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TORQUE CONTROL OF BLDC MOTOR DRIVE USING MATLAB/SIMULINK

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Abstract:- Now a days BLDC motor is getting more attraction due to its high efficiency, good performance and ease of control for many applications. This paper proposes a model for Brushless DC (BLDC) motor drive for constant torque applications. At first, a theoretical analysis of a BLDC motor drive is presented and the validity of the proposed analysis is verified via simulation. The torque is controlled via current via current directly. The motor model is then simulated using MATLAB/SIMULINK, with trapezoidal waveforms of back-EMF.

Keywords: BLDC motor, Torque, Trapezoidal Back emf.

I.INTRODUCTION

Electric motors have played a crucial role in the evolution of the automotive industry. Existing trends in more electrification of automobiles indicate a further increase in deployment of electromechanical energy devices in coming years. Due to historical, technical and economical incentives, DC brushed machines have been the favourite choice for numerous automotive applications ranging from starters to auxiliary devices. Its advantages are ease of control, capital investment and relatively low cost of manufacturing compared to other energy machines. On the other hand, due to brushed, DC motors suffer from a lower reliability, since 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 long lifetime, faster response and capability of high-speed drive in comparison with DC motor and has been more 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 BLDC motor is mainly influenced by the waveform of back-EMF. Ideally, BLDC motor 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 mainlydue to EMF waveform imperfections, current ripple and phase current commutation.

II.ANALYSIS OF BLDC MOTOR DRIVE SYSTEM

Modelling 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 7.2. 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.

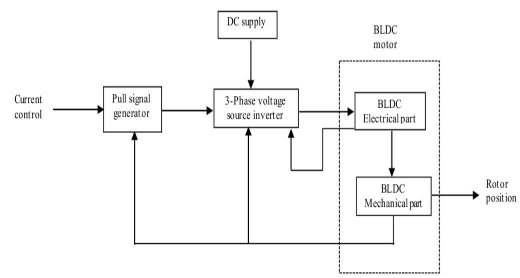

Fig.1 Block diagram of a BLDC motor

Fig.2 shows the equivalent circuit of three phase 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 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.

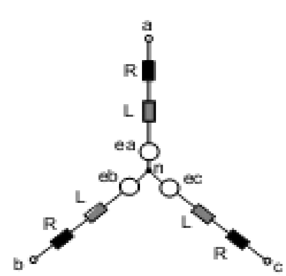

Fig.2 Equivalent circuit of three-phase BLDC motor

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$$\begin{bmatrix} v_a \\ v_b \\ v_c \end{bmatrix} = \begin{bmatrix} R & 0 & 0 \\ 0 & R & 0 \\ 0 & 0 & R \end{bmatrix} \times \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} + \begin{bmatrix} L-M & 0 & 0 \\ 0 & L-M & 0 \\ 0 & 0 & L-M \end{bmatrix} \frac{d}{dt} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} + \begin{bmatrix} e_a \\ e_b \\ e_c \end{bmatrix} \quad (1)$$

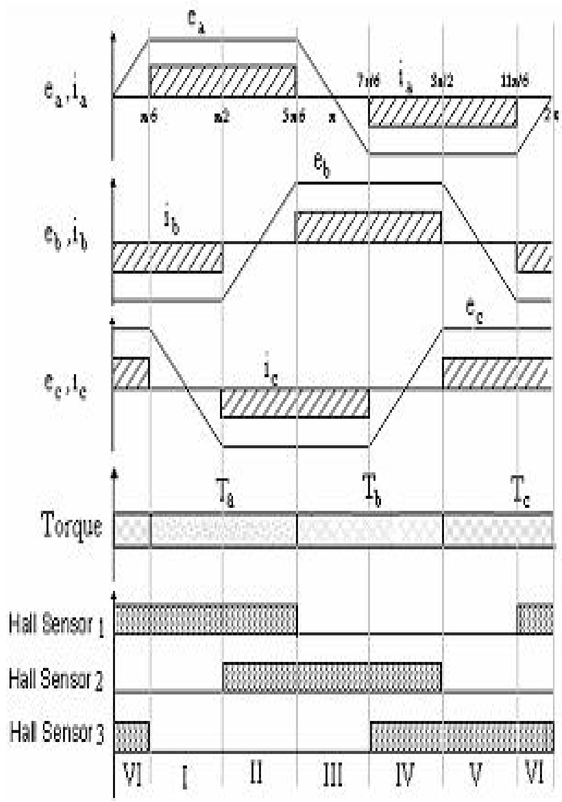

Fig.3 Signal Waveforms of BLDC motor

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 (V_{dc}). The PWM three-phase inverter operation can be 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 through the conduction operating modes and the third phase is silent. So, we can use just one current sensor located in 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

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

Where e_a, e_b and e_c are back emf's. L is self inductance, M is mutual inductance and R is phase resistance.

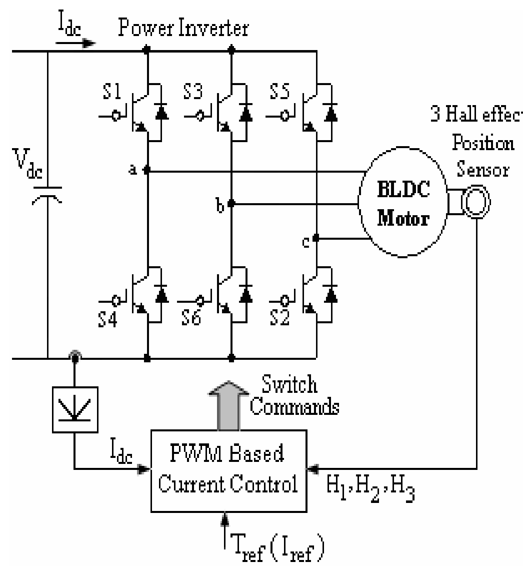

Fig.4 Basic configuration of trapezoidal BLDC motor drives with DC link current controlled

IV.SIMULATION RESULTS

A.INVERTER (120 Degrees)

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

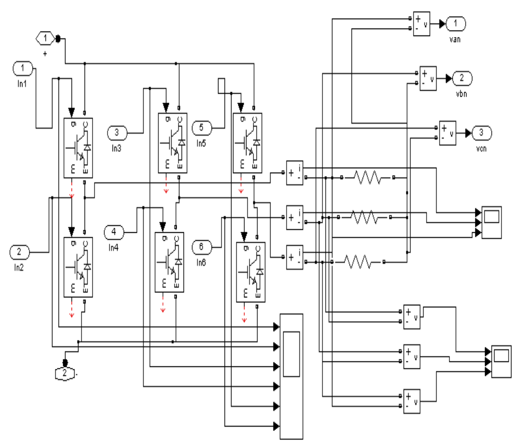

Fig.5 Voltage source inverter model

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VSI's operation is divided into six sectors according to the current conduction states as shown in Fig.5 and Fig.6.

B.ELECTRICAL SYSTEM

The outputs of the VSI is 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.

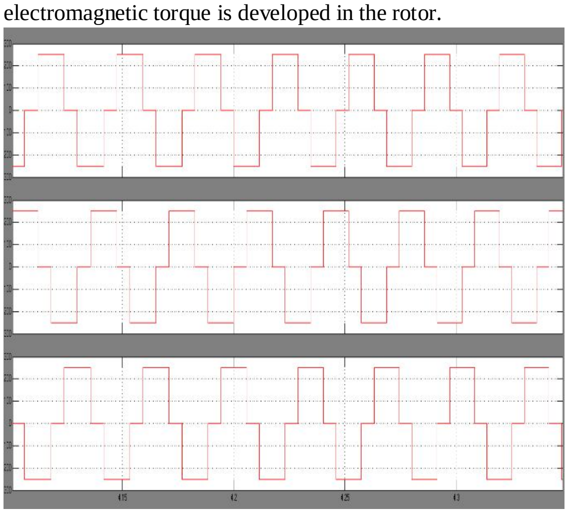

Fig.6 Phase Voltages

The electrical system model is shown in Fig.7

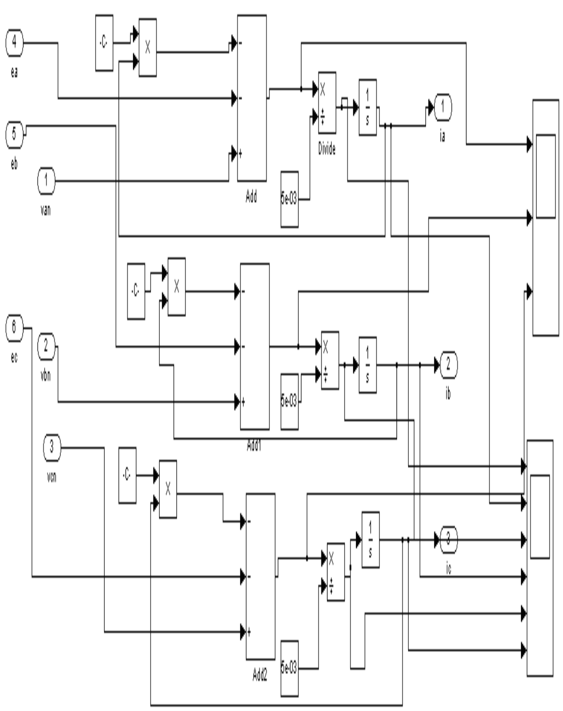

Fig.7 Electrical system model

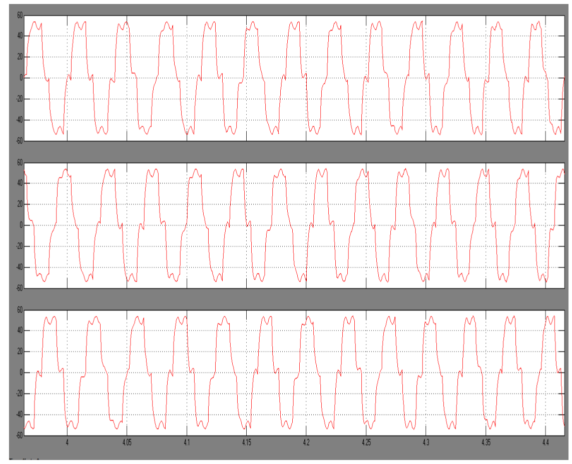

Fig.8 Current waveforms

By using equation (1)

$$Va = Ri_a+(L-M)(di_a/dt)+e_a \qquad (2)$$

$$(L-M)(di_a/dt)=V_a-Ri_a-e_a \qquad (3)$$

$$i_a=\int (V_a-Ri_a-e_a)/(L-M) \qquad (4)$$

Electromagnetic torque (t_m) developed in rotor is given by

$$t_m = (p/2)*(e_ai_a+e_bi_b+e_ci_c/\omega_{m)} \qquad (5)$$

C.MECHANICAL SYSTEM

The mechanical system of BLDC motor contains the moment of inertia(J), damping constant(B), friction(F) and the governing equation of the system is as follows

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

Fig.9 shows the mechanical system model.

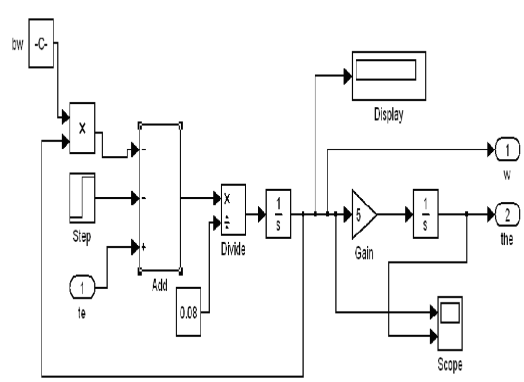

Fig.9 Mechanical System

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

$e_b = k_b\omega_m\cos(\theta t\text{-}120)$ (8)

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

Back-EMF waveforms are generated by using the mechanical system equations speed and mechanical angle (θ).

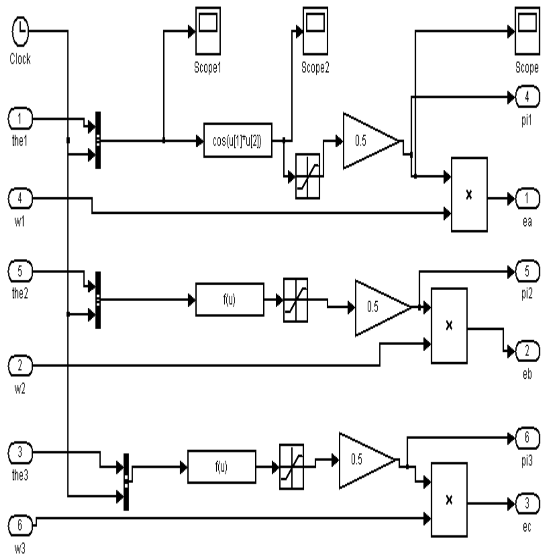

Fig.10 Back EMF generator

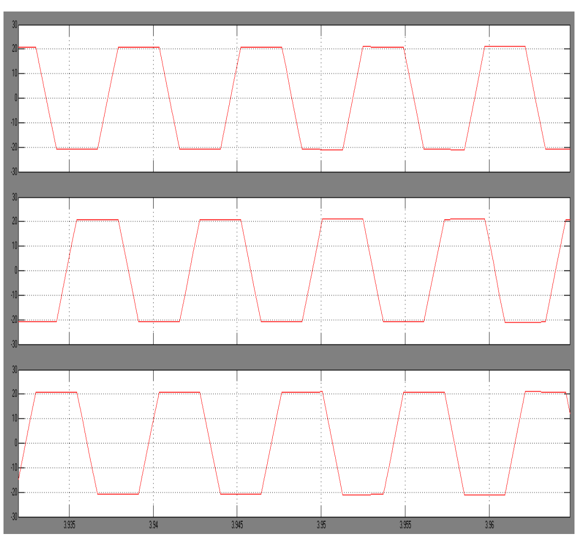

Fig.11 Trapezoidal Back EMF waveforms

D.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 K_p and K_i 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.12 shows the hall signals of the BLDC motor.

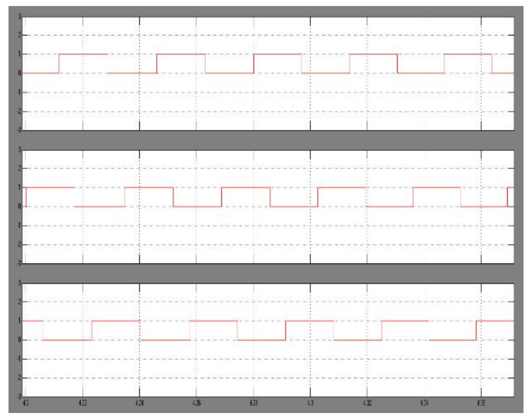

Fig.12 Hall Signals

By using AND gates we are going to develop the six independent pulses for the six inverter switches. Pulses from the decoder circuit is shown in the Fig.13.

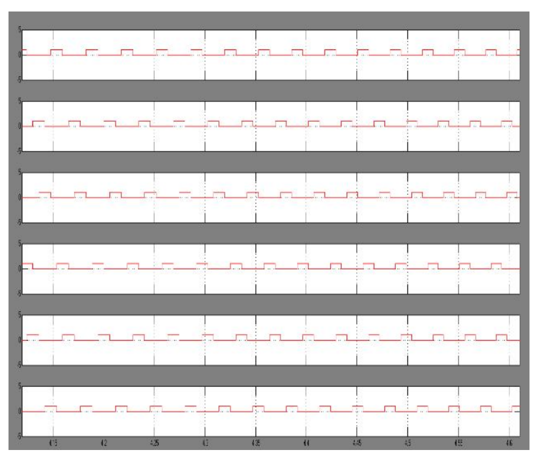

Fig.13 Gate pulses

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

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be seen that the torque pulsations due to the current controller 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 the resulting torque pulsations, which is the same result as for as the previous.

V.CONCLUSION

The control controller system of BLDC motor which can be used in traction applications is studied in this paper. If any deviation occur 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 is extremely small and its effect on the speed is not even noticeable.

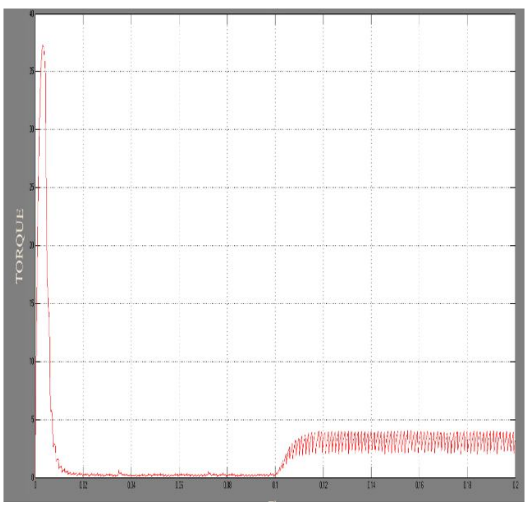

Fig.14 Torque waveform

Table I: Rated parameters of BLDC motor

P_{rated}	300[W]	N_{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[Ω]	K_t	0.57[N-m/A]
L_{line}(2*(L-M))	1[mH]	K_e	0.3[V/RPM]

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