ISSN: 2277-3754
ISO 9001:2008 Certified
International Journal of Engineering and Innovative Technology (IJEIT)
Volume 3, Issue 1, July 2013

Speed Control of Brushless DC Motor Implementing Extended Kalman Filter

Joyce Jacob, Surya Susan Alex, Asha Elizabeth Daniel

Abstract*—BLDC motors or brushless dc motors are permanent magnet synchronous motors that work similar to dc motors. The rotor position information is important for the speed control of BLDC motor. Rotor position detection can be done using sensors which include the use of encoders or optical sensors. The Hall sensor are the most commonly used one. Also, sensor less techniques can be applied for the rotor position detection. The Extended Kalman Filter (EKF) is a sensor less method of rotor position detection wherein the rotor position is estimated from the machine parameters. In this paper, the BLDC motor has been modeled. Rotor position estimation using the Extended Kalman Filter (EKF) is done and speed control is achieved. Also, rotor position detection using Hall sensor signals is done and speed control is achieved. Here, the bipolar PWM technique with hard switching is employed.

***Index Terms*—BLDC motor, electronic commutation, Extended Kalman Filter, Hall sensor.**

I. INTRODUCTION

The growing use of permanent magnets in electrical machines is due to the advantages such as no excitation losses, simplified construction, improved efficiency, fast dynamic performance, and high torque or power per unit volume. It was during the early 19th century that the permanent magnets were first used in electrical machines, but due to the poor quality of permanent magnet materials, it did not gain popularity until 1930. It was only after the 1930s that the better quality permanent magnet materials like Alnico were developed. Squirrel cage induction motors had gained popularity during the 20th century due to its rugged construction, but had the disadvantages of poor power factor and efficiency [1]. Synchronous motors and dc commutator motors on the other hand had to face the problems of speed, noise problems, wear and EMI due to the use of commutator and brushes. These led to the development of Permanent Magnet Brushless DC Motors (PMBLDC), simply referred to as Brushless DC (BLDC) motors. BLDC motors have gained popularity due to its better characteristics and performance. Also they are used in a great amount of industrial sectors because their architecture is suitable for any safety critical applications. From the modeling perspective, BLDC motors are dc motors inside out. While dc motors have a permanent magnet stator and rotor windings, the BLDC motors have a permanent magnet rotor and three phase distributed stator windings. They are characterized by a trapezoidal back emf. The commutation in dc motors is performed by commutators and brushes, while in BLDC motors, electronic commutation is employed. Speed control of BLDC motor requires the information regarding the rotor position. For speed control, the input voltage to the motor and hence the flux developed has to be controlled. For this, the BLDC motor is fed from a PWM controlled three phase inverter. The rotor position gives us information regarding the instant and duration for which any switch in the inverter has to be operated so that a particular commutation sequence is followed.

II. METHODS OF ROTOR POSITION SENSING

For the operation of the BLDC motor, it is important that the stator windings be energized in a proper sequence. For the correct switching of the inverter switches, the information regarding the rotor position is necessary. For this purpose, the rotor angular position needs to be detected using some method. There are two methods of rotor position detection. They are

- Sensor methods
- Sensor less methods

Using any of the above mentioned methods, the rotor position is detected and based on which the inverter switching is carried out so that the stator windings are energized in a particular sequence.

A. Sensor method

In sensor methods, an auxiliary device such as an optical encoder or resolver is used to detect the rotor position. Fig.1 shows the block diagram of a position sensor used for the rotor position detection [4]. Here the rotor position is used by a speed controller for motor speed control.

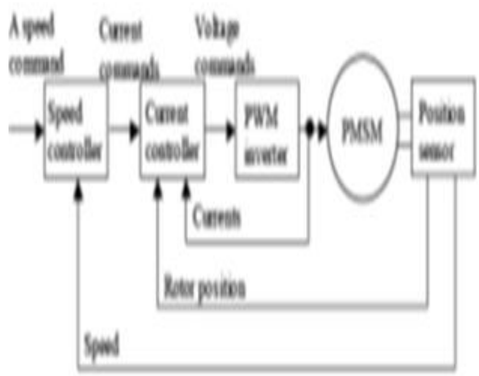

Fig.1. Block Diagram of Sensor Methods [4]

Different algorithms can be employed for the control of BLDC motors, like the Hysteresis control and pulse width modulation control (PWM) [8]. Hall Effect sensors are a common type of sensors used for the detection of rotor position sensors in BLDC motors.

ISSN: 2277-3754
ISO 9001:2008 Certified
International Journal of Engineering and Innovative Technology (IJEIT)
Volume 3, Issue 1, July 2013

B. *Sensor less method*

The many disadvantages of the sensor methods have given way to the development of the sensor less methods. Sensor less methods offer many advantages [2].

- Low installation cost as the phase windings are the only electrical connections to the machine.
- As there are no connecting leads to the controller, the position data will not be tampered by electromagnetic interference.
- Cost will be considerably less due to the elimination of the position encoding device.

There are many sensor less methods of rotor position detection, some of which are the Back emf Method, Rotor Position Detection from Third Harmonic of Back emf, Observer Based Method, Inductance Variation Sensing Method, Flux Linkage Variation Sensing, Parameter estimation using Extended Kalman Filter (EKF) etc.

III. BLDC MOTOR MODEL

The BLDC motor modeling is done based on its dynamic equations. For control of BLDC motor, we require information regarding it's rotor position. The rotor position information as well as the speed signal required for its speed control is obtained from the motor model. In the simulation work done here, the Hall sensor signals shown in table 1 are used. Corresponding to each rotor position detected, a Hall signal will be produced.

Equations used for BLDC motor modeling

Terms used [3]:

e - Back emf.
i – Line current.
v- Terminal voltage.
E- Back emf constant.
N – no. of conductors connected in series per phase.
w_m– Angular velocity
$\emptyset$- Flux linkage
R- Resistance of the stator winding
L – Inductance of the stator winding
M – mutual inductance
J - moment of inertia
B- Frictional coefficient
T_e – Motor developed torque
T_l – load torque
P- no. of poles

The back emf is given by

$$e = E * f(\theta) \qquad (1)$$

where Back emf constant

$$E = N * \emptyset * w_m \qquad (2)$$

$$f(\Theta) = \begin{cases} 1 & 0<\Theta<120 \\ (6/\pi)(\pi - \Theta)-1 & 120<\Theta<180 \\ -1 & 180<\Theta<300 \\ (6/\pi)(\Theta - 2\pi)+1 & 300<\Theta<360 \end{cases} \qquad (3)$$

The line current is obtained from the equation

$$\frac{di}{dt} = \frac{(v - R*i - e)}{(L+M)} \qquad (4)$$

The developed torque

$$T = \frac{(e_a i_a + e_b i_b + e_c i_c)}{w_m} \qquad (5)$$

The motor speed is obtained from the equation

$$J\frac{w_m}{dt} + Bw_m = (T_e - T_l) \qquad (6)$$

The rotor angular position is obtained from the equation

$$\frac{d\Theta}{dt} = \frac{P}{2} * w_m \qquad (7)$$

From the above dynamic equations, the BLDC motor modeling was done.

IV. HALL SENSOR SIGNALS

Hall effect sensors are a common type of sensors used for the detection of rotor position sensors in BLDC motors. Hall effect sensors comprise of three sensor unit's mounted on a permanent magnet disc. The sensors are placed 120 electrical degrees apart. The magnetic disc has two north poles and two south poles. Each time the north-south boundary crosses a sensor, the sensor output changes from a zero to a one or from a one to a zero. Depending upon the rotor position, the sensor gives a binary output comprising of a three bit word. With the three sensors, there is a possibility of eight digital codes, i.e., 000 to 111. Table 1 shows the Hall sensor signals corresponding to the rotor position.

Table 1. Hall sensor signals

No.	Hall sensor signals		
	Rotor position (degrees)	**Hall signals**	**Phase energized**
1	0-60	101	AB
2	60-120	100	AC
3	120-180	110	BC
4	180-240	010	BA
5	240-300	011	CA
6	300-360	001	CB

Of these, only six digital codes are used, eliminating the use of the codes 000 and 111, which are considered as illegal values, to be flagged as fault conditions. The occurrence of the digital codes 000 and 111 as sensors outputs is an indication of bad connection, or some problem related to the hall sensor power supply. With the indication of the rotor position from the hall sensor output, we can determine the stator coils to be turned on and off to get the best torque response from the motor. So it is necessary to have an accurate detection of the rotor position.

V. PARAMETER ESTIMATION USING EXTENDED KALMAN FILTER (EKF)

Extended Kalman Filter (EKF) is an effective state estimation algorithm that can be applied to non-linear systems. Regardless of the precision of the measurement variables, the EKF provides a quick and accurate estimate of the variables to be estimated [7]. In the context of BLDC

ISSN: 2277-3754
ISO 9001:2008 Certified
International Journal of Engineering and Innovative Technology (IJEIT)
Volume 3, Issue 1, July 2013

motors, EKF can be employed for estimating the speed and rotor position of the motor. The EKF algorithm has two steps [6] :

- Predictor step.
- Corrector step.

Predictor step

$$\hat{x}_{(k+1/k)} = F_k \hat{x}_{(k/k)} + G_k u_k \quad (8)$$

$$\widehat{P}_{(k+1/k)} = F'_k \widehat{P}_{(k/k)} F'^T_k + Q_k \quad (9)$$

Where F =I+AT,
G= BT T- sampling interval

$$F' = \frac{d(F_k x_{(k)} + G_k u_k)}{dx_k} \quad (10)$$

Corrector step

$$K_k = \widehat{P}_{(k+1/k)} H^T [H \widehat{P}_{(k/k+1)} H^T + R_k]^\wedge(-1). \quad (11)$$

$$\widehat{P}_{k/k} = [I - K_k H] \widehat{P}_{(k/k-1)} \quad (12)$$

$$\hat{x}_{k/k} = \hat{x}_{(k/k-1)} + K_k [y_k - H x_{(k/k-1)}] \quad (13)$$

P- Estimation error covariance.
Q- State noise covariance.
R- Measurement noise covariance.
Using the above equations, the rotor position and the motor speed can be estimated.

VI. SIMULATION MODEL AND RESULTS

A. Speed control of BLDC motor using Hall sensor signals

Simulation Model

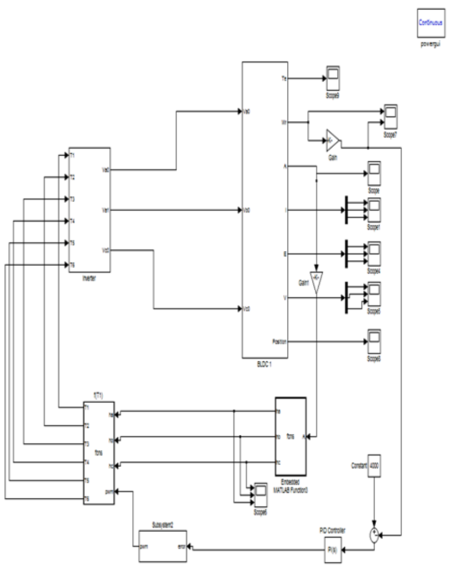

Fig.2 simulation model with Hall Sensor signals

Simulation results

Speed waveform

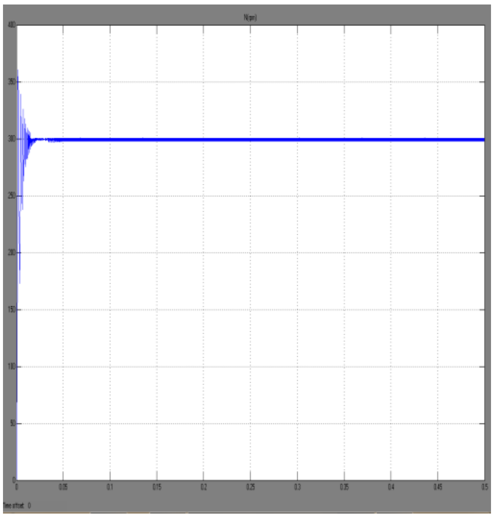

Fig. 3 Speed waveform

For a reference speed of 300rpm, the motor speed waveforms are obtained, and they are found to be close to the reference speed value.

Back emf waveform

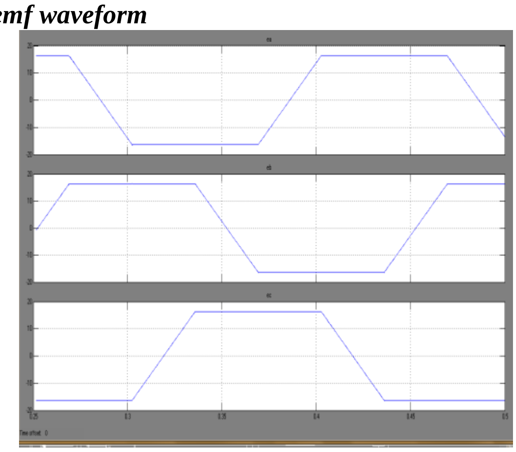

Fig.4 Waveforms for Back emf

The trapezoidal back emf waveforms are obtained. The emf waveforms obtained are phase shifted by 120 degrees.

Current waveform

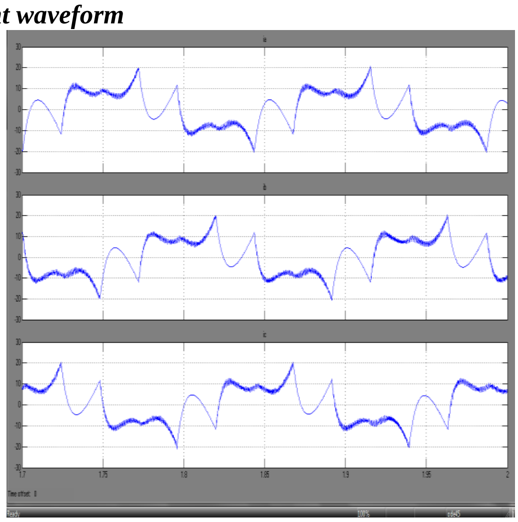

Fig.5 waveforms for current

The line current waveforms were obtained.

ISSN: 2277-3754
ISO 9001:2008 Certified
International Journal of Engineering and Innovative Technology (IJEIT)
Volume 3, Issue 1, July 2013

Voltage Waveform

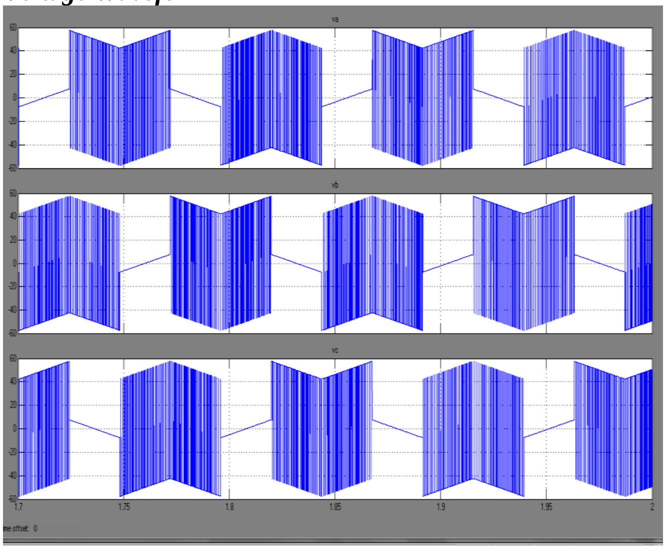

Fig.6 waveforms for terminal voltage

The terminal voltage waveforms were obtained.

Torque Waveform

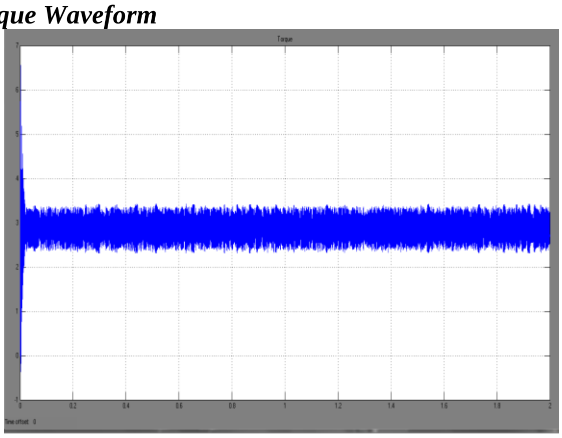

Fig.7 waveforms for torque developed

The load torque value used for simulation is 2Nm. The developed torque has an average value of around 2Nm.

B. Speed control of BLDC motor using Extended Kalman Filter Algorithm

Simulation model

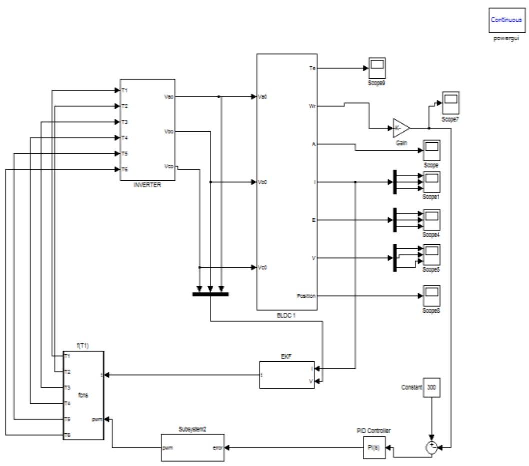

Fig.8 Simulation model with EKF Simulation results Speed waveform

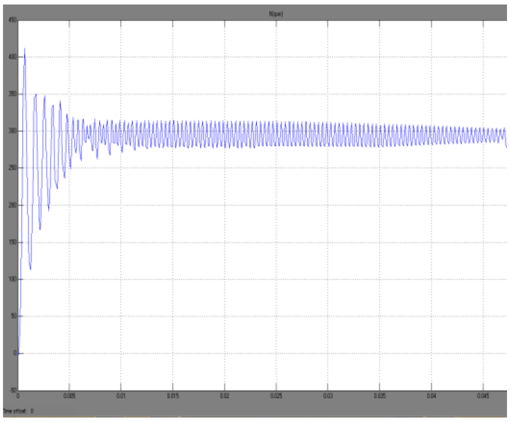

Fig.9 speed waveform

With Extended Kalman Filter the estimated motor speed was found close to the actual speed.

VII. CONCLUSION

The Permanent Magnet Brushless DC Motor (PMBLDC) are gaining popularity because of it's performance and reliability. Sensor based speed control techniques have widespread application but they have certain disadvantages like cost, size etc. So, nowadays the present focus is on sensor less techniques like the EKF. Advancement in power electronics and DSP based technologies present possibilities of improved control of BLDC motors. Also Application Specific Integrated Circuits (ASIC) offer low cost control of BLDC motors. In this paper, modeling of BLDC motor for speed control is done. The rotor position information is obtained using both, the Hall sensor signals and the Extended Kalman Filter Algorithm. The simulation results show that the speed control results obtained using the Extended Kalman Filter Algorithm is comparable to that obtained using the Hall sensor signals.

REFERENCES

[1] Bhim Singh and Sanjeev Singh," State of the Art on Permanent Magnet Brushless DC Motor Drives", Electrical Engineering Department, Indian Institute of Technology, Delhi, New Delhi, India.

[2] Paul P. Acarnley and John F. Watson, "Review of Position-Sensor less Operation of Brushless Permanent-Magnet Machines", IEEE Transactions on Industrial Electronics, Vol. 53, No. 2, April 2006.

[3] R.Krishnan,"Electric motor drives, model, analysis and control".

[4] Kentarou Hatakeyama, Shinsuke Nakano, Nobuyuki Kurita and Takeo Ishikawa," Accurate Estimation of Initial Rotor Position for Brushless DC Motor Position Sensor less Drive", Department of Electronic Engineering, Gunma University.

[5] TI Motor Control Compendium 2010.

[6] Bozo Terzic and Martin Jadric, "Design and Implementation of the Extended Kalman Filter for the Speed and Rotor Position Estimation of Brushless DC Motor", IEEE Transactions On Industrial Electronics, Vol. 48, No. 6, December 2001.

[7] Rached Dhaouadi, Ned Mohan , Lars Dorum, "Design and implementation of an Extended Kalman Filter for the State Estimation of a Permanent Magnet Synchronous Motor", IEEE Transactions on Power Electronics, Vol. 6, No.3, 3 July 1991.

[8] A. Tashakori, M. Ektesabi, "Comparison of Different PWM Switching Modes of BLDC Motor as Drive Train of Electric Vehicles", World Academy of Science, Engineering and Technology 67 2012

[9] P. Damodharan and Krishna Vasudevan, "Sensor less Brushless DC Motor Drive Based on the Zero-Crossing Detection of Back Electromotive Force (EMF) From the Line Voltage Difference", IEEE Transactions On Energy Conversion, Vol. 25, No. 3, September 2010.

AUTHOR BIOGRAPHY

Joyce Jacob is from India. She did her B.tech in Electrical and Electronics Engineering from the Mahatma Gandhi University, Kottayam. Currently, she is doing her M.tech in Power Electronics and Power System at FISAT, Angamaly under the affiliation of Mahatma Gandhi University, Kottayam.

Surya Susan Alex is from India. She did her B.tech and M.tech from the Calicut University. She is pursuing her Ph.D from the Cochin University of Science And Technology. Currently, she is working as Assistant Professor in the EEE Dept. at FISAT, Angamaly, Kerala.

Dr. Asha Elizabeth Daniel is from India. She completed her Ph.D from IIT, Bombay. Currently, she is working as Associate Professor in the Division of Electrical Engineering, SOE, CUSAT, Kerala.