PWM BASED SENSORLESS DIRECT TORQUE CONTROL FOR BLDC MOTOR

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Abstract: Generally, due to higher efficiency, high power density, easy maintenance and control, and high torque to inertia ratio these Brushless dc motors are one of the growing electrical drives in present scenario. This paper proposes a concept of sensor less PWM based direct torque and indirect flux control of BLDC has been investigated. There are several methods that are projected for BLDC to gain better torque and current control i.e with minimum torque and current pulsations. Most of the proposed techniques are complex and they does not take stator flux control in to account, so that high speed operations are not possible. The proposed sensorless method is similar to the usual Direct Torque control method which is utilized for sinusoidal Alternating Current motors so that it controls torque directly and stator flux indirectly by varying direct axis current. And the electric rotor position can be found by using winding inductance and stationary reference frame stator fluxes and currents. The validity of the projected sensorless three phase conduction Direct Torque Control of BLDC motor drive method is established in the MATLAB/SIMULINK and results are observed.

Keywords— Brushless dc(BLDC) Motor, Direct Torque Control(DTC), stator flux control, Space Vector Modulation(SVM)

1. INTRODUCTION

For applications like high accuracy, high efficiency and high power density [1] Brushless DC motors are the better choice in present days. Usually BLDC motor is accounted as high pursuance motor which is efficient in generating more amounts of torque over wide speed ranges. BLDC motors are inside-out of common dc motors and they exhibit the same torque-speed characteristics [14]. The main difference lies in usage of brushes. Like DC motor brushless dc motor do not have brushes so that they are electronically commutated. Commutation is nothing but changing the motor phase currents at desired time to create rotational torque. The commutation sequences are desired by the rotor position and the rotor position is detected either by using position sensors or by sensor less techniques.

For Brushless DC [1] motors with trapezoidal back emf [1] obtaining low frequency ripple free torque, and instantaneous torque and flux are major considerations. There are different methods are stated for controlling the brushless dc motor and generally there are: 1) Measurement of back EMF, 2) Back EMF integration method, 3) Flux estimation method and 4) Freewheeling current detection method. The merits and de-merits for this above stated methods are based on their own operation. And this paper presents a basic sensorless direct torque and indirect flux control of BLDC motor, the current, torque and flux signals used in this DTC technique are sinusoidal [1] in nature as like normal DTC controller. This method provides advantages of conventional DTC such as fast torque response...
compared to vector control, and position-sensorless drive. The electrical rotor position is known by calculating winding inductance and stationary reference frame stator flux linkages and currents [1].

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 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.

II. Modelling of Brushless DC Motor

BLDC motors is one of the classifications in permanent magnet synchronous motors [1]. As its name indicates as synchronous motor, the magnetic field created by both the stator and rotor rotates with the same frequency. So BLDC motors do not experience any “slip”. BLDC motor is built with a permanent magnet rotor and wire wound stator poles.

To achieve proper commutation permanent magnet DC motors use mechanical commutators and brushes. But in case of BLDC motor it uses Hall Effect sensors [15] in place of mechanical commutators and brushes. So BLDC is said to be electronically commutated. Brushless DC motor is just inside-out of DC motor. The stator of BLDC motor contains [15] winding coils and the rotor with permanent magnets. The stator develops the magnetic field to make the rotor to rotate. The Hall Effect sensors which are placed 120 electrical degrees apart detects the rotor position so as to make proper commutation sequence. Therefore, BLDC motors replaces the coils with permanent magnets in armature so it does not require any brushes and commutators as shown in figure 1.

Fig 1: Cross sectional view of BLDC Motor

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

Fig 2: Basic schematic diagram for BLDC.

1. It has three symmetrical windings.
2. Has no magnetic saturation.
4. Ignorance of mutual inductance.
5. And neglecting armature reaction.
The mathematical modelling is obtained by considering the KVL equations for figure 2.

\[ V_a = i_a r_a + L \frac{di_a}{dt} + e_a \]
\[ V_b = i_b r_b + L \frac{di_b}{dt} + e_b \]
\[ V_c = i_c r_c + L \frac{di_c}{dt} + e_c \]

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,

\[
\begin{bmatrix}
V_{ab} \\
V_{ca}
\end{bmatrix} = \frac{1}{3} \begin{bmatrix}
-1 & -1 \\
\sqrt{3} & -\sqrt{3} \\
\frac{1}{3} & \frac{1}{3}
\end{bmatrix} \begin{bmatrix}
V_a \\
V_b \\
V_c
\end{bmatrix}
\]

The matrix coordinates obtained from the above line to line park’s transformation are transformed to orthogonal matrix coordinates \((\alpha, \beta)\).

Similarly, same like as voltage, the three phase currents also transformed to two phase orthogonal matrix. These two phase currents \((I_\alpha, I_\beta)\) and voltage \((V_\alpha, V_\beta)\) are used for calculating the flux linkages \((\psi_\alpha, \psi_\beta)\) from the expression described as,

\[
\psi_\alpha = \frac{1}{L_\alpha} (V_\alpha - i_\alpha r_\alpha)
\]
\[
\psi_\beta = \frac{1}{L_\beta} (V_\beta - i_\beta r_\alpha)
\]

And from this equation the phase angle is calculated as,

\[
\psi = \psi_\alpha + j \psi_\beta
\]
\[
\theta = \tan^{-1}(\frac{\psi_\beta}{\psi_\alpha})
\]

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

\[
\begin{bmatrix}
i_d \\
i_q
\end{bmatrix} = \frac{2}{3} \begin{bmatrix}
-\sin(\theta - 30) & \sin(\theta + 30)
\end{bmatrix} \begin{bmatrix}
i_\alpha \\
i_\beta
\end{bmatrix}
\]

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.

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

\[ T_e = T_m + J \frac{d\omega_m}{dt} + B\omega_m \]

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

\[ T_e = \frac{e_p i_a + e_p i_b + e_p i_c}{w_m} \]

Assuming the three phase windings are symmetrical, so that the magnitudes of back emfs 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 is given to SVM controller for obtaining the gate pulses to the three phase inverter.

III. MODULATION TECHNIQUE:

In this section a simple modulation technique is described to control the new NPC converter for a three phase system. The modulation is based on that described in [16], but in our case, the new technique called space vector modulation is used instead of the carrier-based PWM. A sixth part of the vector diagram for a five-level converter is shown in Figure 3, where (−V, 0, V) voltage levels are denoted as 2, 1 and 0 respectively.

IV. Principle of Operation of PWM-DTC Scheme for BLDC Drive

The basic control block diagram shows the implementation of the Direct Torque [1] Control based PWM technique [16] 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, 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. The complete block diagram for the PWM based DTC controller is shown in figure 4.

Fig 3: SPWM technique for output voltages

Fig 4: Control Diagram of DTC-SVM Technique
V. Selection of Electric Rotor Position

The electric rotor position $\theta_{re}$ which is required in torque estimation, can be found using the equation.

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

The electric rotor position is found by using winding inductance and stationary reference frame stator flux linkages and currents [1]. And the value of $\theta_{re}$ is used in calculation of electromagnetic torque $T_e$.

VI. 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.

Fig 5: Simulation Diagram for BLDC Drive.

6: Simulation Result for Electromagnetic Torque at $T_m=10.5$ N-m

Fig 7: Simulation Result for Speed

Fig 8: Simulation Result for Stator Currents
Fig 9: Simulated indirectly controlled Flux linkage when Ids is zero under 10.5 N-m load torque

VI. CONCLUSION

This paper has presented a concept of PWM 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 PWM 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 PWM-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.

VII REFERENCE

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