ISSN (Print) : 2320 – 3765
ISSN (Online): 2278 – 8875

International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering

(An ISO 3297: 2007 Certified Organization)

Vol. 2, Issue 12, December 2013

Simulation of sensorless operation of BLDC motor based on the zero-cross detection from the line voltage

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ABSTRACT: This paper presents the simulation of sensorless operation of permanent magnet brushless direct current (BLDC) motor. The position sensorless BLDC drive simulated, in this paper, is based on detection of zero crossing from the terminal voltages differences. This method relies on a difference of line voltages measured at the terminals of the motor. It is shown, in the paper, that this difference of line voltages provides an amplified version of an appropriate back EMF at its zero crossings. The commutation signals are obtained without the motor neutral voltage. The effectiveness of this method is demonstrated through simulation.

Keywords: BLDC motor, simulation, sensorless operation, zero crossing

I. INTRODUCTION

In the literature there are several simulation models available for BLDC motor drives. These models employ state-space equations, Fourier series or d-q axis model. Even though these models have made a great contribution in the BLDC motor drives, there is no comprehensive model for the analysis of motor used in sensorless operation [1]. The machine models are often transformed to a rotating reference frame to simplify and to improve the computational efficiency. But, this approach will not improve the computational efficiency because the d-q transformations are suitable only for machines with sinusoidal voltage as discussed in [2]. The BLDC motors are normally powered by conventional three phase voltage source inverters (VSI) or current source inverters (CSI) which are controlled based on the rotor position information obtained from hall sensors, resolvers or absolute position sensors. But these position sensors have numerous drawbacks like increase in cost, complexity in control, temperature sensitivity requiring special arrangements. These sensors reduce the system reliability and acceptability. Therefore, sensorless techniques have become a subject of great interest in recent times. A number of sensorless techniques have been developed for BLDC motor. Some of the techniques presented [3] in the literature are based on position sensing using back emf zero detection crossing, terminal voltage sensing, sensing third harmonics of the motional emf, integration of the back emf, position sensing using inductance variation, position sensing based on flux linkage variation, Extended Kalman filter estimation or detecting the freewheeling diode conduction in open phase proposed in [4, 5].

In BLDC motors, only two out of three phases are excited at any time leaving the third winding floating. The back emf in the floating winding can be measured to determine the switching sequence for commutation of power switching devices in the 3 phase inverter. The terminal voltage of the floating winding with respect to the neutral point of motor is needed to get the zero crossing time of the back emf. The sensorless control technique based on Zero Cross Point (ZCP) of the back emf has been widely used for low cost application proposed by J. Shao [6]. In the ZCP method the back emf cannot be obtained when the BLDC motor is at standstill or operating nearly zero speed as discussed by Yen-Shin Lai and Yongkai Lin [7]. Therefore, a special control is needed for smooth and reliable sensorless control operation of BLDC motor [8].

In this paper a Matlab/Simulink sensorless operation is developed. This paper simulates a simple and reliable method for the detection of back EMF zero-crossings for sensorless operation using MATLAB/SIMULINK as discussed and

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simulated using SABER software in [8] . In this paper, the zero crossings of the back EMF are estimated indirectly from the terminal voltages measured with respect to dc negative terminal. The method does not involve any integrations. Further, since line voltages are used, the requirement of neutral potential has been eliminated. This also eliminates the common mode noise. Device drops and their variations would also not play a part since line voltages are used. Using this model of BLDC motor suitable for the dynamic behavior of the motor is studied. Also simulation has been carried out to study the effectiveness of the sensorless control based on detection of zero crossing from the terminal voltages differences. The organization of this paper is as follows. Section II describes the proposed back EMF zero-crossing estimation method. Section III presents the simulation results of the proposed method. Section IV presents the conclusion.

II.PROPOSED BACK EMF ZERO-CROSSING ESTIMATION METHOD

Consider a BLDC motor having three stator phase windings connected in star[8]. Permanent magnets are mounted on the rotor. The BLDC motor is driven by a three phase inverter in which the devices are triggered with respect to the rotor position as shown in Fig. 1. The phase A terminal voltage with respect to the star point of the stator V_{an}, is given as

$$V_{an} = R_a i_a + L_a \frac{di_a}{dt} + e_{an}$$

Where R_a is the stator resistance, L_a is the phase inductance, e_{an} is the back EMF, and i_a is the phase current of the "A" phase.

Similar equations can be written for the other two phases, as

$$V_{bn} = R_b i_b + L_b \frac{di_b}{dt} + e_{bn}$$

$$V_{cn} = R_c i_c + L_c \frac{di_c}{dt} + e_{cn}$$

Where symbols have their obvious meanings.

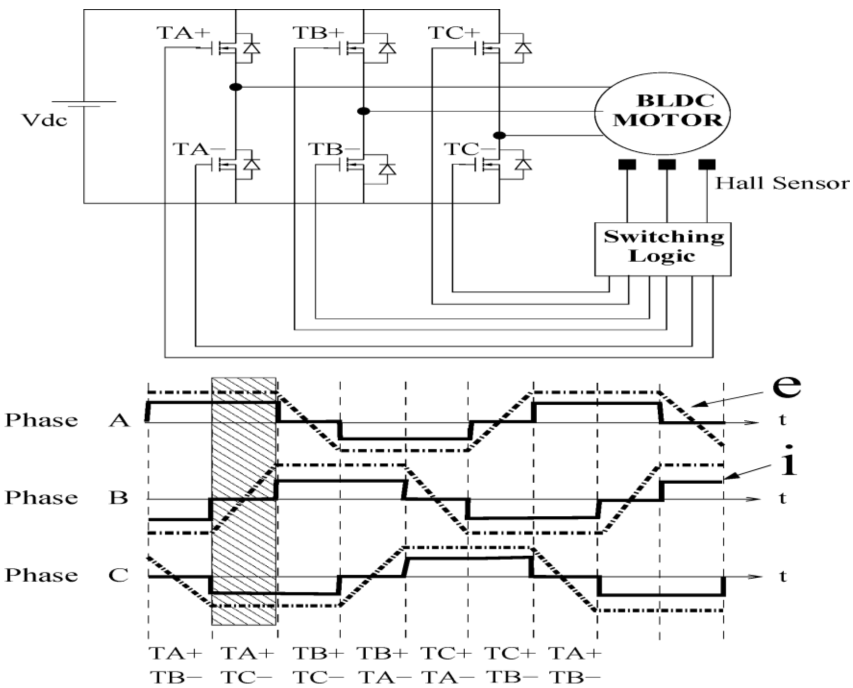

Fig.1. BLDC motor drive along with typical phase current and back EMF[8]

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ISSN (Online): 2278 – 8875

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From above equations, the line voltage V_{ab} may be determined as

$$V_{ab} = V_{an} - V_{bn} = R(i_a - i_b) + L\frac{d(i_a - i_b)}{dt} + e_{an} - e_{bn}$$

Similarly

$$V_{bc} = V_{bn} - V_{cn} = R(i_b - i_c) + L\frac{d(i_b - i_c)}{dt} + e_{bn} - e_{cn}$$

$$V_{ca} = V_{cn} - V_{an} = R(i_c - i_a) + L\frac{d(i_c - i_a)}{dt} + e_{cn} - e_{an}$$

These line voltages can, however, be estimated without the need for star point by taking the difference of terminal voltages measured with respect to the negative dc bus.
Subtracting V_{bc} from V_{ab} gives

$$V_{abbc} = V_{ab} - V_{bc}$$
$$= R(i_a - 2i_b + i_c) + L\frac{d(i_a - 2i_b + i_c)}{dt} + e_{an} - 2e_{bn} + e_{cn}$$

Consider the interval when phases A and C are conducting and phase B is open as indicated by the shaded region in Fig. 4.3. In this interval, phase A winding is connected to the positive terminal of the dc supply, phase C to the negative terminal of the dc supply and phase B is open. Therefore, $i_a = -i_c$ and $i_b = 0$. It can be seen from Fig. 1 (shaded region) that the back EMF in phases A and C are equal and opposite. Therefore, in that interval V_{abbc} may be simplified as

$$V_{abbc} = V_{ab} - V_{bc} = e_{an} - 2e_{bn} + e_{cn} = -2e_{bn}$$

The difference of line voltages waveform is, thus, an inverted representation of the back EMF waveform. The EMF values would be those in a resistance, inductance, EMF (RLE) representation of the phase (not referred to ground). It may also be noted that the subtraction operation provides a gain of two to the EMF waveform thus amplifying it. It is again evident from Fig.1 that during this interval (shaded portion) the back EMF e_{bn} transits from one polarity to another crossing zero. Therefore, the operation $V_{ab} - V_{bc}$ (V_{abbc}) enables detection of the zero crossing of the phase B EMF. Similarly, the difference of line voltages V_{bcca} enables the detection of zero crossing of phase C back EMF when phase B and C back EMFs are equal and opposite. The difference of line voltages V_{caab} waveform gives the zero crossing of phase A back EMF where phases C and B have equal and opposite back EMFs. Therefore, the zero-crossing instants of the back EMF waveforms may be estimated indirectly from measurements of only the three terminal voltages of the motor.

The simulated sensorless method uses this approach to estimate the zero-crossing instants of the back EMF from the terminal voltages of the motor from which the correct commutation instants are estimated. This sensorless method is simulated in MATLAB/SIMULINK software. The functional sequence of operations of the simulated back EMF zero-crossing detection for sensorless operation is shown in Fig. 2.

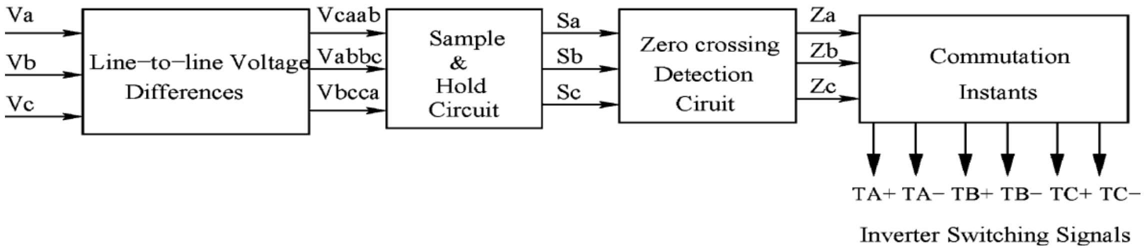

Fig. 2 Functional sequence of operations[8]

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ISSN (Online): 2278 – 8875

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III. SIMULATION AND RESULTS

This section presents the aspects of continuous sensorless operation. This sensorless method is simulated in MATLAB/SIMULINK. The motor parameters are given in Table I.

Table I

Parameter	Values
Stator phase resistance	2.8750 Ohms
Stator phase inductance	8.5 mH
Flux linkage established by magnets	0.175 V.s
Voltage constant	146.6077(V_ peak L-L/krpm)
Torque constant	1.4 N.m/A _ peak
Back emf flat area	120 degrees
Inertia	0.8m kgm^2
Friction factor	1m N.m.s
Number of poles	8

The functional sequence of operations of the simulated back EMF zero-crossing detection for sensorless operation is shown in Fig. 2, and is further explained in the following.

The Fig. 3 shows the circuit diagram of simulation of BLDC MOTOR, in sensorless mode From the sensed terminal voltages with respect to negative dc bus (V_{ab}, V_{bc}, Vc_{ca}), line voltages, and subsequently their differences (V_{caab}, V_{abbc}, V_{bcca}) are determined. Fig. 4 shows the simulated back EMF waveform of the three phases and the corresponding line voltage difference waveforms. From the line voltage difference waveforms zero crossings are detected using the zero crossing detection model shown in fig. 5. These zero crossings are decoded to corresponding signals using ZCD decoding system shown in fig. 6. These decoded signals are fed to Hall sensor decoder system which provides gate signal to the inverter. Two control loops are used. The inner loop synchronizes the inverter line voltage difference zero crossing signals with the electromotive forces. The outer loop controls the motor's speed by varying the DC bus voltage. The simulated speed waveform is shown in Fig. 7.

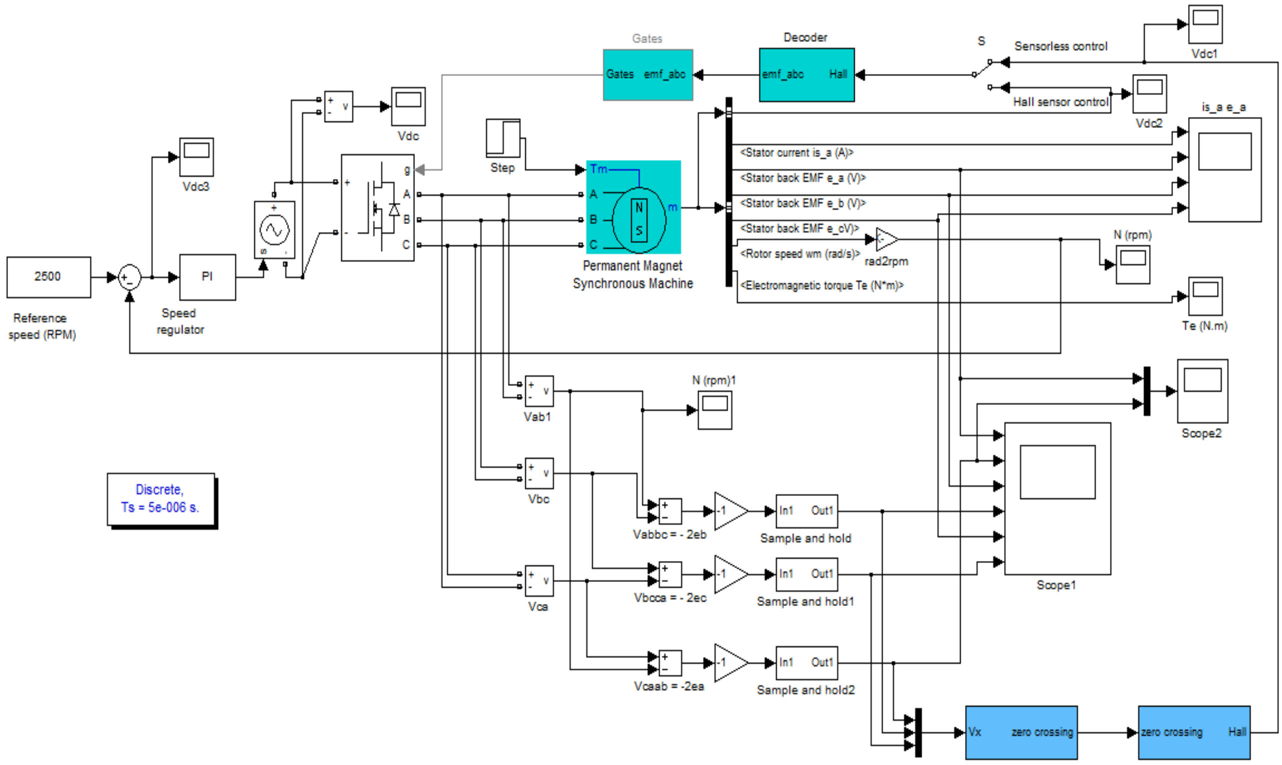

Fig. 3 Simulation of BLDC motor in sensorless mode

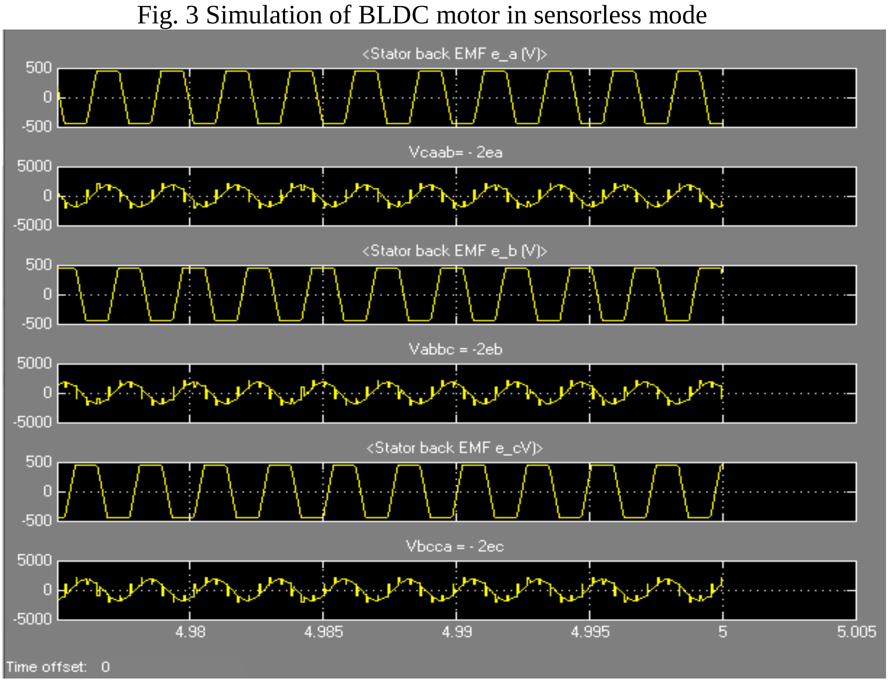

Fig. 4 Back EMF and corresponding line voltage difference waveforms

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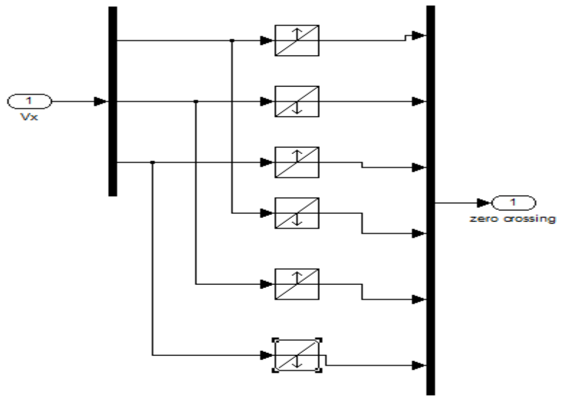

Fig 5 Zero crossing detection model

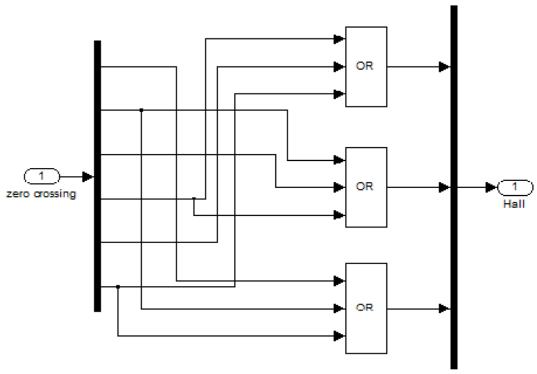

Fig 6 ZCD Decoding model

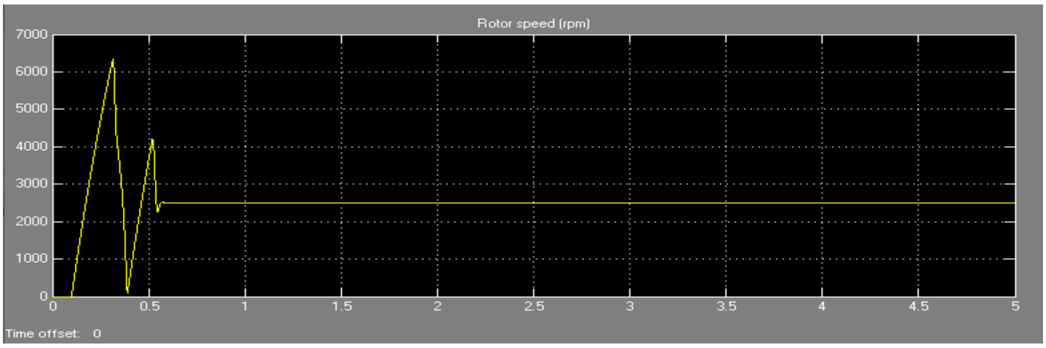

Fig. 7 Simulated speed waveform of BLDC motor in sensorless operation

IV. CONCLUSION

A simple technique to detect back EMF zero crossings for a BLDC motor using the line voltages is simulated using MATLAB/SIMULINK. It is shown that the method provides an amplified version of the back EMF. Only three motor terminal voltages need to be measured thus eliminating the need for motor neutral voltage. Running the machine in sensorless mode is then simulated, in this paper. Hardware model can be developed based on the proposed simulation method of sensorless control of BLDC motor. Thus this primitive model can be extended as an industrial module, by incorporating the safety features, such as over current, over-voltage protection. This can be achieved by monitoring the inverter input voltage and also the inverter input current. . It is also required to monitor the temperature of the semiconductor power-devices, as these devices are very sensitive to temperature.

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