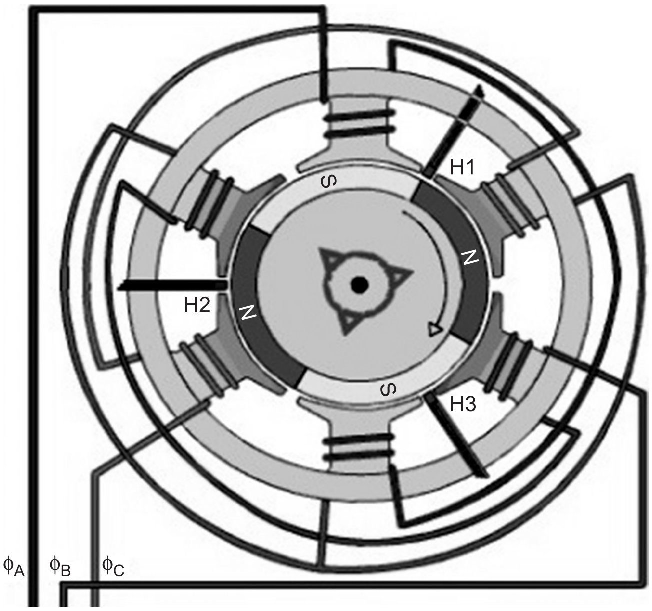

Figure 1: View of BLDC Motor.

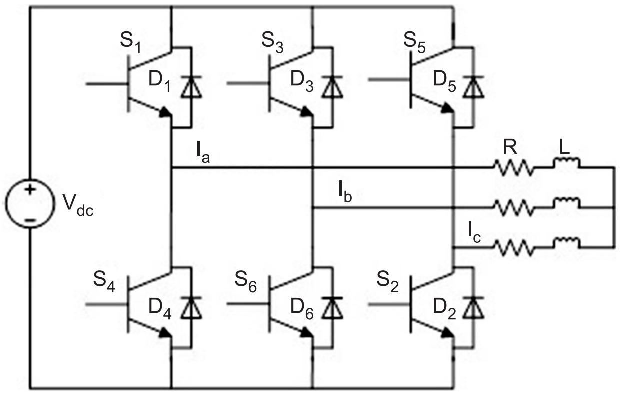

Figure 2. Basic schematic diagram for BLDC.

The mathematical modelling for BLDC drive is obtained by considering the following considerations such as,

1. It has three symmetrical windings.
2. Has no magnetic saturation.
3. Neglecting hysteresis and eddy current losses.
4. Ignorance of mutual inductance.
5. And neglecting armature reaction.

The mathematical modelling is obtained by considering the KVL equations for Figure 2.

$$\mathrm{V}_a = i_a r_a + \mathrm{L}\frac{di_a}{dt} + e_a$$

$$\mathrm{V}_b = i_b r_b + \mathrm{L}\frac{di_b}{dt} + e_b$$

$$\mathrm{V}_b = i_c r_c + \mathrm{L}\frac{di_c}{dt} + e_c \tag{1}$$

For solving these equations, in this paper we used a concept of line-to-line park's transformation technique. This line-to-line parks transformation converts the three phase voltages to two phase coordinators expressed as,

$$\begin{bmatrix} \mathrm{V}_{ab} \\ \mathrm{V}_{ca} \end{bmatrix} = \begin{bmatrix} -\frac{1}{3} & -\frac{1}{3} \\ \frac{\sqrt{3}}{3} & -\frac{\sqrt{3}}{3} \end{bmatrix} \begin{bmatrix} \mathrm{V}_a \\ \mathrm{V}_b \\ \mathrm{V}_c \end{bmatrix} \tag{2}$$

The matrix coordinates obtained from the above line to line park's transformation are transformed to orthogonal matrix coordinates (α, β). Similarly, same like as voltage, the three phase currents also transformed to two phase orthogonal matrix. These two phase currents (I_α, I_β) and voltage (V_α, V_β) are used for calculating the flux linkages (ψ_α, ψ_β) from the expression described as,

$$\psi_\alpha = \frac{1}{\mathrm{L}_\alpha}(\mathrm{V}_\alpha - i_\alpha r_a)$$

$$\psi_\beta = \frac{1}{\mathrm{L}_\beta}(\mathrm{V}_\beta - i_\beta r_a) \tag{3}$$

And from this equation the phase angle is calculated as,

$$\psi = \psi_\alpha + j\psi_\beta$$

$$\theta = \tan^{-1}(\psi_\beta/\psi_\alpha) \tag{4}$$

The measured values of direct axis and quadrature axis currents are obtained by the following matrix,

$$\begin{bmatrix} i_d \\ i_q \end{bmatrix} = \frac{2}{3}\begin{bmatrix} -\sin(\theta - 30) & \sin(\theta + 30) \\ \cos(\theta + 30) & -\cos(\theta - 30) \end{bmatrix}\begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix} \tag{5}$$

These obtained measured are compared with reference direct and quadrature axis currents for obtaining error tolerance. The reference current signals are obtained by the electromagnetic torque. From the definition of newton's law of motion, the total applied torque is equal to sum of all individual torques across each element.

$$T_e = T_m + J\frac{dw_m}{dt} + Bw_m \tag{6}$$

The electromagnetic torque generated by a BLDC motor is expressed as

$$T_e = \frac{e_a i_a + e_b i_b + e_c i_c}{w_m} \tag{7}$$

Assuming the three phase windings are symmetrical, so that the amplitudes of currents and back emfs should be equal for three phases. From the above two equations, the electromagnetic torque can be developed by a BLDC motor at any instant is

$$T_e = \frac{2e_p i_p}{w_m} \tag{8}$$

Where e_p is called phase back emf and i_p is a non-zero phase current.

The back EMF for a BLDC motor is given as

$$e_p = kw_m \tag{9}$$

The error difference is obtained from comparison of the currents is given to SVM controller for obtaining the gate pulses to the three phase inverter.

3. SPACE VECTOR MODULATION TECHNIQUE

It is a different approach for getting gate triggering signals instead of general pulse width modulation technique which is based on the space vectors generated by the system two phase vector components *d*, *q* axis.

Figure 3 shows the space vector representation of the adjacent vectors S_1 and S_2 with 8 space vector switching pattern positions of inverter.

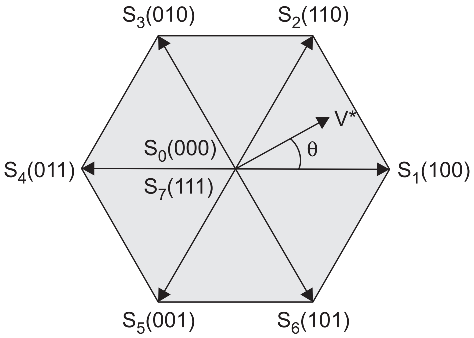

Figure 3: Space Vector Modulation Technique

Generally, the Space Vector Modulation Technique is one of the most popular methods in PWM techniques fed for the three phase voltage source inverters. By using Space Vector Modulation the harmonic content in both output voltage and output currents are reduced. The space vector modulation technique is used in this paper for creating the reference vectors generated by modulating the switching time sequence of space vectors in each of six sectors as shown in Figure 3. From Figure 3, six switching sectors are used for inversion purpose and two sectors are behave like a null vectors.

Space vector PWM can be implemented by the following steps:

1. Transform 3-phase to 2-phase quantity and determine V_s and angle.
2. Determine time duration T_1, T_2 and T_0.

Equation (10) gives the reference space vector V*, where T_1, T_2 are the time intervals of application of vector S_1 and S_2 respectively, and zero vectors S_0 and S7 are selected for T0.

$$V \times T_z = S_1 \times T_1 + S_2 \times T_2 + S_0 \times \frac{T_0}{2} + S_7 \times \frac{T_0}{2} \tag{10}$$

The electric rotor position θ_{re} which is required in torque estimation can be found using the Equation.

$$\theta_{re} = \tan^{-1}\left(\frac{\psi_{s\beta} - L_s i_{s\beta}}{\psi_{s\alpha} - L_s i_{s\alpha}}\right) \tag{11}$$

4. PRINCIPLE OF OPERATION OF SPACE VECTOR MODULATION SCHEME FOR BLDC DRIVE

The basic control block diagram shows the implementation of the Direct Torque Control based Space Vector Modulation technique is as shown in Figure 4. With this proposed control technique, first the values for estimated torque and flux linkages are determined from the actual three phase component currents and the three phase stator voltages. For doing these calculation we are considered the two phase rotational orthogonal matrix vectors. And after determination of estimated torque and flux linkages, these are used for generating triggering sequences. Two proportional integral controllers are used to regulate the current errors. The gate switching signals for the inverter is obtained from the voltage vectors which are obtained from controlling and comparison of actual phase values of voltage and current vectors. The complete block diagram for the SVM based DTC controller is shown in Figure 4.

The electric rotor position θ_{re} which is required in torque estimation can be found using the Equation.

$$\theta_{re} = \tan^{-1}\left(\frac{\psi_{s\beta} - L_s i_{s\beta}}{\psi_{s\alpha} - L_s i_{s\alpha}}\right) \tag{12}$$

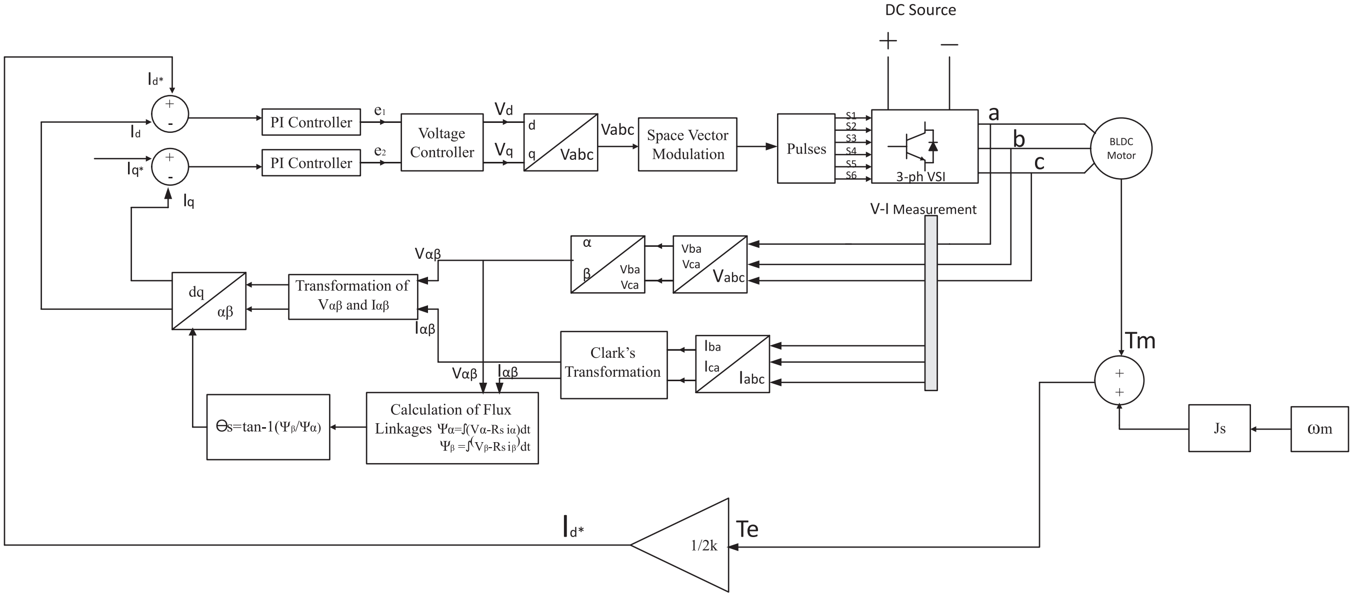

Figure 4: Control Diagram of DTC-SVM Technique

5. SIMULATION DIAGRAM AND RESULTS

The experimental setup for DTC- SVM based BLDC drive is done in Matlab/Simulink model. Switching pulses for the three phase inverter are obtained from the switching table which decides the pulses from the error signals of stator currents. The absolute value of current is estimated from the estimated torque which is derived from the mechanical modelling and motor parameters such as phase voltage and phase currents. The complete simulation model of the system is shown in Figure 5.

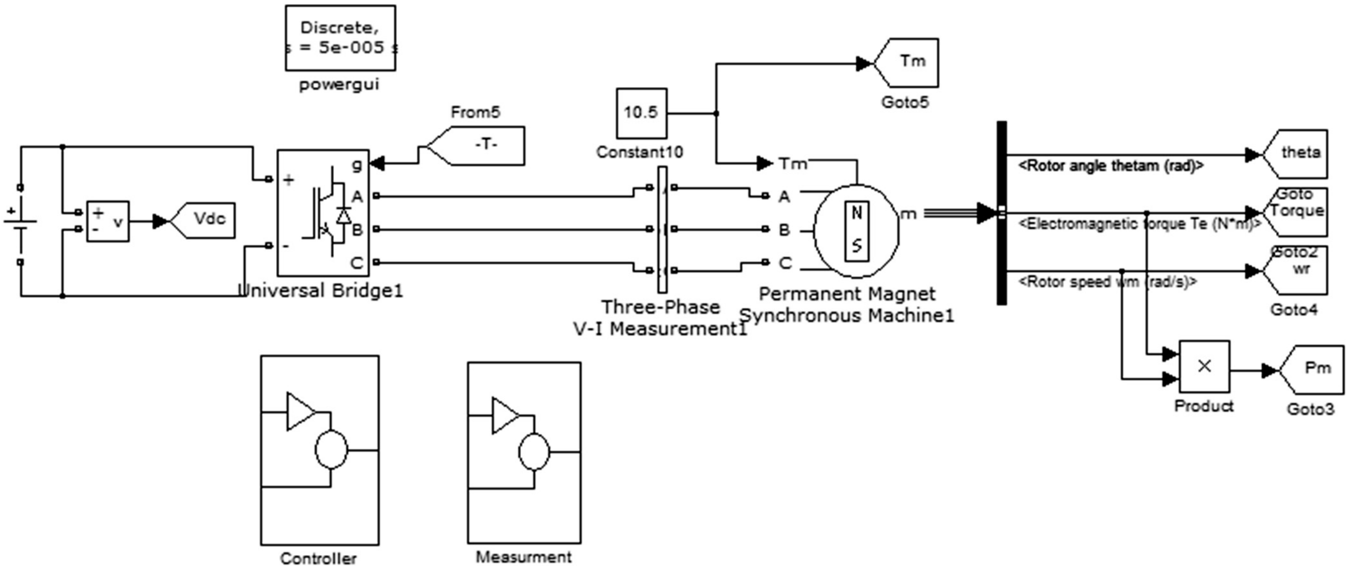

Figure 5: Simulation Diagram for BLDC Drive.

The obtained simulation result for this system is shown in Figure 6-11. In this Figure 6 shows the Simulation Result for Electromagnetic Torque at Tm=10.5 N-m. Figure 7 shows the simulation results for speed of BLDC drive system under different variation in load torque. The wave forms for the three phase stator current which is varying in proportional with load torque is as shown in Figure 8. Figure 9 shows the Simulated indirectly controlled Flux linkage when Ids is zero under 10.5 N-m load torques.

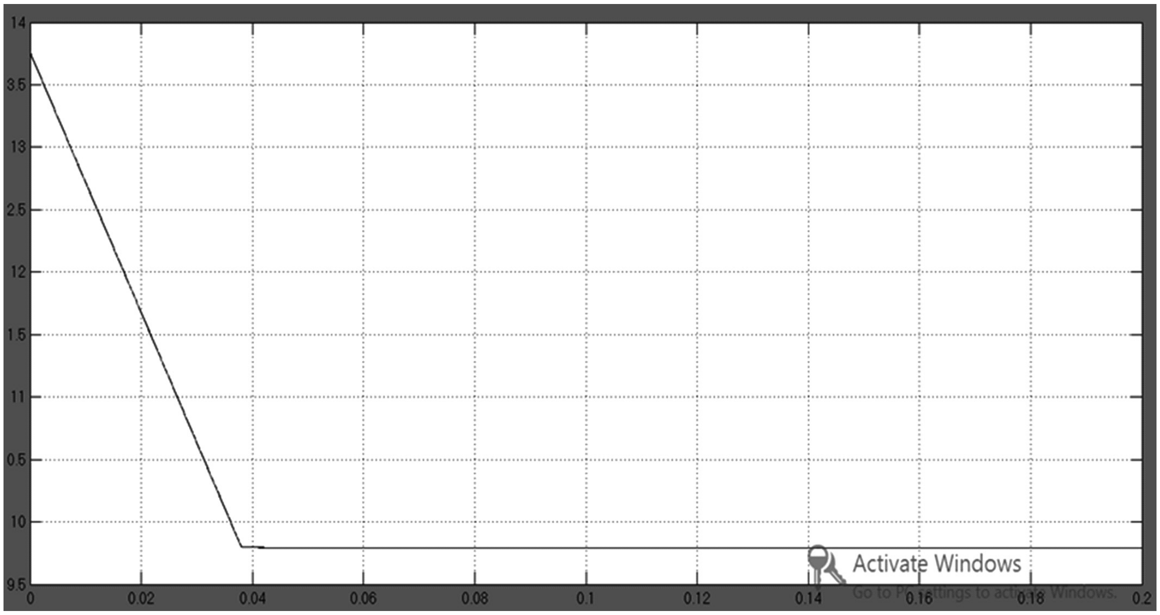

Figure 6: Simulation Result for Electromagnetic Torque at Tm=10.5 N-m

6. CONCLUSION

This paper has presented a concept of Space vector pulse width modulation technique based direct torque controller for BLDC motor drive system. The DTC control strategy is an alternative method to Field

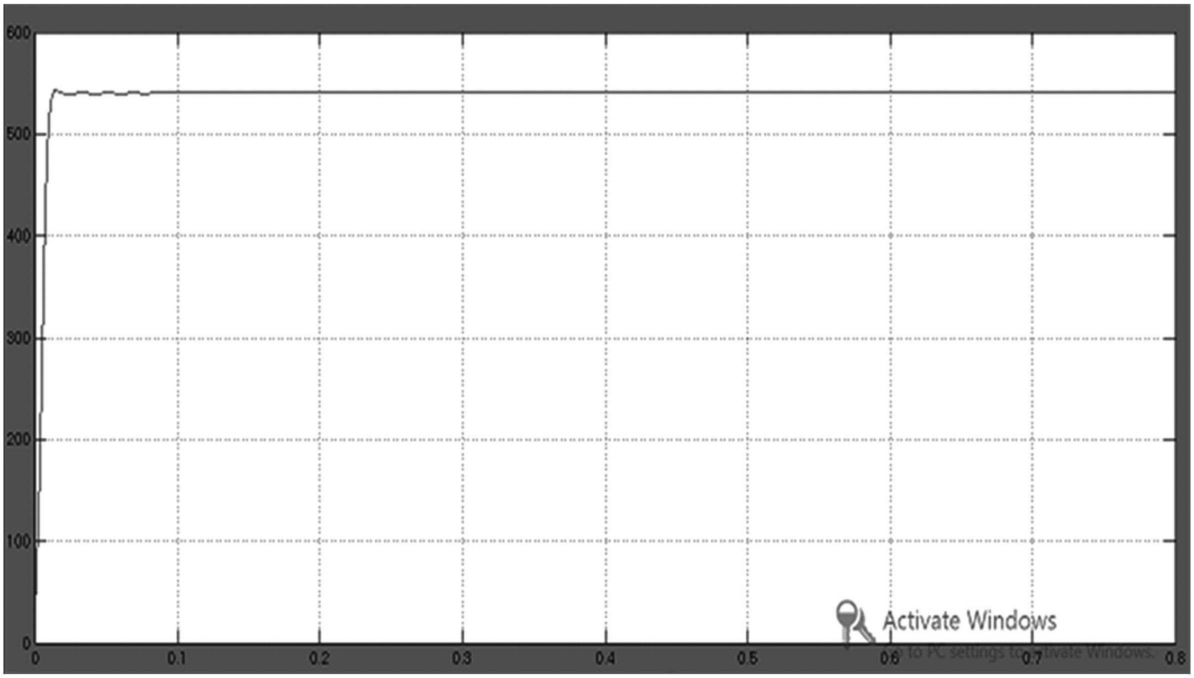

Figure 7: Simulation Result for Speed

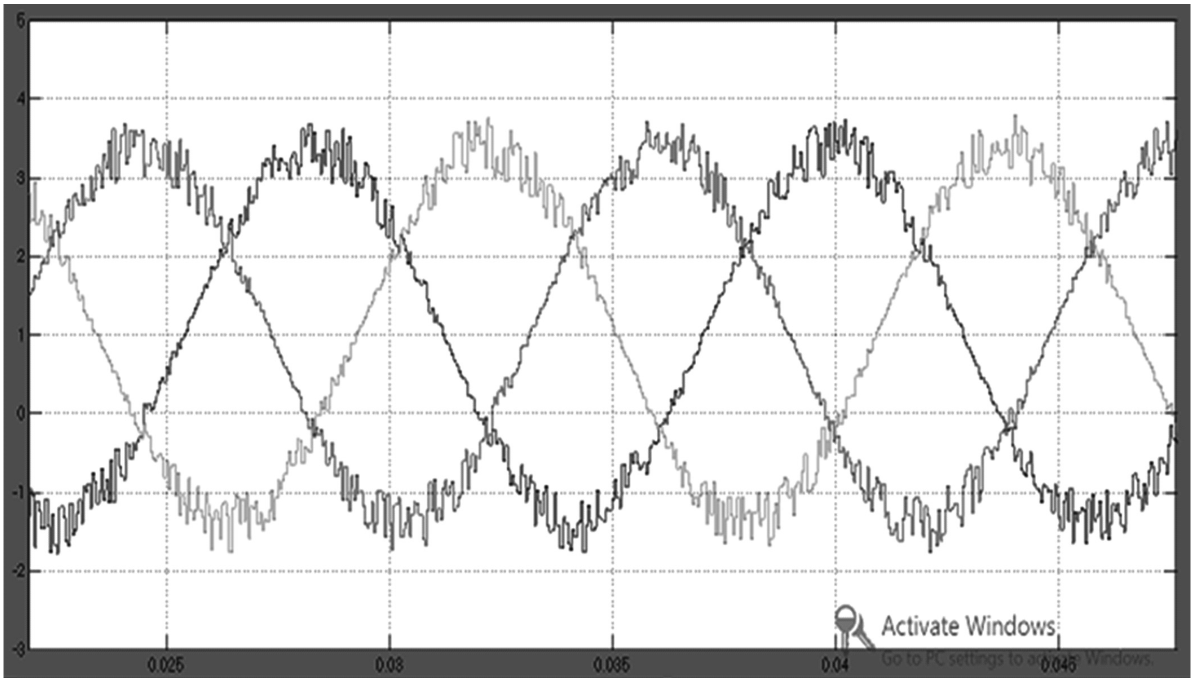

Figure 8: Simulation Result for Stator Currents

Oriented Control. For controlling an AC drives the basic DTC strategies are classified into two types: i.e. one is hysteresis-based switching table DTC, and another one is constant switching frequency pattern operating with space vector modulation technique. Out of these two controllers we considered a Constant switching frequency DTC based space vector modulation technique as it has the capability to improve performance of drive by reducing the disturbances in the torque and stator flux linkages. Therefore, finally, it conclude that the SVPWM-DTC based technique is an excellent solution for controlling Brushless DC motor drive. Finally it conclude that the Torque control principle will play a strategic role in the improvement of high performance drives.

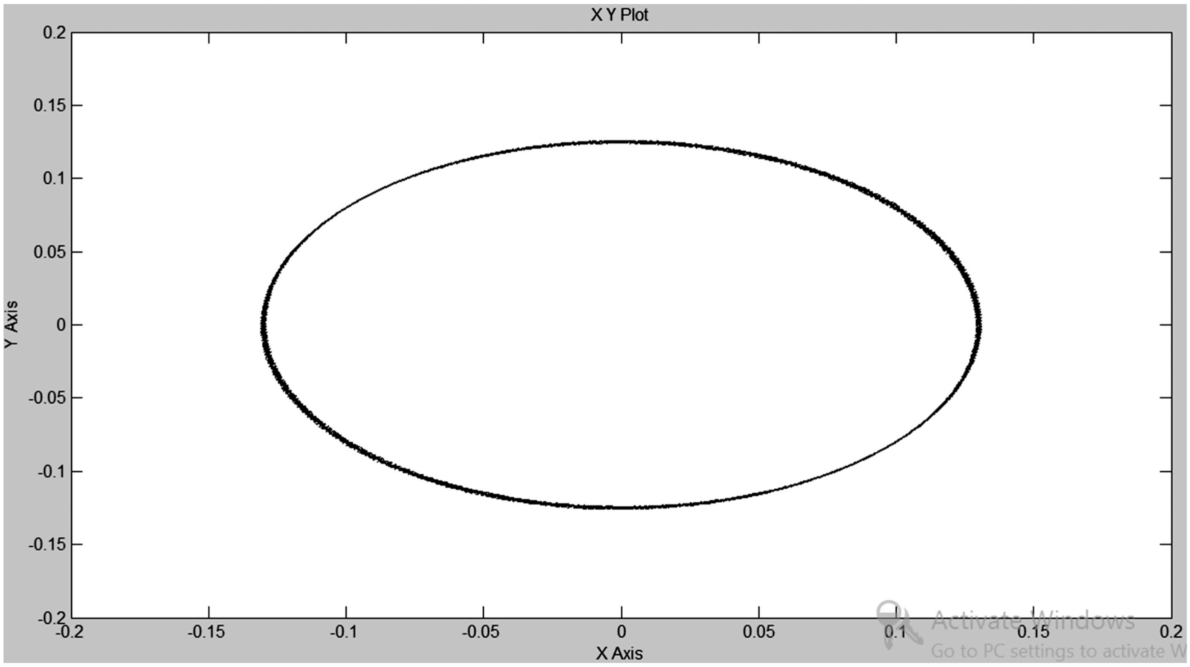

Figure 9: Trajectory of flux linkages under 10.5N-m load torque

Circuit Parameters

Element	*Range*
Number of poles	4
Winding Inductance	8.5 mH
Mutual Inductance	0.3125 mH
Winding Resistance	2.8750 ohm
Flux linkages	0.175 wb
Inertia	0.0008 Kg-m^2
Motor Constant	0.10476

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