Sensor Less Speed Control of Brushless DC motor using Back EMF Observer

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Abstract— In this paper Back EMF Observer is presented in order to estimate the phase-to-phase trapezoidal back-EMF in a Brushless DC (BLDC) motor by using only the measurements of the stator voltages and Currents. This estimated back-EMF was then used to deduce the rotor speed of the motor. In this proposed method consist of two loops, one is outer speed loop and another is inner current control loop, which is Hysteresis current controller (HCC), the effectiveness of the proposed method is demonstrated through MATLAB/SIMULINK simulations results.

Key words: Brushless DC (BLDC) motor, Hysteresis current controller (HCC), Back EMF Observer

I. Introduction

In recent years, BLDC motors, also called Permanent Magnet DC Synchronous motors .These motors are one of the motor types that have more rapidly gained popularity, mainly because due to their high efficiency, silent operation, high power density, reliability and low maintenance. A BLDC motor is an inside out brushed DC motor with mechanical commutator replaced by an electronic switching converters called electronic commutator. Usually, three Hall-effect sensors are employed as position sensors to perform current commutations. In order to obtain quasi-square current waveforms, with dead time periods of 60 degree.so the knowledge the six rotor positions is required. The main drawback of using this Hall Effect sensor is increases cost, mounting of rotor position sensors and sensitive to high temperature so, it has motivated to research in the area of position Sensorless BLDC motor drives. With these Sensorless approach, position sensors will be eliminated, cost of the system also tend to be reduce and the overall system reliability will increase.

As a result, in recent years a great attention has been given to Sensorless control of BLDC motor, that is, control the BLDC motor without using the position sensors.so in proposed literature the number of methods are surveyed toobtain or estimate the rotor positions and speed of BLDC motors. Various methods with variety of strategies, such as includes back-EMF voltage sensing from non-energized coils, detection of the freewheeling diodes conduction, back-EMF integration and flux estimation [1,2,3] to know the rotor position. However, the above mentioned strategies work well only over a limited range of speed.so for wide range of speed observer based control method are to be used, such Extended Kalman filter(EKF) can be used to estimate the instantaneous rotor position and speed of the BLDC motor[4,5]. But drawback is that, the speed estimation accuracy is mostly reduced, especially at low speeds and it is computationally tedious to implement and is sensitive to the influence of noise. In this paper, Back EMF Observer is proposed to estimate the trapezoidal back-EMF from non-energized coils of a BLDC motor [6,7,8]. The estimated back-EMF is in turn used to deduce the rotor position and speed of the motor.

The outline of the paper is as follows. In the section 2, the model of BLDC motor is developed on the basis of which a back EMF observer of the phase-to-phase trapezoidal back-EMF is constructed. In Section 3, Hysteresis current controller is presented. In Section 4, explained about commutation signal obtain from phase to phase back-EMF from observer, to switch hall sensor decoder, which will helps in deduce reference current for HCC to generate switching gate pulse and also explained the approach to obtain the speed from the estimated phase-to-phase back-EMF is presented. In Sections 5 and 6 are includes the simulation results. Finally, some conclusions are drawn on the overall design and the results obtained.

II. BLDC motor model

In BLDC motors, two phase conduction takes place so the third phase remain off at any point of time, generally neutral point of stator winding of motor is floating and is not accessible. This often makes it impossible todirectly measure phase voltages.

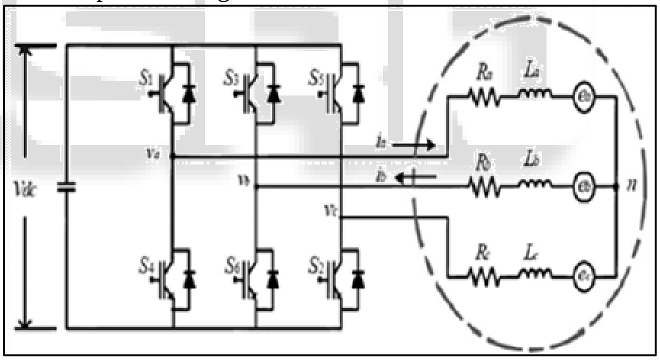


Fig. 1: Equivalent circuit of BLDC motor drive with inverter

So the BLDC motor can be modelled in stator (abc)-reference frame using the following equations considering that the phase voltages are balanced:

$$\begin{aligned}\frac{d(I_a - I_b)}{dt} &= -\frac{R}{L}(I_a - I_b) - \frac{1}{L}E_{ab} + \frac{1}{L}V_{ab}\\ \frac{d(I_b - I_c)}{dt} &= -\frac{R}{L}(I_b - I_c) - \frac{1}{L}E_{bc} + \frac{1}{L}V_{bc}\\ \frac{d(I_c - I_a)}{dt} &= -\frac{R}{L}(I_c - I_a) - \frac{1}{L}E_{ca} + \frac{1}{L}V_{ca}\end{aligned} \quad (1)$$

Where R and L are the resistance and inductance of the BLDC motor, respectively (Vab, Vbc, Vca) are line voltages of the inverter, (Eab, Ebc, Eca) are the line back EMF and (Ia, Ib, Ic) are the phase currents.

III. Design of the proposed back EMF observer for BLDC motor

Now the system shown in Eq. (1) depends mainly upon the line currents and line voltages. Then Eq. (1) is transformed into back EMF observer equations, therefore now its takes the following form as shown in Eq. (2) below;

The following Back emf observer generate phase to phase back emf (Eab, Ebc, Eca) using Eq. (2) and from such back emf will help to deduce speed and commutation signal.

$$\frac{d\hat{x}_1}{dt} = -\frac{R}{L}\hat{x}_1 - \frac{1}{L}\hat{E}_{ab} + \frac{1}{L}V_{ab} + K_{11}(\tilde{i}_{ab}),$$

$$\frac{d\hat{x}_2}{dt} = -\frac{R}{L}\hat{x}_2 - \frac{1}{L}\hat{E}_{bc} + \frac{1}{L}V_{bc} + K_{22}(\tilde{i}_{bc}),$$

$$\frac{d\hat{x}_3}{dt} = -\frac{R}{L}\hat{x}_3 - \frac{1}{L}\hat{E}_{ca} + \frac{1}{L}V_{ca} + K_{33}(\tilde{i}_{ca}),$$

$$\frac{d\hat{E}_{ab}}{dt} = K_{31}(\tilde{i}_{ab}), \quad (2)$$

$$\frac{d\hat{E}_{bc}}{dt} = K_{42}(\tilde{i}_{bc}),$$

$$\frac{d\hat{E}_{ca}}{dt} = K_{53}(\tilde{i}_{ca}),$$

Where x_1 is the line current difference between phases a and b; x_2 is the line current difference between phases b and c; x_3 is the line current difference between phases c and a; symbol "^" means estimated value; K_{11}, K_{22}areK_{33} the line current observer gains; K_{31}, $K_{42}$and K_{53} are the back EMF observer gains.

In order to ensure the convergence of the observer, proper gain value is to be selected, the gains should satisfy the following conditions,

$$K_{11} > \frac{1}{L}|E_{ab}|_{max} \text{ and } K_{22} > \frac{1}{L}|E_{bc}|_{max}$$

$$\frac{K_{31}}{K_{11}} < 0 \text{ and } \frac{K_{42}}{K_{22}} < 0$$

Here $K_{S1}= K_{11}= K_{22}=K_{33}$ and $K_{S2}= K_{31}= K_{42}=K_{53}$.

IV. HYSTERESIS CURRENT CONTROLLER

The basic implementation of hysteresis control is based on deriving the switching signals from the comparison of the current error with a fixed tolerance band. This control is based on the comparison of the actual phase current with the tolerance band around the reference current associated with that phase.

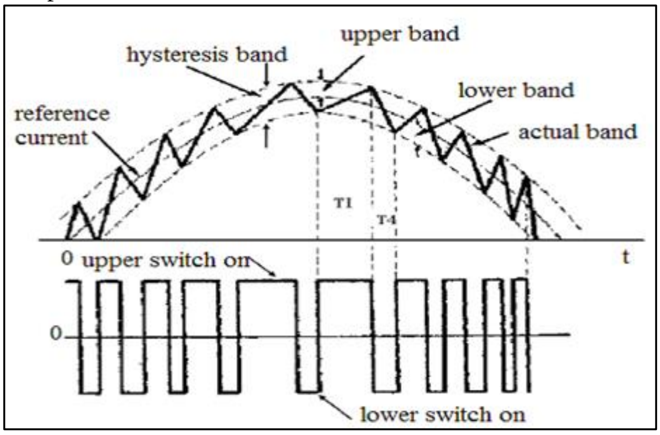


Fig. 2: Hysteresis Band Current Control scheme

The switching logic is performed as

– If I_a< (I_a*-HB) upper switch is OFF and lower switch is ON in leg "a" of three phase inverter.
– If I_a> (I_a*-HB) upper switch is ON and lower switch is OFF in leg "a" of three phase inverter.

Similarly, the switches of legs "b" and "c" are be activated. Here, Hysteresis band(HB) is denoted as the width of the hysteresis band around which the reference currents. In this manner, respective reference values of the supply currents are regulated within the hysteresis band.

V. HALL SENSOR DECODING AND SENSOR LESS SPEED ESTIMATION

Mostly in sensor type control Hall sensor are used, whose commutation signals are needed to decode to generate gate pulse for switching the three phase inverter switches to run the BLDC motor . But in this paper Sensorless approach is used.so hall sensors are eliminated, now here the commutation signal are obtained from angle generate from speed and following speed is deduce from phase to phase back emf ,which is generated from back emf observer. Here, decoded signal used for generating reference current for comparison in HCC for generating gate pulse. The following table is given the relation between hall sensor signal and back emf Table (1) And phase to phase emf relation with switching status is switches of inverter given in Table (2) below

Ha	Hb	Hc	Emf_A	Emf_B	Emf_c
0	0	0	0	0	0
0	0	1	0	-1	+1
0	1	0	-1	+1	0
0	1	1	-1	0	+1
1	0	0	+1	0	-1
1	0	1	+1	-1	0
1	1	0	0	+1	-1
1	1	1	0	-1	+1

Table 1: Truth Table of relationship between hall sensor signal and back emf

E_{ac}	E_{ba}	E_{cb}	S_1	S_2	S_3	S_4	S_5	S_6
0	0	0	0	0	0	0	0	0
1	-1	1	1	0	0	0	0	1
1	-1	-1	1	1	0	0	0	0
1	1	-1	0	1	1	0	0	0
-1	1	-1	0	0	1	1	0	0
-1	1	1	0	0	0	1	1	0
-1	-1	1	0	0	0	0	1	1
0	0	0	0	0	0	0	0	0

Table 2: Truth Table of relationship between phase to phase back emf and switching status switches of inverter

The Commutation signal (Sa, Sb, Sc) is obtained from the angle (θ) generated from speed ($\acute{\omega}_m$) by following equation (3) given below such as;

$$\omega_m = \frac{d\theta}{dt}, \quad (3)$$

$$\theta = \int \omega_m dt$$

Now the following angle (θ) is used to deduce commutation signal (Sa, Sb, Sc) used following Table (3) given below;

Angle(θ)	Sa	Sb	Sc
(0-60)	1	0	1

(60-120)	1	0	0
(120-180)	1	1	0
(180-240)	0	1	0
(240-300)	0	1	1
(300-360)	0	0	1

Table 3: Commutation signal

Now the Sensorless speed estimation is done from phase to phase back emf signal obtained from back emf observer using following equation(4) given below,

$$\omega_m = \frac{E_{max(phase-to-phase)}}{(2 * p * \lambda)} \quad (4)$$

Where Emax is the amplitude of phase-to-phaseback-EMFs, p is number of pole of motor, λ is flux linkage establish by magnets (V.s).

VI. SIMULATION RESULTS

The overall block diagram of the proposed Sensorless speed control of BLDC motor shown in figure 5.1 below;

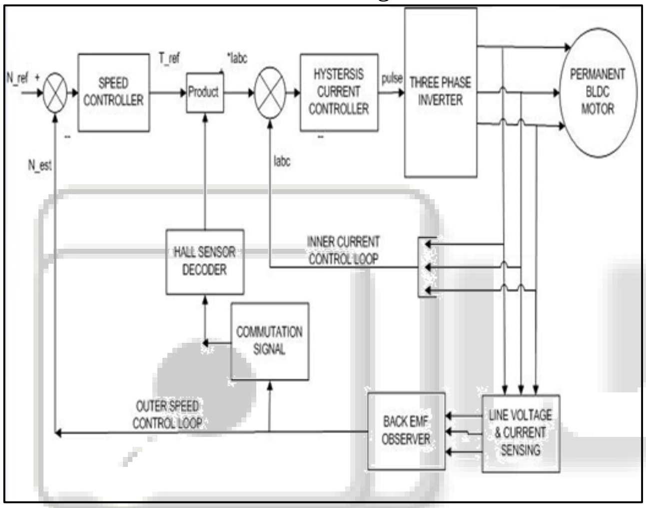


Fig. 3: Overall block Diagram of Sensorless speed control of BLDC motor using back EMF Observer

In this section the simulation analysis of Sensorless speed of BLDC motor is done by comparing estimated speed with motor speed. In this back emf observer is used to estimate Sensorless speed motor. The developed model of Sensorless speed control of BLDC motor in MATLAB/SIMULINK environment is shown in Fig. 5.2

Parameters of brushless dc motor used in simulation are listed in Table (4) and parameter of back emf observer is listed in Table (5) The Sampling interval is 2 micro seconds

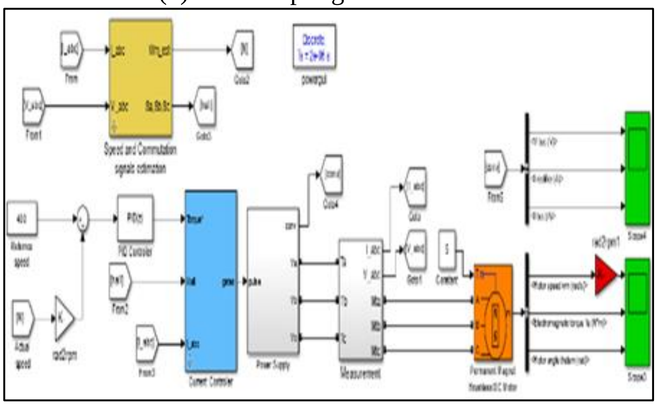


Fig. 3: Simulink model of Sensor less speed control of BLDC motor

Parameter	Value	Units
Power rating	3	HP
Terminal Voltage	310	V
Phase Resistance	0.2	ohm
Phase Inductance	8.5	mH
Back-EMF constant	1.4	V/(rad/sec)
Moment of inertia	0.089	$Kg.m^2$
Frictional co-efficient	0.005	N.m.s
Flux linkage established by magnets	0.175	V.s
Pole Numbers	4	-

Table 4: Parameters of brushless dc motor

Parameter	Value
Current Observer Gain(Ks1)	3000
Back EMF Observer gain(Ks2)	-49500

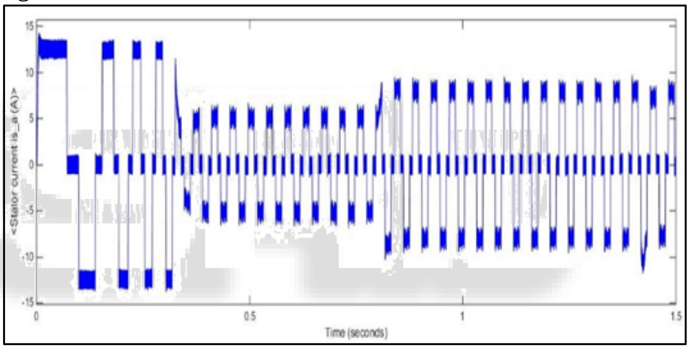
Table 5: Parameters of Back EMF Observer

Here simulation is done under two condition such as;

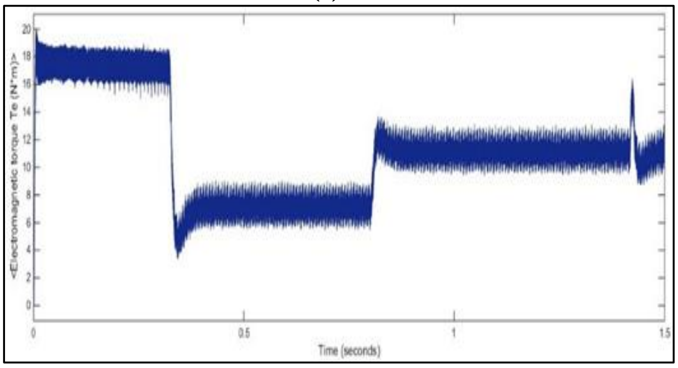
- Constant Speed and Varying Load Torque Condition.
- Varying Speed and Constant Load Torque Condition

A. Constant Speed and Varying Load Torque Condition

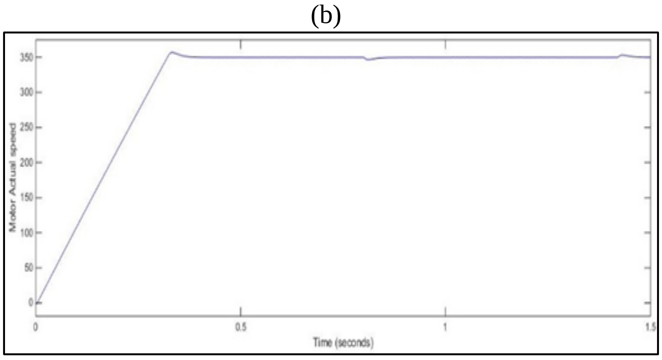
Under this condition Reference speed is kept constant at 350 rpm and varying the load torque, i.e. at initially load torque is kept at 7 Nm and at t=0.8,load torque of 11 Nm is applied. Both actual and estimated speed is analysed as shown in figure 5.3 below



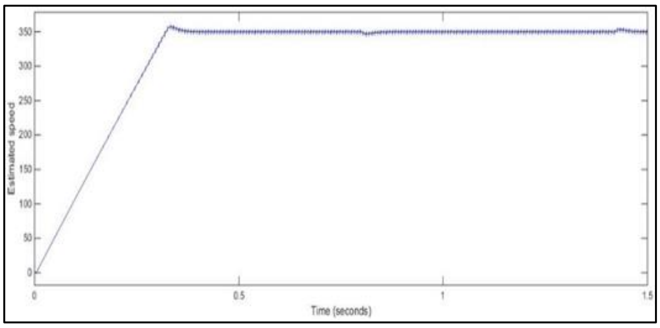
(a)



(b)



(c)

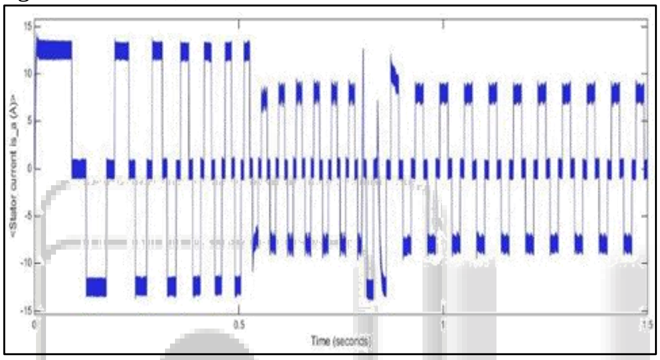


(d)

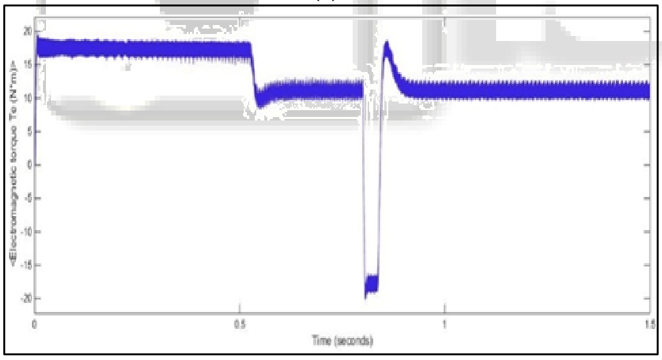
Fig. 4: (a) stator current, (b) electromagnetic torque, (b) motor actual speed, and (d) estimated speed

B. Varying Speed and Constant Load Torque Condition

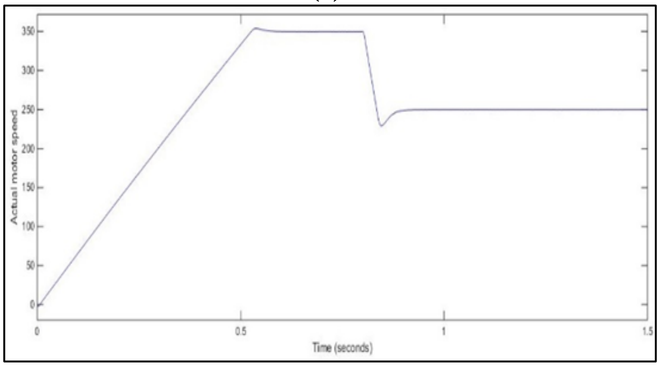
Under this condition load torque is kept constant at 11 Nm and varying the Reference speed, i.e. at initially speed is is kept at 350 rpm and at t=0.8, speed of 250 rpm is applied. Both actual and estimated speed is analysed as shown in figure 5.4 below;



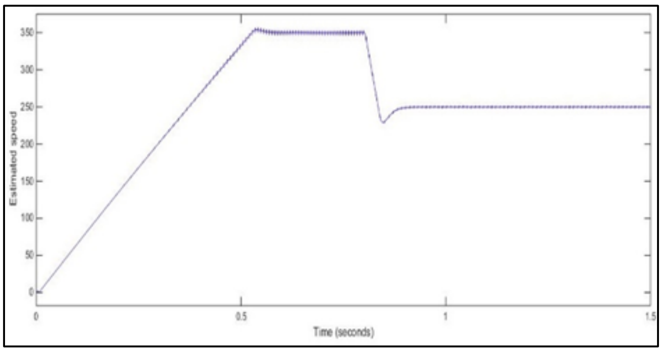
(a)



(b)



(c)



(d)

Fig. 6: (a) stator current,(b) electromagnetic torque, (b) motor actual speed, and (d) estimated speed.

As shown in Fig. 5.3 and Fig. 5.4,the simulation results for Sensorless speed estimated using back emf observer and motor actual speed, from results it is seen that speed obtain from observer and motor is nearly same and simulation is verified at different condition.

VII. CONCLUSION

A Sensorless speed control system for BLDC motor based on Back EMF Observer is implemented in this paper. The speed of the BLDC motor is estimated from the phase-to-phase back EMF. The resultsobtained by simulation show the effectiveness of the method.

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