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Sensorless Control of Brushless DC Motor using Modified back-EMF Detection

T. Siva[1] and Anith Sampathkumar[2]

[1]Department of Electrical and Electronics Engineering, Jerusalem College of Engineering, Velachery Main Road, Narayanpuram, Pallikaranai, Chennai – 600100, Tamil Nadu, sivasrira@gmail.com
[2]Department of Electrical and Electronics Engineering, Bharath University, 173, Agharam Road, Selaiyur, Chennai – 600073, Tamil Nadu, India; anith.eee@bharathuniv.ac.in

Abstract

This paper proposes a modified Back-EMF Detection sensorless control scheme for Brushless DC motor drive system. Even though several methods are available for sensorless control, they are found to be unsuitable for closed loop systems controlled by Pulse Width Modulation (PWM) technique. The proposed is well suited for the systems controlled by pulse width modulation technique and can be easily realized through inexpensive PIC microcontrollers. The simulink model of the proposed system is developed using MATLAB to investigate the performance of the proposed sensorless control technique. In the proposed method, a speed dependent time delay unit is developed to produce virtual hall sensor signals. Simulation results are presented to validate the performance of the proposed sensorless control scheme for different reference speeds and load torques.

Keywords: Back-EMF Detection, Brushless DC Motor, MATLAB/Simulink, Speed Dependent Time Delay

1. Introduction

The recent improvement in motor control and power electronics technologies leads to the development of Brushless DC Motor (BLDCM). The most important feature of it is the mechanical commutation constituted by commutators and brushes is replaced by electrical commutation circuitry. It solves the problem caused by mechanical commutation and maintains the merits of using a DC motor in varying speed field. BLDC motors are used in many applications like power steering, engine cooling fan, fuel/water pump, Heating, Ventilating and Air-Conditioning (HVAC) blower motors.

The rotor position signal of BLDCM is usually provided by hall sensor. The existence of hall sensor has number of drawbacks. They increase the cost and require special arrangement for mounting the hall sensor in the motor. These hall sensors are temperature susceptible and hence limit the motor operation. The reliability is reduced due to extra components and wiring. In this paper, the rotor position is detected via detecting the three phase terminal voltages. This kind of method don't use position sensor, reduce the system cost and the volume of the motor, especially improves the characteristics of the system.

Sensor and sensorless are two methods of control of BLDC motors. An approach to position sensorless BLDC motor drive is discussed in. A new Algorithm for sensorless control was proposed in. Two types of sensorless control techniques of BLDC motors are discussed in. The first type is the position sensing using back EMF of the motor, and the second type is position estimation using motor parameters. The position estimation scheme usually needs complicated computation, and the cost of the system is relatively high. The back EMF sensing scheme is suitable for many application requires no detailed knowledge of motor parameters. This technique is suitable for motor control using Pulse Width Modulation (PWM).

* Author for correspondence

In BLDC motor, only two out of three phases are excited at any time, leaving the third winding floating. The back EMF of the floating winding is measured to establish the switching sequence for commutation of power devices in the three-phase inverter driving the motor. The method for determining the zero-crossing point of back-EMF via terminal voltages is given in. A second order Low Pass Filter (LPF) is required to remove the high frequency switching noise signals caused by the use of Pulse Width Modulation (PWM) signals. Due to the use of filter a time delay is produced, thereby deteriorating the torque response and efficiency. The zero-crossing point of back-EMF can be determined from mathematical calculation. In this method, terminal voltages are sampled when PWM is in ON state. It involves lot of complex calculations and need Digital Signal Processor (DSP) to implement it.

In this paper, the Time Delay created due to the use of the filter is reduced by designing a Speed Dependent Time Delay Unit. This will overcome the problem of using filter and it can be easily implemented by using low cost micro controllers. The main focus of the paper is to control the speed of Brushless DC motor by using modified Back-EMF Zero Crossing Detection. The Simulation of the proposed system is completed and results are presented. The realization of the proposed method using experimental setup is under progress.

2. Proposed Back EMF Detection Method

Consider a 3 phase, Star connected BLDC motor, is driven by a three phase inverter in which the devices are triggered with respect to the rotor position[1]. Figure 1. shows the terminal voltages of the three phase winding. "V_a" denotes the terminal voltage of the phase A connected to the positive dc link rail. "V_c" indicates the terminal voltage of the phase C connected to the negative dc-link rail. "V_b" is the terminal voltage of the floating phase C. The back-EMF voltage is detected via the terminal voltage of floating phase[2]. under open loop condition. Once the Back-EMF has become significantly high to detect the zero crossing point the control is switched to closed loop operation. In the experimental setup,

PIC 16F877A Micro controller is used to implement the proposed method.

From Figure 1., the following voltage equations can be written

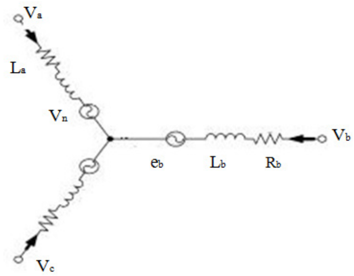

Figure 1.

$$V_a R_a I_a L \frac{dI_a}{dt} E_a V \tag{1}$$

$$V_b R_b I_b L \frac{dI_b}{dt} E_b V_n \tag{2}$$

$$V_c R_c I_c L \frac{dI_c}{dt} E_c V_n \tag{3}$$

The motor adopts 120º conducting mode, so only two phases are energized at a time and current in the two phases has the same amplitude but in opposite direction. In floating phase, the current is zero[3,17]. Adding the above three equations, we get

$$V_a + V_b + V_c = E_a + E_b + E_c + 3V_n \tag{4}$$

The sum of the Back-EMF, $E_a + E_b + E_c = 0$ can be obtained at the instant, when each phase Back-EMF crosses zero. Therefore, at the zero-crossing point of Back-EMF,

$$V_n \frac{1}{3} V_a V_b V_c \tag{5}$$

When phase winding current is zero, its phase Back-EMF is increasing from or decreasing to zero. For example consider phase A, $E_a = V_a - V_n$, when $V_a = V_n$, then $E_a = 0$. Therefore, neutral point voltage can be obtained from the phase terminal voltages. When the terminal voltage is equal to the neutral voltage, the zero crossing point of the back-emf is detected[4–7].

3. Block Diagram

The Figure 2. shows the block diagram of the sensorless control of the BLDC motor. The terminal voltage is sensed to detect the Zero Crossing point of the Back-EMF[8]. Under very low speeds, Back-EMF is too low to detect. So under such conditions, the controller is programmed to start the motor.

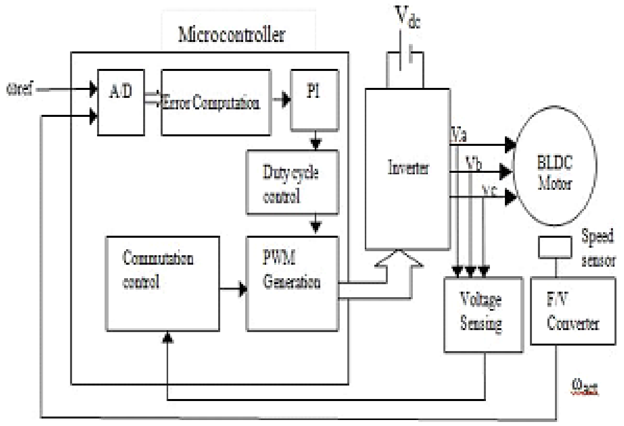

Figure 2. Block Diagram of the proposed method.

4. Simulation of the Proposed Method

The simulation of the proposed method is performed in MATLAB Environment. The overall simulation block is shown in the Figure 3. The simulink model consists of speed Controller, PWM Generation, Terminal Voltage Sensing and Zero Crossing Detector and Commutation Control[9,16]. The virtual hall sensor signal and direction of rotation of the motor are calculated from the Back-EMF signals. The PWM signals given to the inverter switches are proportional to the speed of the motor[10,15]. The reference and actual speed are compared to obtain the error value. This error is input to PI speed controller and its output is used for PWM generation. The output of the PWM generator block gives pulses proportional to the corresponding speed. These pulses are used to drive the inverter switches. The neutral point voltage Vn is obtained by creating a virtual ground. Low Pass Filter (LPF) is used to remove the ripples created due to use of Pulse Width Modulation (PWM) signals. The Delay Calculation block is used to calculate the time delay between the Zero Crossing instant of Back-EMF signal and the commutation instant[11-14]. In this proposed method, the drawback created due to the use of filter is eliminated by the use of the delay calculation block.

5. Result and Analysis

The proposed method is simulated in the Matlab and the results obtained are shown in the Figure 4 to Figure 8. The phase voltage without using filter is shown in Figure 4 The PWM signal will introduce lot of ripples in the terminal Voltage. This creates difficulty in detecting the zero crossing point of the Back-EMF. So a second order Low Pass Filter (LPF) is used to remove the ripples in the phase voltage. The resultant waveform using filter is shown in the Figure 5. The cutoff frequency of the filter is carefully designed so that it won't affect the shape of the back-emf signal.

The comparison between the generated and real hall sensor signals is shown in the Figure 6. The result shows that both the waveforms are synchronized and maintains synchronization even under loaded condition. The delay calculation block shown in Figure 3 is used to adjust

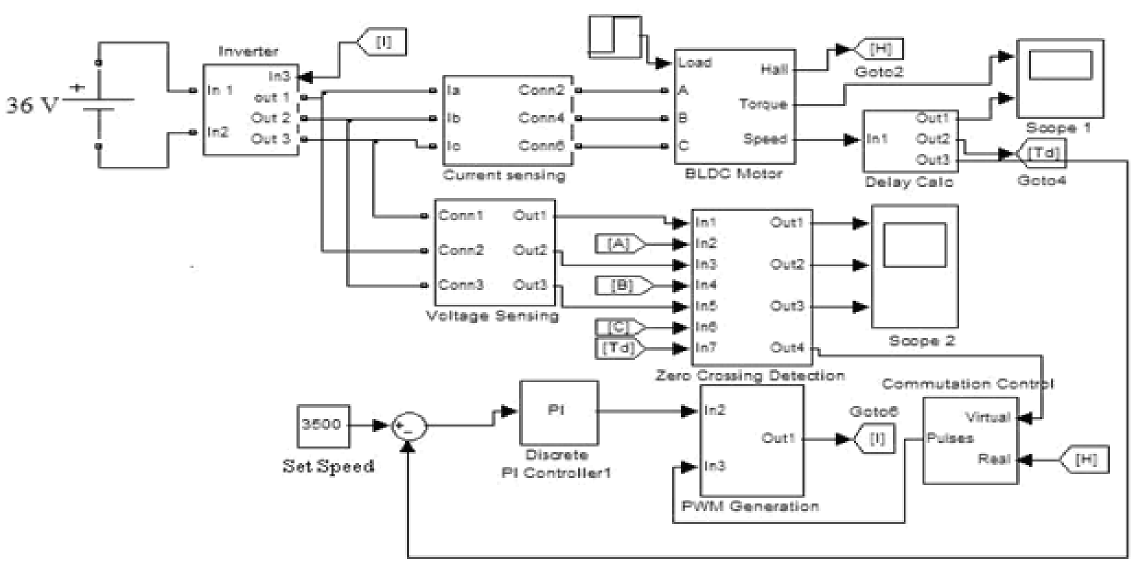

Figure 3. Block Simulink Model of the Proposed Method.

the time delay between the zero crossing event of the back-emf and the commutation pulses given to inverter. The 30° time delay between the zero crossing point and commutation instants is not fixed. It is calculated according to the speed of the motor. So it provides better synchronization between real and generated hall sensor signals.

The back emf and current are perfectly in-phase with each other. For simplicity, only phase A is shown in the Figure 7. For proper commutation to take place both current and back-emf should be in-phase.

The speed response for the set speed of 3500rpm is shown in Figure 8. The PI controller provides robust control over wide speed range. The actual speed matches with the reference speed. The load torque of 0.2Nm is applied at 0.3sec and the PI controller responds quickly and takes the necessary controlaction. The Speed response shows that Virtual Hall Sensor Signal is remain synchronised even under loaded condition

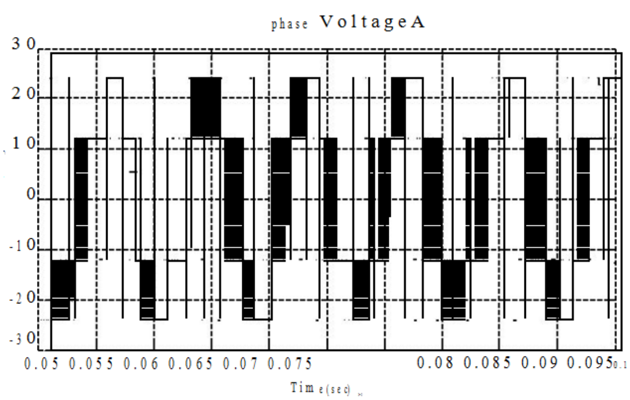

Figure 4. Phase A voltage without Filter.

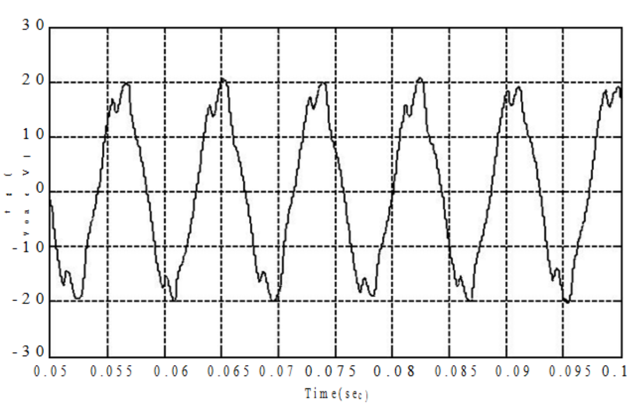

Figure 5. Phase A Voltage with Filter.

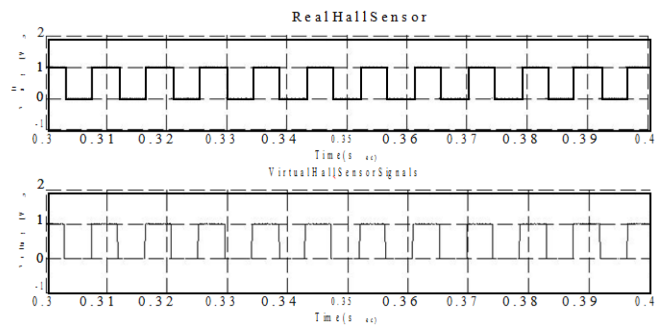

Figure 6. Real and Virtual Hall sensor signal.

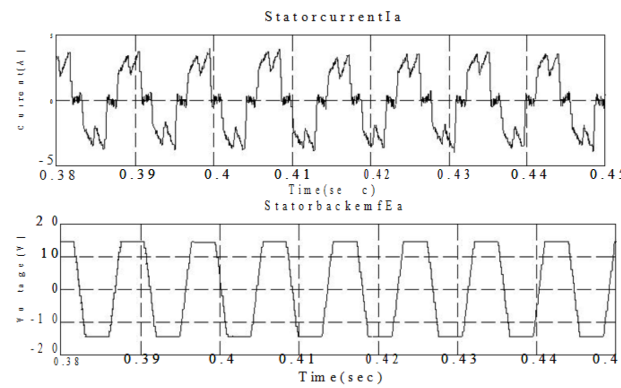

Figure 7. Current **(Ia)**, and Back-EMF **(Ea)**.

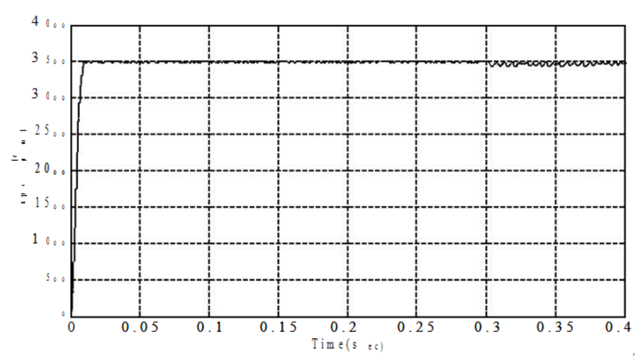

Figure 8. Speed response when load torque of 0.2 Nm is applied at 0.3 sec.

6. Conclusion

The simulation results obtained using the proposed BLDC drive system has proved the simplicity of sensorless speed control of BLDC motor. The implemented Back-EMF sensing method has superior performance and provides control over wide speed range at low cost. The validity of the developed sensorless BLDC drive system using back EMF detection is implemented on a 3-phase, 175 W, 4-pole, BLDC motor. In general, the proposed method is suitable for sensorless BLDC motor control using PWM signals.

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APPENDIX
Motor Parameters

Power	175 watts
Voltage	36V
Current	5 A
Speed	4000 rpm
Torque Constant	0.082
Motor type	3 phase, Star connected
Inductance per phase	1.5 mH
Resistance per phase	0.87 ohm