LINE TO LINE VOLTAGE BASED SENSORLESS CONTROL FOR HIGH SPEED BLDC MOTOR

Greeshma satheesh
College of Engineering
Trivandrum, India
greeshmasathi1994@gmail.com

Prof.Anu G
College of Engineering
Trivandrum, India
anugsivakumar@gmail.com

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

Keywords—sensorless control method, BLDC motor, line to line

Voltage, commutation.

I. INTRODUCTION

Nowadays, the use of brushless direct current (BLDC) motor is increasing, due to its simple structure, high efficiency, high torque and low cost. The BLDC motor is also known as electronically commutated motor and the electronic commutation is based on rotor position. The control of the BLDC motor is possible by both sensor and sensorless methods. Usually hallsensors are used in sensor based control methods, such position sensor has several drawbacks such as high cost and large size and special arrangement are needed for mounting sensor [1].

To overcome the drawbacks of sensor based control, sensorless based control method are used. In this type of control method, first to get the commutation signal in a wide speed range. Some studies are already done to get the commutation signals. Usually back EMF based control methods are used. 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 [3] and indirect back- EMF detection methods includes the back-EMF integration, third harmonic voltage integration [4] and free- wheeling diode conduction. For high speed applications, the outputs obtains with the back- EMF method contains more ripples and this method cannot be used for wider speed range. In [7] describes a neutral network method in this method a neutral network is used to find out the rotor position instead of using a position sensor, but its application is limited in large calculation and large needed of hardware and software. A torque constant extraction method is used to acquire precise commutation signals the extracted torque constant value is used for detect the position. All these methods are not used directly in a high speed BLDC motor. There will be some commutation delay due to different speed range, different hardware parameters and other factors. These commutation delay reduces the electromechanical performance.

This paper introducing a line to line voltage based sensorless control for a high speed BLDC motor for minimizing the current and torque ripple. The remaining section of the paper is organized as follows. Section I discusses the mathematical modelling of the BLDC motor. In section II discusses the conventional control techniques. Section III discuss the proposed speed control system. MATLAB simulation of the whole system is included in section IV.

II. MATHEMATICAL MODELLING OF THE BLDC MOTOR

The circuit diagram of the BLDC motor drive is shown in.
figure1.

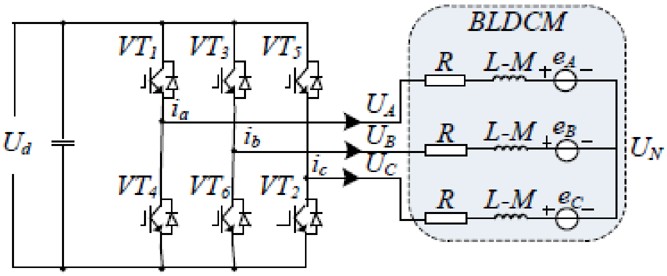

Fig. 1. Circuit diagram of BLDC motor drive system

The electrical and mechanical mathematical equations of
BLDC are given in this section. The stator voltage equations,

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

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

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

The equations of back- EMF can be given as:

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

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

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

The equations of electrical torques can be given as:

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

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

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

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

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

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

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

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
ω_m is the Angular speed of rotor.

The simulink model of a BLDC motor is shown in figure2.

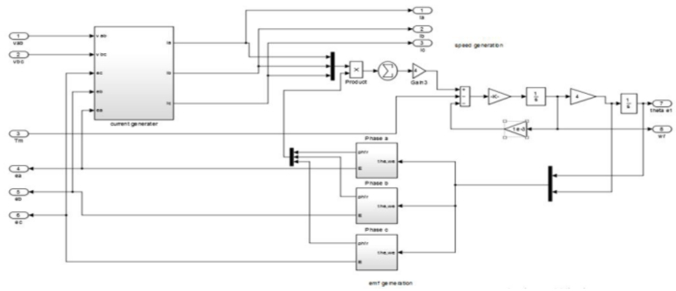

Fig. 2. Simulink model of BLDC motor drive system

Table I. Motor parameters of a BLDC motor

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

The motor parameters is shown in Table I. These parameters
are used for modelling the BLDC motor.

III. CONVENTIONAL SENSORLESS SPEED CONTROL METHODS

There are two kinds of sensorless control techniques. One of the methods for sensing the position using the back EMF of the motor. The second method is position approximation method; this method need processors to do calculations and the system is expensive. So Back EMF method is commonly used. It is divided into two,

- Direct Back-EMF Sensing Method
- Indirect Back-EMF Sensing Method

A. Direct back-EMF Sensing Methods

In this method the back-EMF of floating phase is sensed and its zero crossing is detected by comparing it with neutral voltage [2]. Due to PWM switching this method have large Common mode voltage and high frequency noise. To reduce these effects it requires voltage dividers and low-pass filters.

These methods can be classified as,

- Back EMF Zero Crossing Detection (ZCD) or Terminal

Voltage Sensing.

- PWM strategies.

B. Indirect Back-EMF Sensing Method

At high speeds filtering causes commutation delay and at low speed, attenuation causes reduction in signal sensitivity [5]. Therefore the speed is limited in direct back EMF sensing method. This method are classified as,

- Back-EMF Integration.
- Third Harmonic Voltage Integration.
- Free-wheeling Diode Conduction or Terminal Current Sensing.

Terminal voltage sensing is the easiest method in direct sensing back- EMF method and it depends on detection of the instant at which the back- EMF in the un-energized phase crosses zero. For a classic operation of a BLDC motor, the back-EMF and phase currents are arranged to generate constant torque. The conduction time of each phase is 120 electrical degrees. In order to produce maximum torque, the inverter should be commutated at every 60 degree, by detecting the ZCPs of back- EMF on the coil of the motor. This method has good performance but it has some problems, it requires high operational speed to detect the Zero Crossing Points of terminal voltages, at low speeds it use noisy terminal voltage to obtain a switching sequence and at transient condition it has degenerative response [6]. These demerits reduces the performance of the motor over wide speed ranges. To solve all the above problems, this paper proposes a new sensorless control method. This method is based on the relationship between line to line voltage and speed. Based on the relationship a compensation algorithm is proposed, which can be applied to the sensorless control methods.

IV. PROPOSED LINE-TO-LINE VOLTAGE METHOD

The obtained commutation signal causes commutation delay in the line to line voltage ZCPs. Inorder to compensate that delay proposes a line to line voltage method. Based on the relationship, a self-compensation algorithm is proposed which can be applied to the sensorless control methods. The block diagram of the proposed speed control system is shown in figure 3. The reference speed and actual speed is compared and it is given to the velocity loop controller; the output of the velocity loop controller is the reference current and it is compared with detected actual current and given to the current loop controller, buck chopper, commutation logic control and to the BLDC motor. Three mains sections in this block diagram are; commutation signals detection circuit, commutation algorithm link and commutation error compensation link. In commutation signal detection circuit; the line to line voltages is calculated and it is given to the commutation signal detection block; the commutation occurs at the zero crossing points and virtually a hallsensor is created from this. The speed is calculated and given to the velocity loop controller. The commutation delay is calculated from the speed of the motor. Delay is compensated in compensation calculation block by adding ψ_1 and ψ_2 we get the commutation delay value α. The simulink model of new switching and commutation is shown in figure 4.

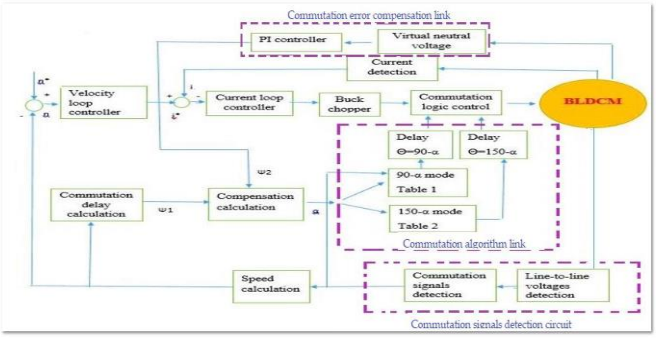

Fig. 3. Block diagram of proposed control method

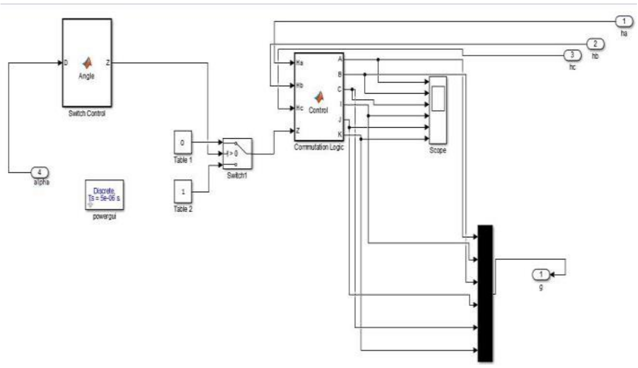

Fig. 4. Simulink model of new switching and commutation logic

A new compensation method based on the line to line 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 line to line voltage. Here there are two modes; 90-α mode and 150-α mode. Based on the compensation value the particular truth table will be selected and the control logic with that truth table will be actuated. There will be two truth tables for the proper selection of commutation logic to the inverter. At low speed ($\psi_1 + \psi_2 < 90$), the signal is switched to 90-α mode and the commutation status of the first mode is tabulated in Table II.

Table II COMMUTATION STATUS OF THE "90-α" MODE

Work status	Commutation time	Commutation phases	Commutation device
1	t(eAC- = 0)	C+,A-	V T5; V T4
2	t(eCB+ = 0)	C+,B-	V T5; V T6
3	t(eBA- = 0)	A+,B-	V T1; V T6
4	t(eAC+ = 0)	A+,C-	V T1; V T2
5	t(eCB- = 0)	B+,C-	V T3; V T2
6	t(eBA+ = 0)	B+,A-	V T3; V T4

At high speed ($\psi 1 + \psi 2 > 90$), the signal is switched to the 150-α mode, the commutation status of the second mode is tabulated in Table III.

Table III COMMUTATION STATUS OF THE "150-α" MODE

Work	Commutation	Commutation	Commutation

status	time	phases	phases
1	t(eBA+ = 0)	C+,A-	V T5; V T4
2	t(eAC- = 0)	C+,B-	V T5; V T6
3	t(eCB+ = 0)	A+,B-	V T1; V T6
4	t(eBA- = 0)	A+,C-	V T1; V T2
5	t(eAC+ = 0)	B+,C-	V T3; V T2
6	t(eCB- = 0)	B+,A-	V T3; V T4

V. SIMULATIOS AND RESULTS

Mathematical modelling is required to simulate the entire system. The simulation results obtained from the simulation of Conventional Back EMF method and proposed speed control method in Matlab/Simulink software is discussing in this section.

A. *Comparative analysis of a conventional system and proposed system.*

The conventional back EMF method is simulated using Matlab/Simulink and the simulation diagram is shown in fig.5. This conventional Back- EMF method has better performance. But the current and torque output contain more ripples; to overcome these drawbacks a new method is proposed. It is based on line to line voltage and speed. The simulink model of proposed sensorless compensation system is shown in fig.6. Based on this, an error compensation algorithm is proposed and applied to this sensorless control method.

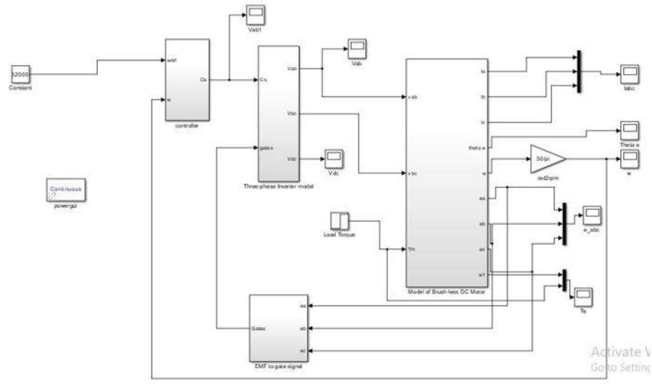

Fig. 5. Simulink model of conventional Back EMF method

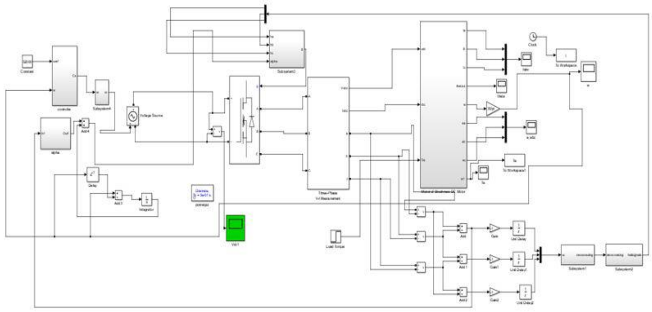

Fig. 6. Simulink model of proposed sensorless speed control method

B. *Speed waveform*

Speed response of conventional system is shown in
fig.7. The rated speed of the motor is 32000r/min and speed response of Proposed system is shown in fig.8.

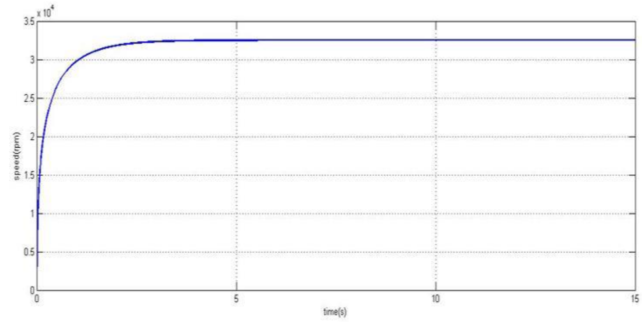

Fig. 7. Speed waveform of conventional system

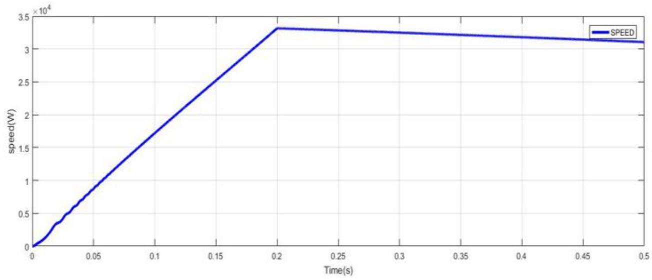

Fig. 8. Speed waveform of proposed system

C. *Back EMF waveform*

The back EMF response of conventional Back EMF
method is shown in fig.9. and proposed system is shown
in fig.10.

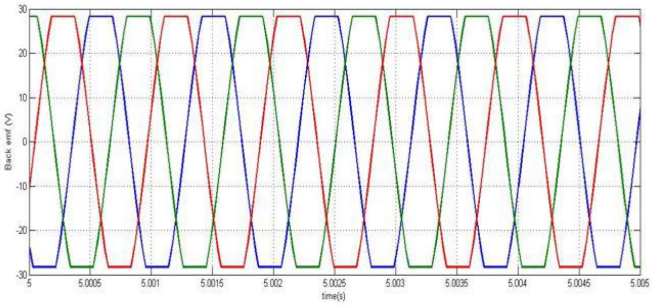

Fig. 9. Back EMF waveform of conventional system

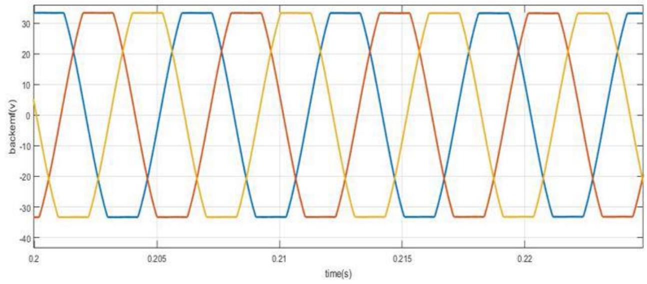

Fig. 10. Back EMF waveform of proposed system

D. *current waveform*

The current characteristics of conventional system is shown in fig.11 and current characteristics of Proposed system is shown in fig.12.

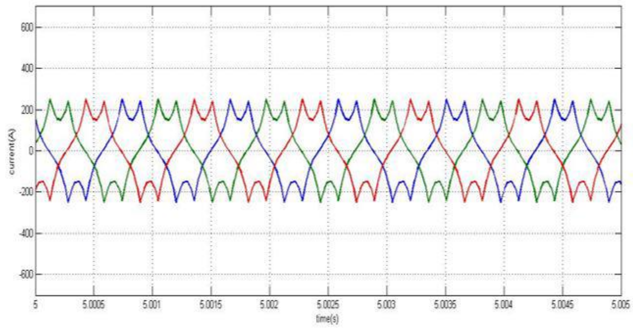

Fig. 11. Current waveform of conventional system

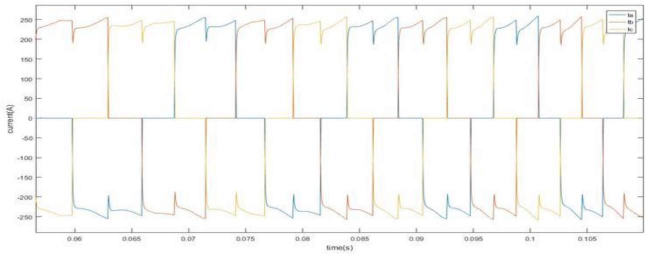

Fig. 12. Current waveform of proposed system

E. *Torque waveform*

The torque characteristics of conventional is shown in fig.13. and Proposed system is shown in fig.14.

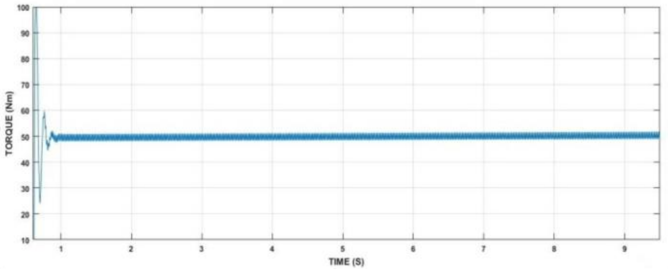

Fig. 13. Torque waveform of conventional system

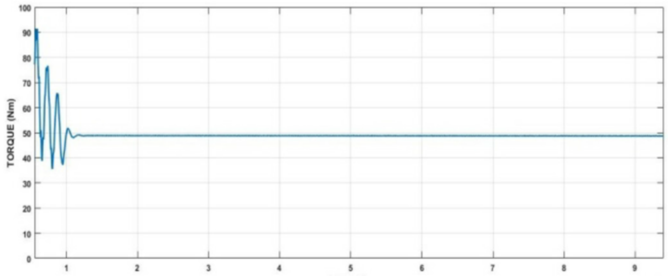

Fig. 14. Torque waveform of proposed system

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 reduced to 48% with the proposed control method. The detailed analysis of the reduction in torque ripple of conventional system is shown in fig.15 and for proposed system is shown in fig.16.

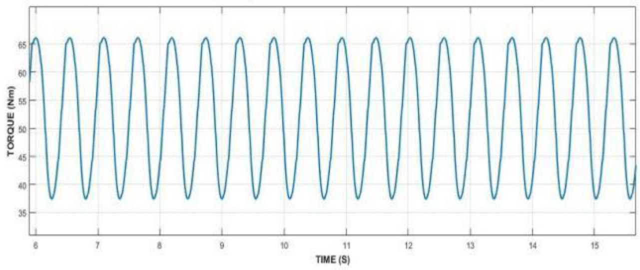

Fig. 15. Torque waveform of conventional system (Expanded view)

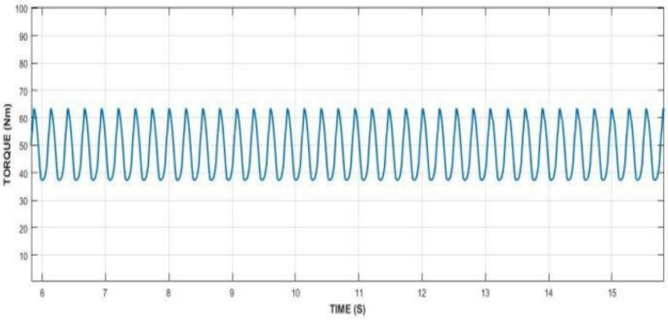

Fig. 16. Torque waveform of proposed system (Expanded view)

VI. CONCLUSION

In this work a new control method has been proposed to minimize the current and torque ripple of BLDC motor. 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.

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