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Control of Brushless DC Motor with Direct Torque and Indirect Flux using SVPWM Technique

Manikantha Teja Lingamsetti* **and Tadivaka Teja Sreenu**

Department of EEE, KL University, Vijayawada - 522502, Andhra Pradesh, India;
tejalingamsetti@gmail.com, tejasreenu.tadivaka@kluniversity.in

Abstract

Background/Objectives: To minimize the high frequency current and torque ripples Space Vector Pulse Width Modulation (SVPWM) technique is applied with the Direct Torque Control (DTC) technique which is the usual control technique applied earlier. **Methods/Statistical Analysis:** The Space Vector pulse width modulation technique is implemented in MATLAB through SIMULINK library. And for controlling the torque directly and flux indirectly Park's and Clark's transformations are used. And the results are verified. **Findings:** A constant switching frequency DTC based space vector modulation technique has the capability to improve the performance of drive by reducing the disturbances in the torque and stator flux linkages. **Application/Improvements:** BLDC motors find applications in every segment of the market. Automotive, appliance, industrial controls, automation, aviation and so on. And with Space Vector Pulse Width Modulation technique the current and torque characteristics have improved. And the performance of motor also increases.

Keywords: Clark's Transformation, Direct Torque Control, Indirect Flux Control, Park's Transformation, Space Vector Pulse Width Modulation technique (SVPWM)

1. Introduction

For Brushless DC (BLDC)[1] motors with trapezoidal back emf[1] obtaining low frequency ripple free torque[2], 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 sensor less control[3] of BLDC they are:

- Measurement of back EMF.
- Back EMF integration method.
- Flux estimation method.
- Freewheeling current detection method.

The above stated methods have their 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.

This paper present a simple position-sensor-less direct torque and indirect flux control of BLDC[3] motor, similar to the normal DTC scheme used for sinusoidal alternating current motors where torque and flux are regulated at the same time. This method provides advantages[4] of conventional DTC such as fast torque response compared to vector control, and position sensor-less drive. The electrical rotor position is known by calculating winding inductance and stationary reference frame stator flux linkages and 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[5]. In the proposed scheme, the main control motto is to keep the motor's torque and amplitude of the stator flux within particular limits. The inverter is triggered by SVM controllers to switch whenever these limits are exceeded.

**Author for correspondence*

2. Modeling of Brushless DC Motor

BLDC[6] motors replaces the coils with permanent magnets in armature so it does not require any brushes and commutators[7] as shown in Figure 1.

And the schematic diagram for Brushless DC motor is shown in below Figure 2.

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

- It has three symmetrical windings.
- It has no magnetic saturation.
- Neglecting hysteresis and eddy current losses.
- Ignorance of mutual inductance.
- And neglecting armature reaction.

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

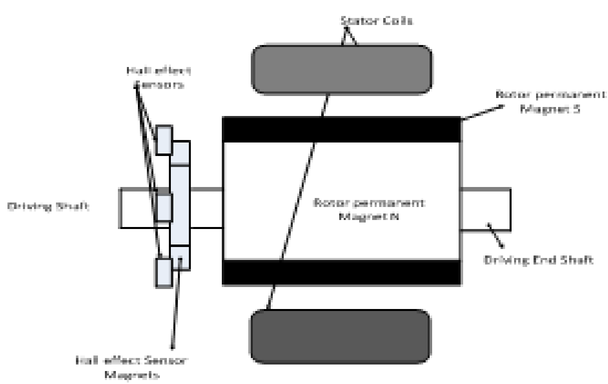

Figure 1. Cross sectional view of BLDC motor.

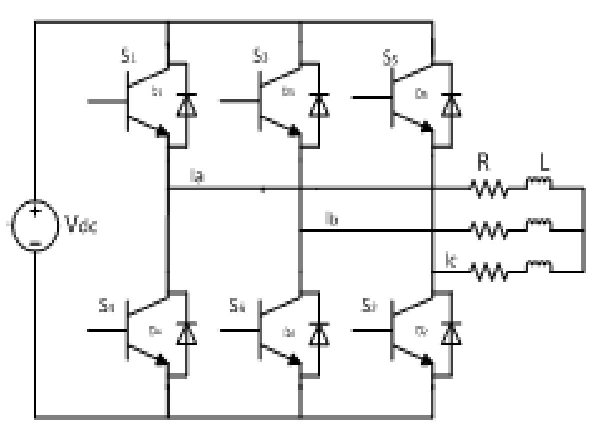

Figure 2. Basic schematic diagram for BLDC.

$$V_a = i_a r_a + L\frac{di_a}{dt} + e_a$$

$$V_b = i_b r_b + L\frac{di_b}{dt} + e_b$$

$$V_c = i_c r_c + L\frac{di_c}{dt} + e_c$$

For solving these Equations, in this paper we have 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,

$$\begin{bmatrix} Vab \\ Vca \end{bmatrix} = \begin{bmatrix} -\frac{1}{3} & -\frac{1}{3} \\ \frac{\sqrt{3}}{3} & -\frac{\sqrt{3}}{3} \end{bmatrix} \begin{bmatrix} Va \\ Vb \\ Vc \end{bmatrix}$$

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,

$$\psi_\alpha = \frac{1}{L_\alpha}(V_\alpha - i_\alpha r_a)$$

$$\psi_\beta = \frac{1}{L_\beta}(V_\beta - i_\beta r_a)$$

And from this Equation the phase angle is calculated as,

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

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

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

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

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[8]. From the definition of newton's law of motion, the total applied torque is equal to sum of all individual torques across each element.

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

The electromagnetic torque generated by a brushless dc motor is expressed as,

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

Assuming the three phase windings are symmetrical, so that the magnitudes of back emf and currents 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,

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

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,

$$e_p = kw_m$$

The error difference is obtained from comparison of the currents[9] 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 α, β axis. Figure 3 shows the space vector representation of the adjacent vectors S1 and S2 with 8 space vector switching pattern positions of inverter as shown in Figure 3.

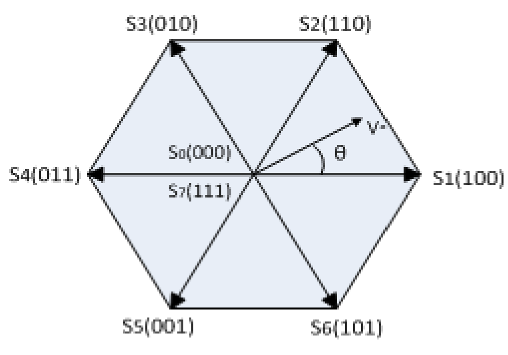

Figure 3. Space vector modulation technique.

Generally, the Space Vector Modulation Technique is one of the most popular methods in pulse width modulation techniques fed for the three phase voltage source inverters. By using Space Vector Modulation the harmonic content in both outputs voltage and output currents are reduced[10]. 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[11] purpose and two sectors are behaved like a null vector.

Space vector PWM can be implemented by the following steps:

- Transform 3-phase to 2-phase quantity and determine Vs and angle.
- Determine time duration T1, T2 and T0.

The reference space vector V∗ is given by Equation 1, where T1, T2 are the intervals of application of vector S1 and S2 respectively, and zero vectors S0 and S7 are selected for T0.

$$V* \; Tz = S1*T1 + S2*T2 + S0*(T0/2) + S7*(T0/2) \quad (1)$$

4. Principle of Operation of Space Vector Modulation Scheme for BLDC Drive

The basic control block diagram shows the implementation of the Direct Torque[12] 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[13] are determined from the actual three phase component currents and the three phase stator voltages. For doing these calculations we have considered the two phase rotational orthogonal matrix vectors. And after determination of estimated torque and flux linkages, then these estimated values 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[14]. The complete block diagram for the SVM based DTC controller is shown in Figure 4.

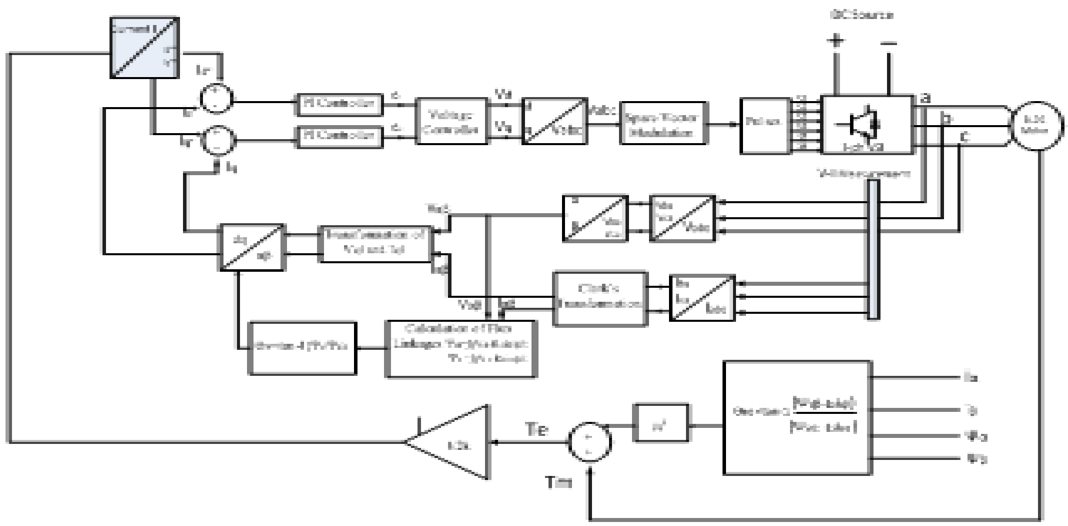

Figure 4. Control diagram of DTC-SVM technique.

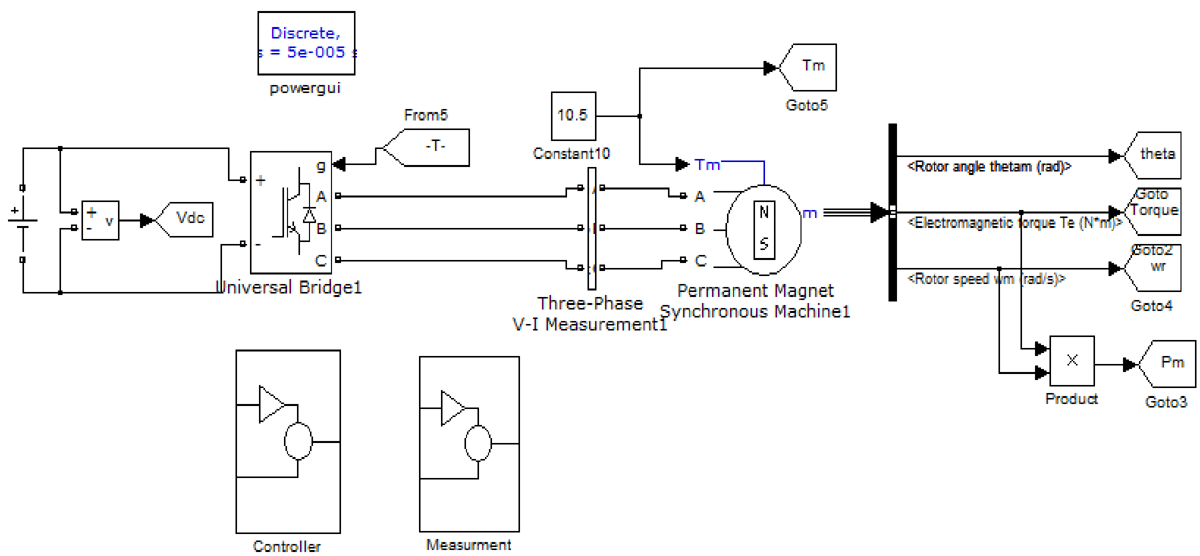

Figure 5. Simulation diagram for BLDC drive.

5. Selection of Electric Rotor Position

The electric rotor position θre which is required in torque estimation can be found using the Equation.

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

The electric rotor position is found by using winding inductance and stationary reference frame stator flux linkages and currents[15]. And the value of θre is used in calculation of electromagnetic torque Te.

6. 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.

The simulation result for this system is shown in Figure 7-11.

In this 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 simulation result for trajectory of flux linkages under 10.5 N-m load torques. Figure 10 and Figure 11 shows the simulation results for direct and quadrature axis currents under varying load torque values.

7. Conclusion

This paper has presented a concept of space vector modulation technique based direct torque controller for brushless dc drive system. The DTC control strategy is an alternative method to Field 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 concludes that the SVM-DTC based technique is an excellent solution for controlling Brushless DC motor drive. Finally it concludes that the Torque control principle will play a strategic role in the improvement of high performance drives. Table 1 represents the parameters of Permanent Magnet Synchronous Machine.

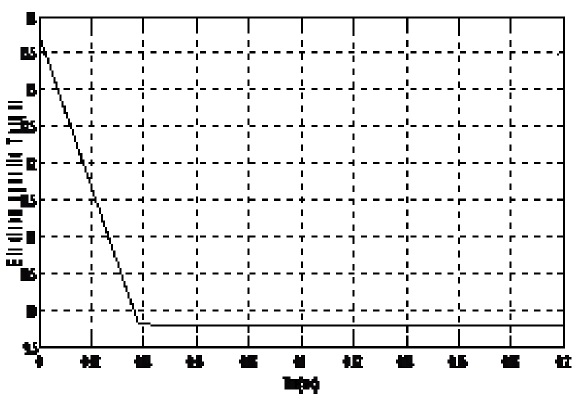

Figure 6. Simulation result for electromagnetic Torque at Tm = 10.5 N-m.

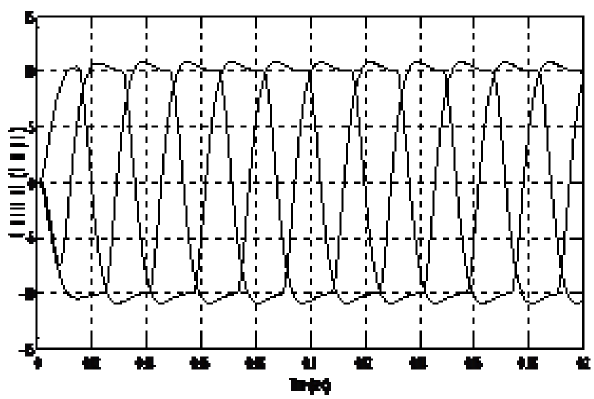

Figure 8. Simulation result for stator currents.

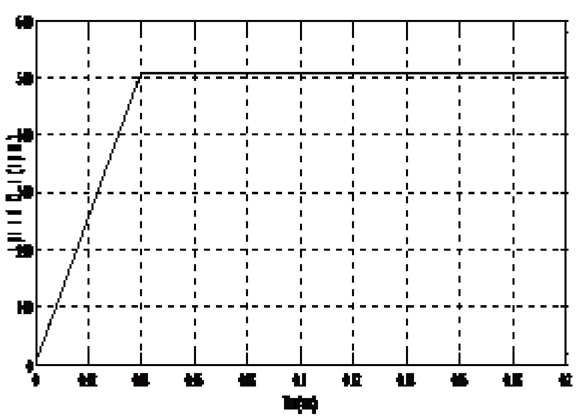

Figure 7. Simulation result for speed.

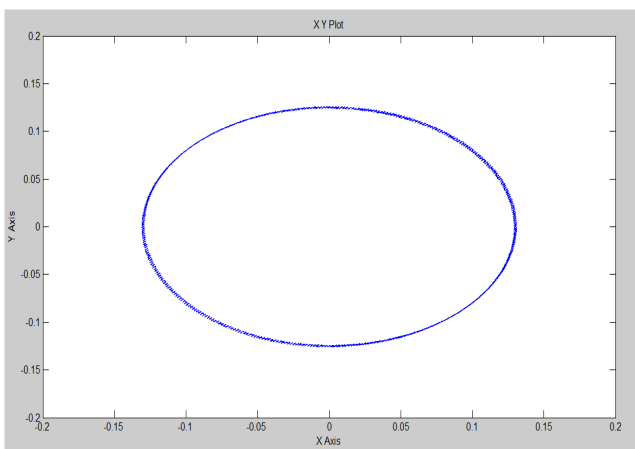

Figure 9. Simulated indirectly controlled Flux linkage when Ids is zero under 10.5 N-m load torques.

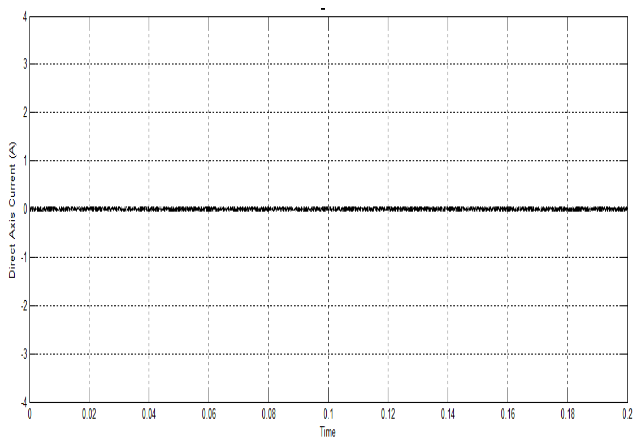

Figure 10. Simulation result for stator direct axis current.

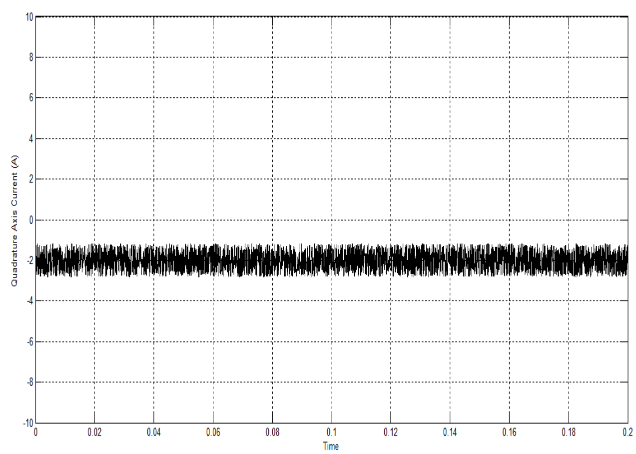

Figure 11. Simulation result for quadrature axis current.

7.1 Circuit Parameters

Table 1. PMSM parameters

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

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