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Simulation of Torque Control of a BLDC Motor Drive

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Abstract:

Now a day's BLDC motor is popular because of its good performance, high efficiency and it is very easy to control in any application. This paper presents a model for Brushless DC (BLDC) motor drive for constant torque applications. Initially theoretical analysis of a BLDC motor drive is presented and the validity of the proposed analysis is verified using simulation. In this, torque is controlled using current. Then the motor model is simulated using MATLAB/ SIMULINK with trapezoidal waveforms of back-EMF.

Key words:

BLDC motor, Torque, Trapezoidal Back emf.

I.INTRODUCTION:

Electric motors play an important role in the evolution of the automotive industry. In the present trend, the electrification of automobiles indicates a further increase in deployment of electromechanical energy devices in upcoming future. Because of historical, technical and economical incentives, dc brushed machines have been employed in the numerous automotive applications ranging from starters to auxiliary devices. The main advantages are the ease of control, capital investment and relatively low cost of manufacturing compared to other energy machines. Whereas the dc motors are of lower reliability as the brushes wear down by operation and need time-to-time maintenance or replacement. This drawback of dc motor can be eliminated by using a BLDC motor [1]. BLDC motor has advantage of faster response, long lifetime and capability of high-speed drive as compared to that of DC motor. Hence these BLDC motors are widely used in industrial area in line with the development of power switching device, microprocessor and digital technology. The BLDC motor type is designed to utilize the trapezoidal back-EMF with square wave currents to generate constant torque. The system mainly consists of four components: 120-degree conduction signal generator, Voltage source inverter, Electrical part of BLDC motor and Mechanical part of BLDC motor. The torque of the BLDC motor is mainly influenced by the waveform of back-EMF. Ideally, BLDC motors have trapezoidal back-EMF waveform and are fed with rectangular stator currents, which give a theoretically constant torque. However, in practice, torque ripple exist, mainly due to EMF waveform imperfections, current ripple and phase current commutation.

II. ANALYSIS OF BLDC MOTOR DRIVE SYSTEM

Modeling of Three-Phase BLDC Motor

BLDC motor has characteristics similar to a DC motor, Where as it is controlled the same as AC motors. The BLDC motor drive system is developed using MATLAB/SIMULINK. Fig.1 shows the block diagram of BLDC motor drive system. As shown in the figure, the system mainly consists of four components: 120-degree conduction signal generator, Voltage source inverter, Electrical part of BLDC motor and Mechanical part of BLDC motor. Fig 2 Shows the three phase currents waveforms with the trapezoidal back-EMF voltages of a BLDC motor.

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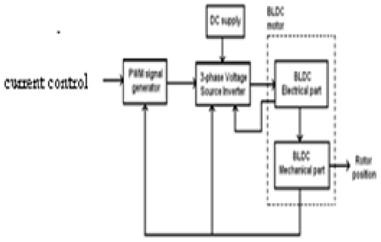


Fig.1 Block diagram of a BLDC motor

Fig. 3 shows the three phase currents waveforms with the trapezoidal back-EMF voltages of a BLDC motor. To generate constant output torque, BLDC motor needs quasi square current waveforms, which are synchronized with the back-EMF as shown in Fig. 1. The typical mathematical model of a three-phase BLDC motor is described by the following equations.

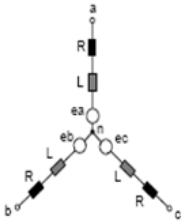


Fig. 2. Equivalent circuit of the three- phase BLDC motor

$$\begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} = \begin{bmatrix} R & 0 & 0 \\ 0 & R & 0 \\ 0 & 0 & R \end{bmatrix} \times \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} + \begin{bmatrix} L-M & 0 & 0 \\ 0 & L-M & 0 \\ 0 & 0 & L-M \end{bmatrix} \frac{d}{dt} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} + \begin{bmatrix} e_a \\ e_b \\ e_c \end{bmatrix} \qquad (1)$$

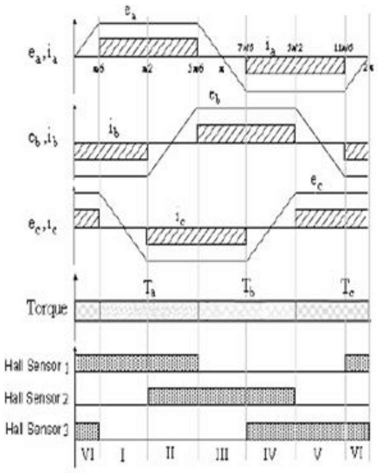


Fig 3.Signal Waveforms of BLDC motor

III. SIMULATION MODEL OF BLDC MOTOR DRIVE SYSTEM

Fig. 4 shows the overall system configuration of the three-phase BLDC motor drive. The inverter topology is a six-switch voltage-source configuration with constant DC link voltage (Vdc). The PWM three-phase inverter operation can be divided into six modes according to the current conduction states as shown in Fig. 1. The three phase currents are controlled to take a form of quasi-square waveform. For this motor, at each time only two phases are excited through the conduction operating modes and the third phase is silent. So, we can use just one current sensor located in the DC-link [5]. The steady state operation of the prototype BLDC motor is simulated in Matlab/Simulink software. BLDC motor model is composed of two parts. One is an electrical part, which calculates electromagnetic torque and current of motor. The other is a mechanical part, which generates revolution of motor. Under the above Assumption, the electrical part of BLDC motor can be represented as

- The motor is not saturated
- Iron losses are negligible
- Stator resistances of all the windings are equal, and self and mutual inductances are constant
- Power semiconductor devices in the inverter are ideal

Where ea, eb and ec are backemf. L is self nductance, M is mutual inductance and R is phase resistance

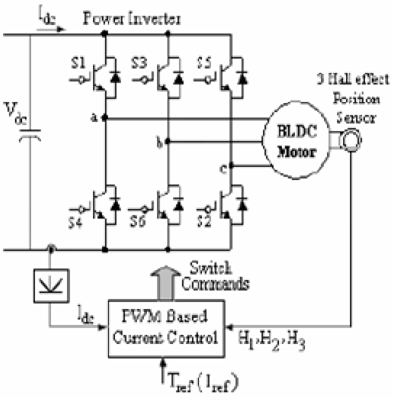


Fig 4. Basic configuration of trapezoidal BLDC motor drives with DC link current controlled.

IV.SIMULATION RESULTS

A. INVERTER (120Degrees)

Fig 5 and Fig 6shows the voltage source inverter simulation diagram and its wave forms.

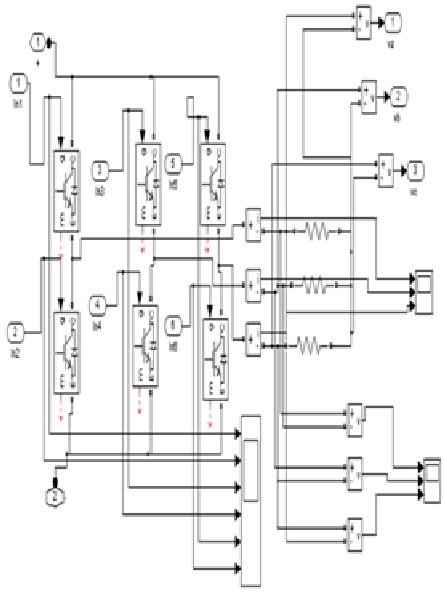


Fig 5 voltage source inverter model

VSI is operation can be divided into six sectors according to the current conductions states as shown in Fig 5 and Fig 6.

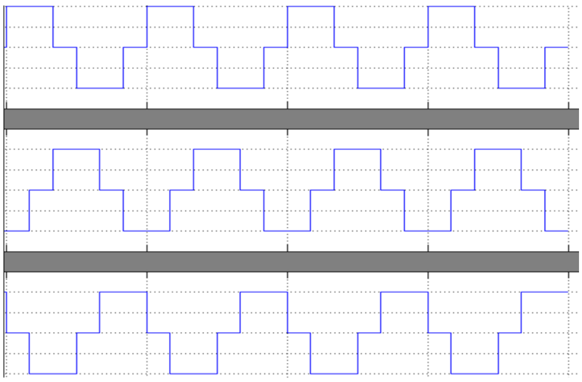


Fig 6 phase voltages

B.ELECTRICAL SYSTEM:

The outputs of the VSI are fed through the stator windings of the BLDC motor, then a rotating magnetic field is produced. This rotating magnetic field interacts with the permanent magnetic field then an electromagnetic torque is developed in the rotor. The electrical system model is shown in Fig 7.

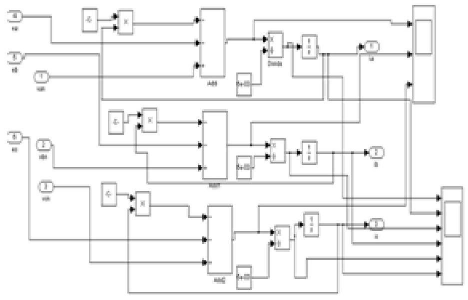


Fig 7 Electrical system model

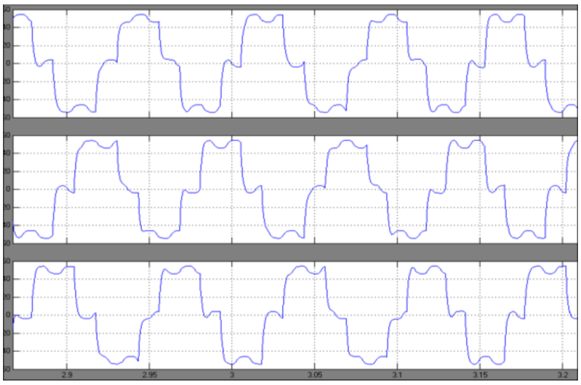


Fig 8 current wave forms

By using equations (1)

$$V_a = Ri_a + (L-M)\frac{di_a}{dt} + e_a \qquad (2)$$

$$(L-M)\frac{di_a}{dt} = V_a - Ri_a - e_a n \qquad (3)$$

$$i_a = \int \frac{V_a - Ri_a - e_a}{(L-M)} \qquad (4)$$

Electromagnetic torque(t_m) developed in rotor is given by

$$t_m = \frac{p}{2}\left(\frac{e_a i_a + e_b i_b + e_c i_c}{\omega_m}\right) \qquad (5)$$

Angular speed of the motor is changes according to the electromagnetic torque.

C.MECHANICAL SYSTEM:

The mechanical syastem of BLDC motor contains the moment of inertia(J), daming constant(B), Friction(F), and the govrning equation of the syatem is as follows

$$t_m - t_l = J\frac{d\omega_m}{dt} + B\omega_m \qquad (6)$$

Fig 9shows the mechanical system model

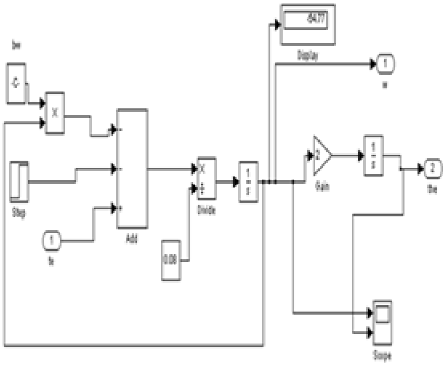


Fig 9 mechanical system

D.BACK EMF GENERATOR:

Trapezoidal back-EMF"s are generated by using the mechanical Position (theta) and angular speed as follows

$$e_a = k_a\omega_m \cos\theta t \qquad (7)$$

$$e_b = k_b\omega_m \cos(\theta t - 120) \qquad (8)$$

$$e_c = k_c\omega_m \cos(\theta t + 120) \qquad (9)$$

Back-EMF wave forms are generated by using the mechanical system equations speed and mechanical Angle(θ)

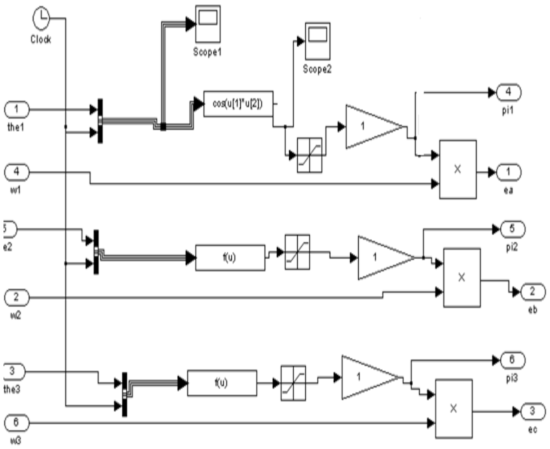


Fig 10 shows back-EMF generator

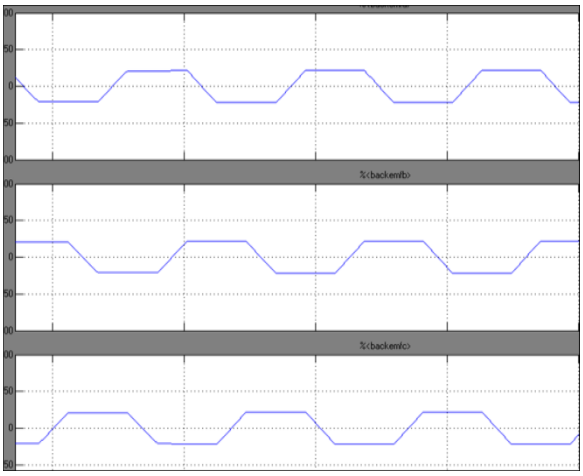


Fig 11 Trapezoidal back-EMF

E.CURRENT CONTROLLER:

Conventional PI controller is used as a current controller for recovering the actual motor torque to the reference. The reference and the measured current are the input signals to the PI controller. The Kp and Ki values of the controller are determined by trail and error method for each set of currents .Then comparator is compares the output signal with repetitive reference signal then a pulses is produced as the output. This pulses is given to the switches of the inverter with help of decoder signals and hall signals. Fig 10 shows the hall signals of the BLDC motor .

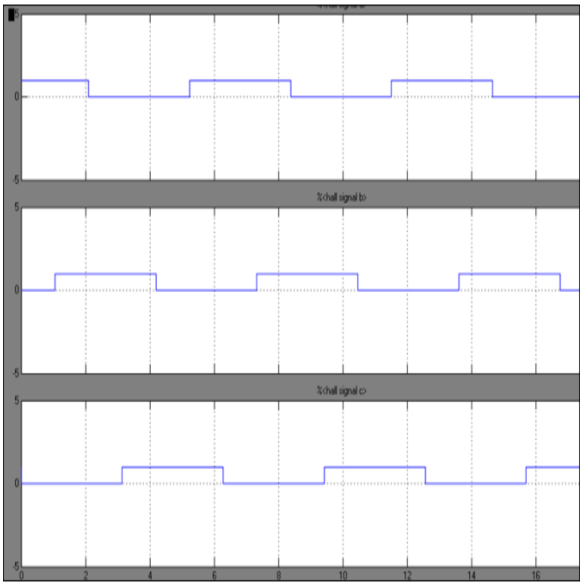


Fig 12 Hall signals

By using AND gates we going to develop the six independent pulses for the six inverter switches .
Pulses from the decoder circuit is shown in the Fig13.

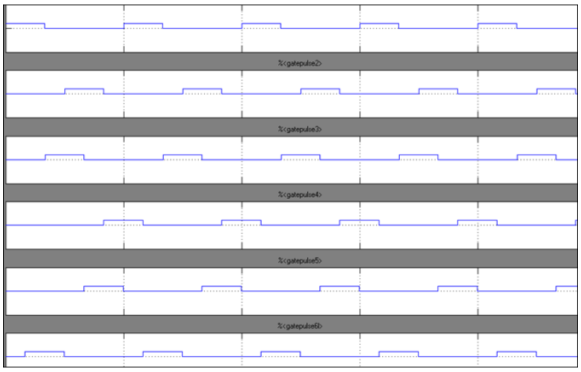


Fig 13 Gate pulses

If any deviations occurs in the system the current loop produce an proportionate error then it should maintain torque constant in the system. The torque response it can be seen that the torque pulsations due to the current controller[5] is extremely small, and its effect on the speed is not even noticeable. Just as in the PMSM drive in Part I, changing the PWM switching frequency does not affect the torque pulsations as much as varying the window size in the hysteresis current controller. Hence the PWM switching frequency should be chosen on the basis of the torque bandwidth and inverter switching capability rather than on theresulting torque pulsations, which is the same result as for the as the previous.

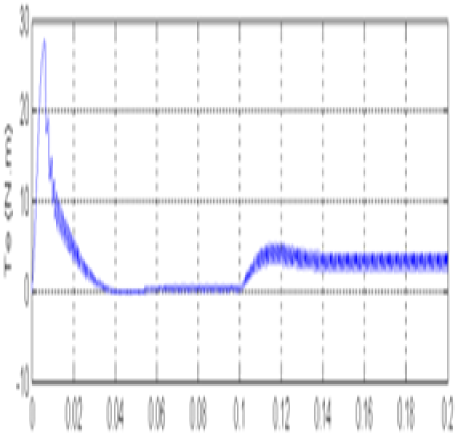
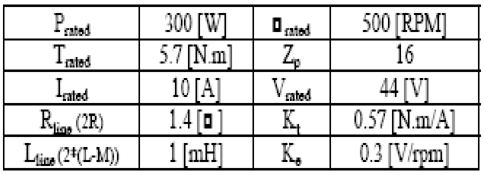


Fig 14 Torque waveform

Table I: Rated parameters of the BLDC motor



P_{rated}	300 [W]	□$_{rated}$	500 [RPM]
T_{rated}	5.7 [N.m]	Z_p	16
I_{rated}	10 [A]	V_{rated}	44 [V]
R_{line} (2R)	1.4 [□]	K_t	0.57 [N.m/A]
L_{line} (2*(L-M))	1 [mH]	K_e	0.3 [V/rpm]

V.CONCLUSION:

In this paper, the torque control system of BLDC motor which can be used in the application of traction. If any disturbance occur in the system the current loop produce an proportionate error which should maintain torque constant in the system. From the torque response, it can be oberved that the torque pulsations which occurs due to the current controller is extremely small, and its effect on the speed is not even noticeable.

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