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A New Approach For The Current And Torque Ripple Minimization Of BLDC Motor Using Phase Voltage Method

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Abstract: This paper introduce a novel sensorless control for the Brushless DC motor drive by phase voltage method for minimizing the torque and current ripple in high speed, high power applications. The commutation signals for the six switch inverter are generated from the phase voltage. In each phase commutation two switches conduct corresponding to the truth table logic. Delay occurring in speed is compensated by the phase voltage deviation. Selection of commutation logic in a parallel mode improves the efficiency of system by reducing the operation delay. Compared with the existing traditional control torque and current ripple of BLDC motor can be significantly reduced by using this proposed method.

Keywords: BLDC motor, Current ripple, Commutation, Phase voltage, Sensorless control.

I. INTRODUCTION

In the present scenario, conventional Direct Current (DC) motors are replaced by Brushless Direct Current (BLDC) motors. Conventional Brushed DC motors are highly efficient and their advantages make them apt for use as a servo motors. However, their main drawbacks are the presence of commutators and brushes,which require regular maintenance [1].

The Permanent Magnet Brushless DC (PMBLDC) motor is became popular in various applications because of its higher efficiency, improved power factor, high torque to weight ratio, simplicity in control and lower maintenance. The major demerits of PM motors are their higher cost and relatively higher complexity introduced by the power electronic converter used to drive them. BLDC motors do not use brushes for commutation, instead they are electronically commutated [2].

The control of BLDC motor is possible by sensor or sensorless method. The sensor based control is the basic control method. In this method the normally used sensor is hall sensor which determines the position of rotor for phase commutation. Using such position sensor has several drawbacks such as increased cost and size of the motor and special arrangement needed for mounting sensor [3].

To overcome the drawbacks of sensor based control, sensorless control methods are used where position sensor can be completely eliminated. In sensorless control it is possible to determine the position of rotor by sensing the back- EMF. The back- EMF sensing methods are direct back- EMF detection methods and indirect back- EMF detection methods. The direct back- EMF detection methods includes the Zero Crossing Detection (ZCD) or the terminal voltage sensing and indirect back- EMF detection methods includes the back- EMF integration, third harmonic voltage integration and free- wheeling diode conduction [4].

Instead of back- EMF phase voltages can be used for the sensorless operation of BLDC motor. Because for the high speed applications the outputs obtains with the back- EMF method contains more ripples. And this method can’t be used for the wider speed range.

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II. DYNAMIC EQUATIONS AND MACHINE MODELLING

The circuit diagram of the BLDC motor drive system is shown in figure below.

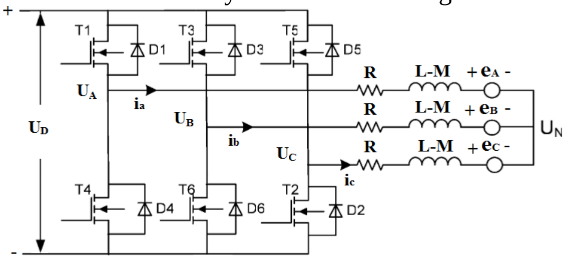

Fig 1. BLDC drive system

The electrical and mechanical mathematical equations of BLDC are given in this section. The stator voltage equations are [5]:

$$U_A = Ri_a + (L - M)\frac{di_a}{dt} + e_A + U_N \quad (1)$$

$$U_B = Ri_b + (L - M)\frac{di_b}{dt} + e_B + U_N \quad (2)$$

$$U_C = Ri_C + (L - M)\frac{di_c}{dt} + e_C + U_N \quad (3)$$

The equations of back- EMF can be given as:

$$e_A = K_e\omega_m F(\theta_e) \quad (4)$$

$$e_C = K_e\omega_m F(\theta_e - 2\Pi/3) \quad (5)$$

$$e_C = K_e\omega_m F(\theta_e + 2\Pi/3) \quad (6)$$

The equations of electrical torques can be given as:

$$T_A = K_t i_a F(\theta_e) \quad (7)$$

$$T_B = K_t i_b F(\theta_e - 2\Pi/3) \quad (8)$$

$$T_C = K_t i_c F(\theta_e + 2\Pi/3) \quad (9)$$

$$T_e = T_A + T_B + T_C \quad (10)$$

$$T_e - T_l = J\frac{d^2\theta_m}{dt^2} + \beta\frac{d\theta_m}{dt} \quad (11)$$

$$\theta_e = \frac{p}{2}\theta_m \quad (12)$$

$$\omega_m = \frac{d\theta_m}{dt} \quad (13)$$

Where

U_N is the neutral point voltage of motor
i_a, i_b, and i_c are the phase currents in A, B, C phases
U_A, U_B, and U_C are the three-phase voltages
e_A, e_B, and e_C are the back EMFs.
R is the winding phase resistance
L is the self inductance of motor
M is the mutual inductance of motor
K_e is the back- EMF constant
K_t is the torque constant
θ_e is the electrical angle of rotor
θ_m is the mechanical angle of rotor

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ω_m is the Angular speed of rotor

With these dynamic equations BLDC motor model was developed. The mathematical model of the motor drive is shown in Fig 2. Motor parameters used for modeling are shown in the Table I.

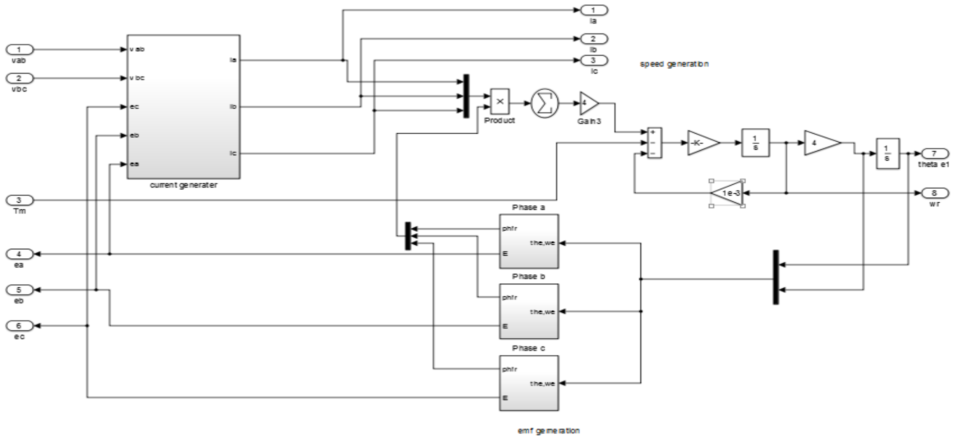

Fig 2. BLDC Motor simulink model

Table I : MOTOR PARAMETERS

Parameters	**Values**
Input voltage	470 V
Rated current	220 A
Rated speed, N	20000 rpm
Rated torque, T	50 Nm
Winding phase resistance, R_S	1.31 mΩ
Phase inductance, L_S	0.052 mH

III. SENSORLESS CONTROL TECHNIQUE

The ZCD method is one of the simplest methods for direct sensing of back- EMF technique and it depends on detection of the instant at which the back- EMF in the un-energized phase crosses zero. For typical operation of a BLDC motor, the phase current and back- EMF should be aligned to generate constant torque [4]. The time for conduction of each phase is 120 electrical degrees. In order to produce maximum torque, the inverter should be commutated at every 60 degree by detecting zero crossing point of back- EMF on the floating coil of the motor. To detect the ZCPs, the phase back- EMF should be monitored during the silent phase.

However, this method also has problems as, it has deteriorated response at transient state and requires high operational speed enough to detect the Zero Crossing Points (ZCP) of terminal voltages. This conventional Back- EMF method has the better performance. But the current and torque output contain more ripples [10]-[13]. The simplicity of the ZCD method leads to increase noise sensitivity in detection of the zero crossing point. This demerit reduces the performance of the motor over wide speed ranges even if the timing interval is not programmed as the function of rotor speed. Another demerit is, use the noisy terminal voltage to obtain a switching sequence at low speeds reduces the efficiency since back- EMF cannot be detected at low speed which is proportional to rotor speed. During transient period the estimated commutation instants have position errors when the speed is accelerated or decelerated rapidly [14].

To solve all the above problems, this paper proposes a new sensorless control method. The method is obtained based on the relationship between phase voltage and speed. According to the relationship, the self - compensation algorithm is proposed which can be applied to the sensorless control methods.

IV. PHASE VOLTAGE METHOD

A novel self compensation method based on the phase voltage of the motor is used here to obtain better performance. A switching logic and a commutation algorithm for the inverter circuit are implemented to generate commutation signal from the phase voltage.

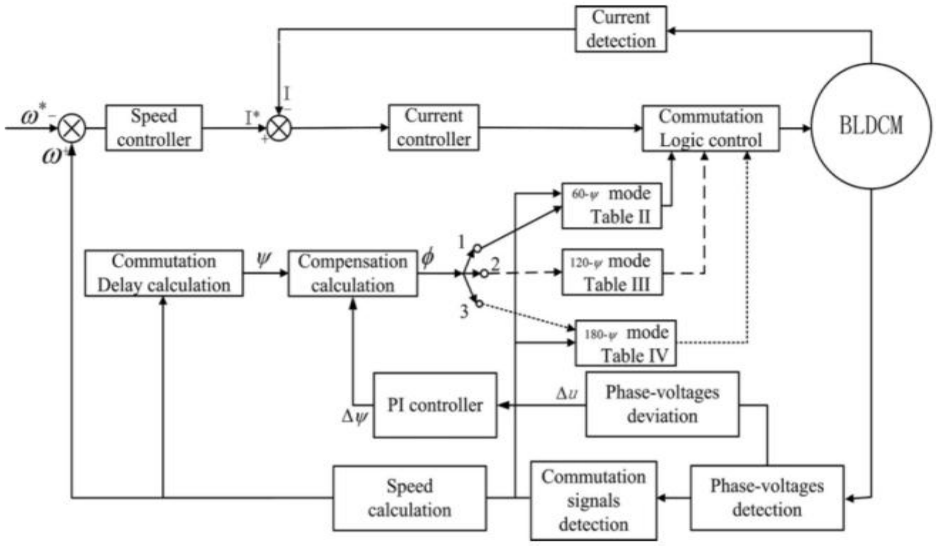

Fig 3. Block diagram of proposed control method

On comparing with the real time approach offline compensation method is very easily affected by small drift of sensors, unbalance in three phases and disturbance occur in the load etc. When suddenly the load is changed, the non real time compensation cannot easily respond to the disturbance occurs. Self tuning or auto regulation of Proportional Integral (PI) controllers in a feedback system is proposed based on the phase voltage deviations.

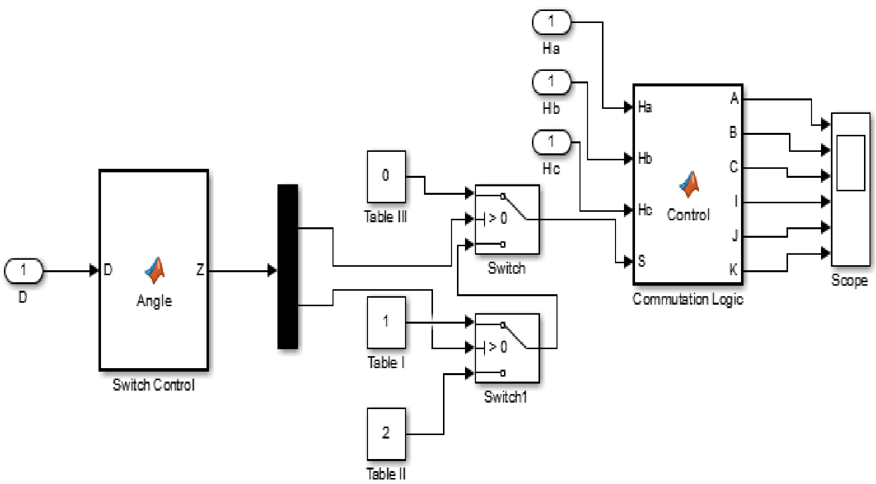

Fig 4. Simulink model of new switching and commutation logic

Fig. 3 shows the block diagram of closed loop control strategy. It contains a current controlling loop, a speed controlling loop, a commutation logic controller with a switching control, a commutation signal detection area, a compensation angle processing path, etc. Comparing the usual BLDCM speed control system; this self compensated sensorless commutation algorithm effectively increases the overall efficiency of the system.

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Table II
STATUS OF THE FIRST TRUTH TABLE

Work status	COMMUTATION STATUS OF THE FIRST MODE		
	Commutation condition	***Commutating phases***	***Commutating devices***
1	1 0 1	A+, C–	VT1 VT2
2	1 0 0	B+, C–	VT3 VT2
3	1 1 0	B+, A–	VT3 VT4
4	0 1 0	C+, A–	VT5 VT4
5	0 1 1	C+, B–	VT5 VT6
6	0 0 1	A+, B–	VT1 VT6

Table III
STATUS OF THE SECOND TRUTH TABLE

Work status	COMMUTATION STATUS OF THE SECOND MODE		
	Commutation condition	***Commutating phases***	***Commutating devices***
1	1 0 1	B+, C–	VT3 VT2
2	1 0 0	B+, A–	VT3 VT4
3	1 1 0	C+, A–	VT5 VT4
4	0 1 0	C+, B–	VT5 VT6
5	0 1 1	A+, B–	VT1 VT6
6	0 0 1	A+, C–	VT1 VT2

Table IV
STATUS OF THE THIRD TRUTH TABLE

Work status	COMMUTATION STATUS OF THE THIRD MODE		
	Commutation condition	***Commutating phases***	***Commutating devices***
1	1 0 1	B+, A–	VT3 VT4
2	1 0 0	C+, A–	VT5 VT4
3	1 1 0	C+, B–	VT5 VT6
4	0 1 0	A+, B–	VT1 VT6
5	0 1 1	A+, C–	VT1 VT2
6	0 0 1	B+, C–	VT3 VT2

The commutation delay is calculated from the speed of motor. And this delay is compensated by the deviation in phase voltages. Corresponding to this compensation value the particular truth table will be selected and the control logic with that truth table will be actuated. There are three truth tables for the proper selection of commutation logic to the inverter.

V. SIMULATIONS AND RESULTS

The simulation for verification of the results is obtained from MATLAB software. The simulink model of a back- EMF method is shown in Fig 5.

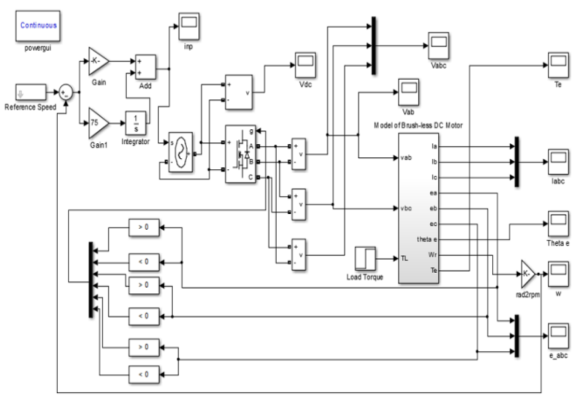

Fig 5: Model of conventional Back EMF method

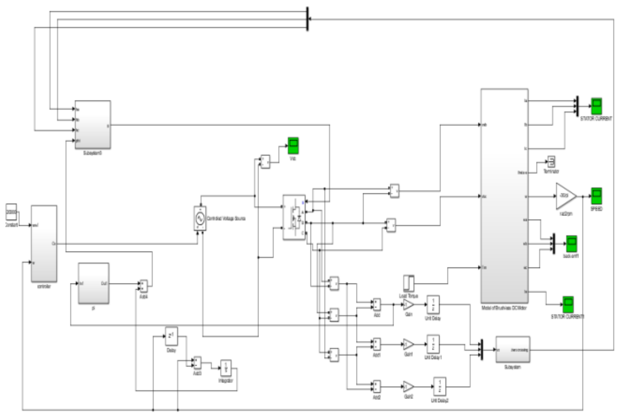

Fig 6: Model of proposed compensation Method

MATLAB model of the phase voltage method is shown in fig. 6. The output characteristics of the conventional back-EMF method and proposed self compensation phase voltage method are shown below. Simulation results of the phase current are also shown in figures. Fig. 7 shows the phase current of the back-EMF method. And the phase current of the proposed system is shown in fig.8. The current ripples are minimized effectively in the proposed method. It is reduced to 33% from 40%.

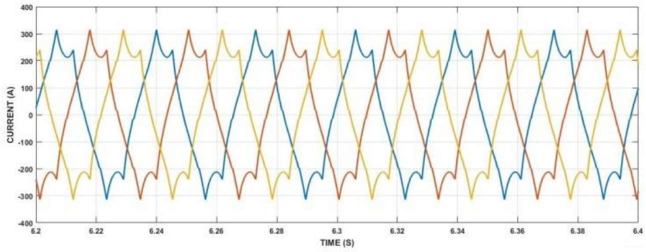

Fig 7: Currents vs Time waveform of conventional system

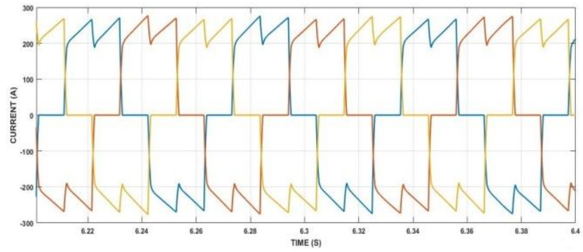

Fig 8: Currents vs Time waveform of proposed system

Speed respons of conventional system is shown in fig.9 and fig.10 shows the speed characteristics of proposed method. In the proposed system rated speed 20000 rpm attained at very fast rate.

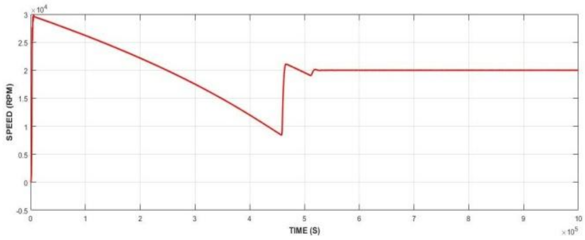

Fig 9: Speed vs Time waveform of conventional system

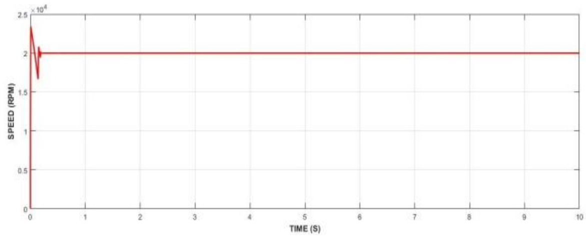

Fig 10: Speed vs Time waveform of proposed system

Torque characteristics of the conventional and proposed system are shown in fig. 11 and fig. 12.

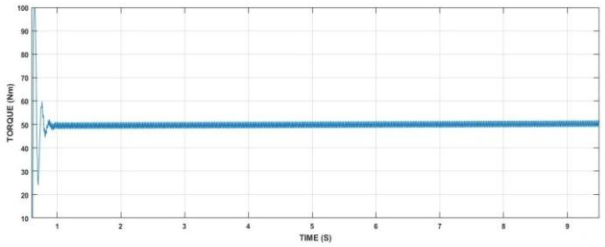

Fig 11: Torque vs Time waveform of conventional system

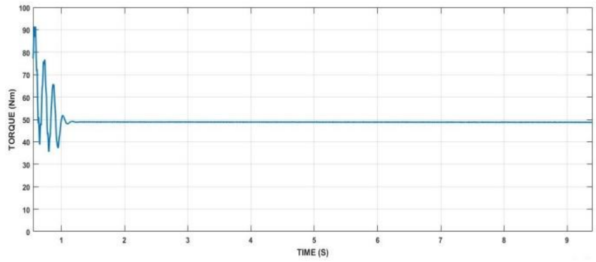

Fig 12: Torque vs Time waveform of proposed system

The detailed analysis of the reduction in torque ripple can be done with the figures below. Both of the results attain the rated torque 50 Nm. But the ripples are effectively minimizes in the proposed method. In conventional method the torque ripples are 55%. It can be redused to 48% with the proposed control. Torque ripple minimization is shown in Fig. 14.

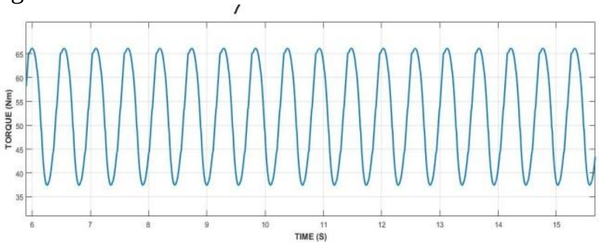

Fig 13: Torque ripple in the conventional system

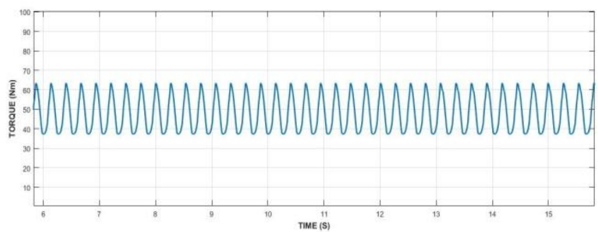

Fig 14: Torque ripple in the proposed system

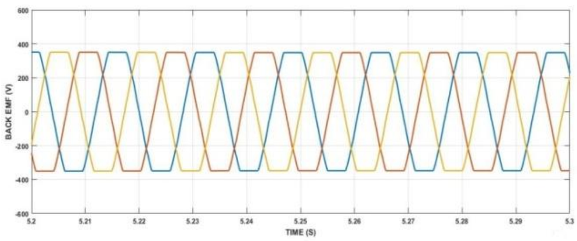

Fig 15: Back- EMF waveform of conventional system

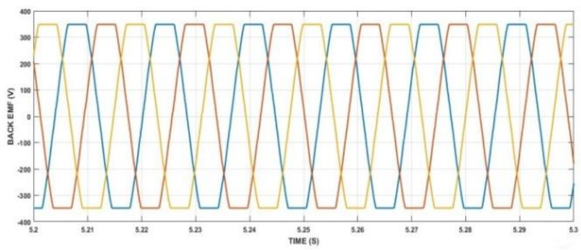

Fig 16: Back- EMF waveform of proposed system

The Back- EMF response of the machine is shown in Fig.15. The waveform is trapezoidal in shape.

VI. CONCLUSION

A new control strategy has been proposed to minimize the current and torque ripple of BLDC motor in this work. With the new switching logic and commutation algorithm simplicity in the control increases and the motor operates in wide speed range. From the simulation results it is found that with the proposed method we can obtains fast convergence speed, minimizing the current and torque ripples effectively. In addition it also improves the dynamic performance and is effective and can be easily implemented.

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