SENSORLESS CONTROL OF BLDC MOTOR USING BACKEMF BASED DETECTION METHOD

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ABSTRACT

Brushless dc motors have been widely used in industrial automation and consumer appliances because of their higher efficiency and power density. BLDC motor has permanent magnets in rotor assembly to generate steady state magnetic field, due to this it is advantageous compared to induction motors. This paper presents the implementation of sensor less control of three-phase brushless DC motor. A sensor less control using back emf based method has been implemented for BLDC drive system. The performance of the sensor less control of BLDC drive is compared with conventional sensored control system and the results are discussed. MATLAB software is used for implementation of the circuit model and the results are verified.

Keywords: Brushless Dc Motor, Back Electro Motive Force

I INTRODUCTION

BLDC motors, also called Permanent Magnet DC Synchronous motors, are one of the motor types that have more rapidly gained popularity, mainly because of their better characteristics and performance. These motors are used in a great amount of industrial sectors because their architecture is suitable for any safety critical applications. BLDC drives are preferred because of less complexity in control as compared with field oriented control of induction motor drives. Brushless dc motors, with their trapezoidal electromotive force profile, requires six discrete rotor position information for the inverter operation. BLDC motors are commutated in six-step pattern with commutation controlled by position sensors. If any sensor is used to detect rotor position, then the sensed information must be transferred to a control. Additional connections to the motor are required which increases the complexity of the drive system, hence, sensor less drive is preferred [1-4].

This paper provides a sensor less methods for controlling Brushless Direct Current (BLDC) motor drives. The performance and reliability of BLDC motor drivers have been improved because the conventional control and sensing techniques have been improved through sensor less technology. The sensor less control implemented in this paper, is based on detection of back electromotive force (back EMF) zero crossing from the terminal voltages. The effectiveness of the proposed method is demonstrated through simulation results.

II MATHEMATICAL MODEL OF BLDC MOTOR

Brushless DC motor produces a trapezoidal shape back-EMF, and excited motor current waveform is preferably rectangular-shaped. The stator winding resistances are assumed to be equal. The self inductance and mutual inductances are constant. The rotor-induced currents are neglected. The three phase voltage equation for BLDC can be expressed as in equation (1) [5-8].

$$\begin{bmatrix} v_{an} \\ v_{bn} \\ v_{cn} \end{bmatrix} = \begin{bmatrix} R_s & 0 & 0 \\ 0 & R_s & 0 \\ 0 & 0 & R_s \end{bmatrix} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} + \begin{bmatrix} L_s - M & 0 & 0 \\ 0 & L_s - M & 0 \\ 0 & 0 & L_s - M \end{bmatrix} \frac{d}{dt} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} + \begin{bmatrix} e_a \\ e_b \\ e_c \end{bmatrix} \quad (1)$$

Where
R_s: phase resistance,
v_{an}, v_{bn}, v_{cn} : phase voltages,
L_s : self-inductance,
i_a, i_b, i_c : phase currents,
M : mutual inductance,
e_a, e_b, e_c : phase back-EMFs.

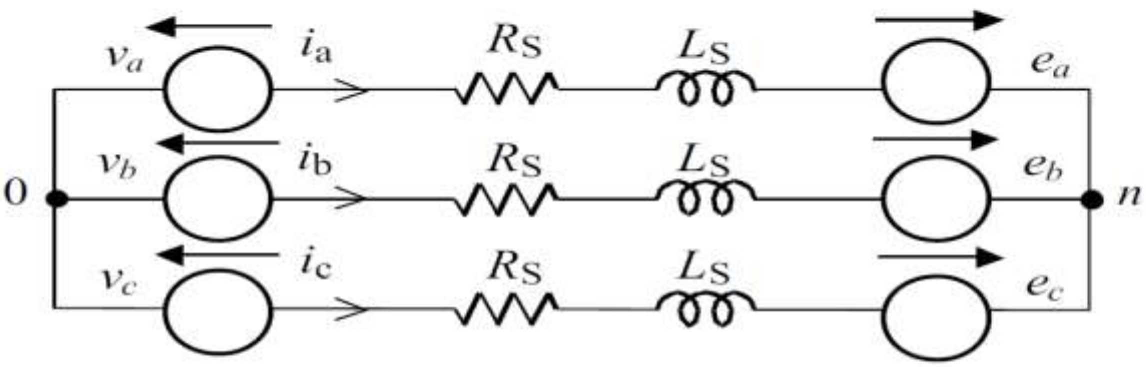

Figure. 1: The equivalent circuit for the BLDC motor.

The equivalent circuit for the BLDC motor is shown in Figure. 1. Due to the interaction of the stator current and the magnetic field from rotor, the electromagnetic torque of BLDC motor is produced as follows

$$T_e = \frac{e_a i_a + e_b i_b + e_c i_a}{\omega_m} \quad (2)$$

Where ω_m is the mechanical speed of the rotor. The motor equation of motion is given by

$$\frac{d\omega_m}{dt} = \frac{T_e - T_L - B_{\omega_m}}{J} \quad (3)$$

Where
T_L : load torque,
B : damping constant,
J : moment of inertia of rotor shaft and load.

For six-step motor control, at each step the instantaneous output power will be delivered from two phase winding connected in series, and the equation is given by

$$P_O = \omega_m . T_e = 2EI \qquad (4)$$

Where I is the current amplitude and E is the induced back-EMF. From equations (2) and (4), the output torque can also be expressed as

$$T_e = 2k\phi I = 2k_t \mathrm{I} \qquad (5)$$

Where k_t is the motor torque constant.

III SENSOR LESS CONTROL OF BRUSHLESS DC MOTOR

Brushless DC motor has a permanent magnet rotor and a wound field stator which is connected to a power electronic switching circuit. The brushless DC motor drive system is based on the rotor position, and it is obtained at fixed points typically every 60 electrical degrees for six-step commutations of the phase currents. The permanent magnets produce an air gap flux density distribution that is of trapezoidal shape waveform, and result in trapezoidal back-EMF waveforms.

Brushless DC motors use electric switches to realize current commutation, and thus continuously rotate the motor. These electric switches are usually connected in a three-phase bridge structure for a three-phase BLDC motor. There are two types of control technique for using BLDC drive system. They are sensored and sensor less control but this paper insists on a sensor less control technique. [8- 11]

Position sensor less control

Voltage or current signals of the motor, which are easily acquired, are processed with an appropriate method to get the rotor position signals in the position sensor less control method, which is also called the indirect rotor-position-detection method. Position sensors may increase the volume of the system. Under certain conditions, such as high temperature and high pressure, position sensor work with poor sensitivity so that the system operates with low reliability. A brushless DC drive that does not require position sensors but only electrical measurements is called a sensor less drive.

Among the sensor less control methods discussed in the literature [12-15], the back EMF based method is the most mature and widely used one at present. A sensor less control strategy for BLDC motor drives using single voltage sensor is proposed and these sensor extract rotor position information from motor terminal voltages.

The proposed sensor less BLDC drive, is based on detection of back EMF zero crossing from the terminal voltages, For typical operation of a BLDC motor, the phase current and back-EMF should be aligned to generate constant torque. The current commutation point shown in can be estimated by the zero crossing point (ZCP) of back-EMFs and a 30° phase shift, using a six-step commutation scheme through a three-phase inverter for driving the BLDC motor. The conducting interval for each phase is 120 electrical degrees. Therefore, only two phases conduct current at any time, leaving the third phase floating. In order to produce maximum torque, the inverter should be commutated every 60° by detecting zero crossing of back-EMF on the floating coil of the motor, so that current is in phase with the back-EMF.

This technique of delaying 30° electrical degrees from zero crossing instant of the back-EMF is not affected much by speed changes. To detect the zero crossing points, the phase back-EMF should be monitored during the silent phase, when the particular phase current is zero and the terminal voltages should be low-pass filtered first. Three low-pass filters are utilized to eliminate higher harmonics in the phase terminal voltages caused by the inverter switching. The time delay of low pass filter will limit the high speed operation capability of the BLDC machine. It's necessary to point out the importance of filters when a BLDC motor drive is designed, which are used to eliminate high frequency components of the terminal voltages and to extract back-EMF of the motor.

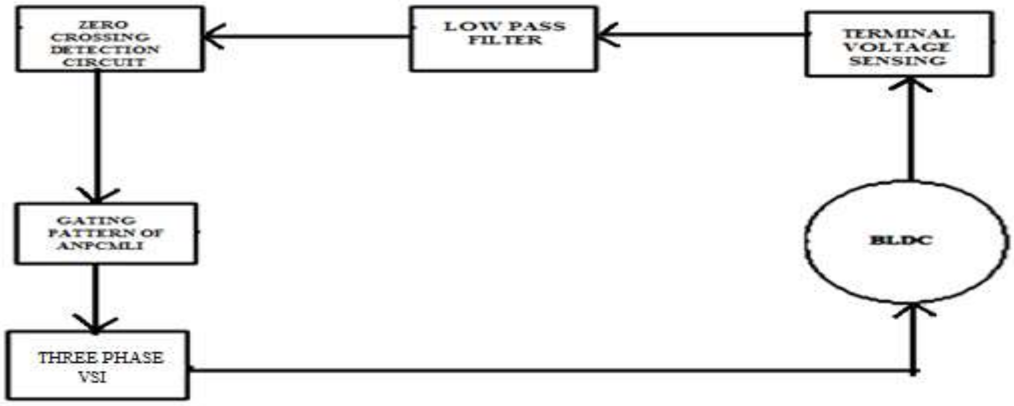

Figure.2: Three phase BLDC motor drive with position sensor less control technique

In this method, the zero crossing points of back EMF are detected and made 30 degree electrical angle lag to get six discrete rotor position signals in each electrical cycle, from which commutation information is obtained by the logical switch circuit, and then the sensor less operation is implemented. Considering a BLDC motor with three stator phase windings connected in star, the motor is driven by a three-phase voltage source inverter in which the switches are triggered with respect to the rotor position. The block diagram is shown in Fig.2.The relationship between zero crossing points of the back EMF and the commutation instants is shown as Fig. 3.

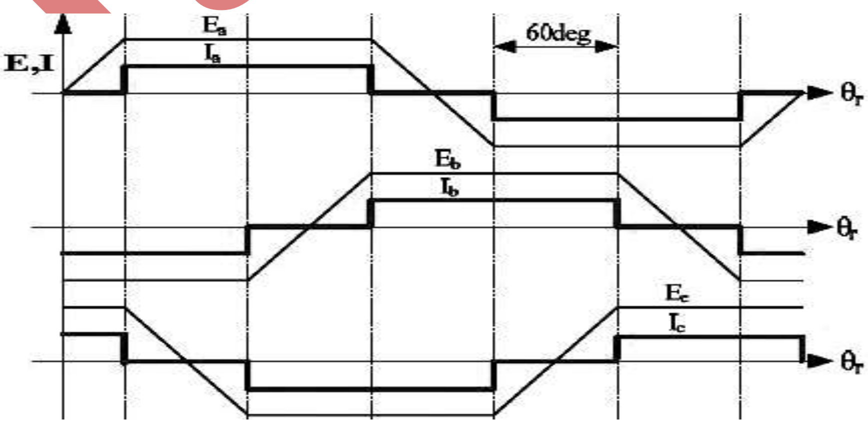

Figure.3: BLDC motor drive along with typical phase current and Back Emf signal.

IV SIMULATION RESULTS

The Simulink model of the sensor less control three phase BLDC motor is shown in Figure.4. Table 1 shows simulation parameter for three phase BLDC drive.

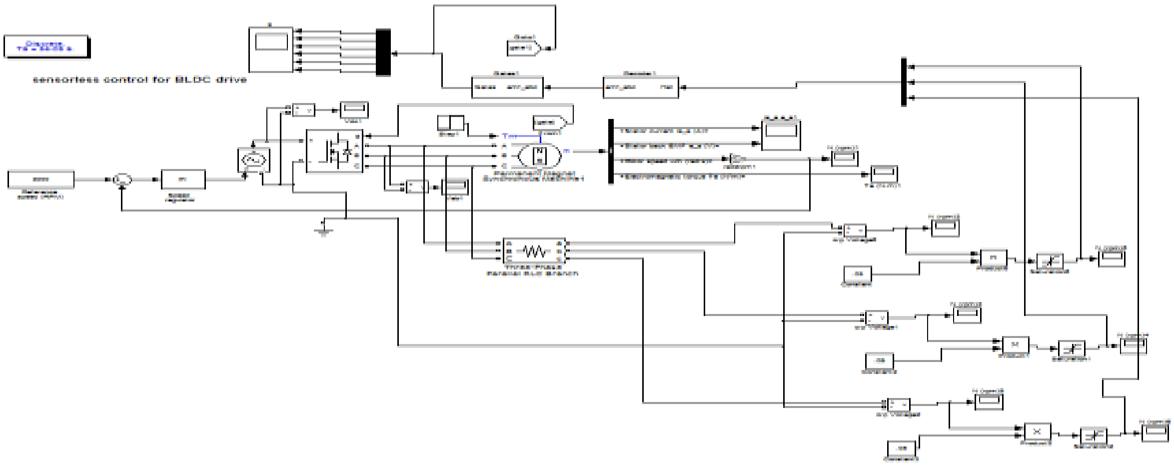

Figure.4: Simulink model of the sensor less control three phase BLDC drive

TABLE 1

Simulation parameters Three phase BLDC drive

Simulation parameters	**Values**
Three phase inverter	V_{in} = 60V
BLDC	P= 1KW, V= 36V, N=3000 rpm, T = 1.4 N/m

The simulated results (rotor speed, electromagnetic torque, stator current and back EMF) of brushless DC motor are shown in Figures [5-8] respectively.

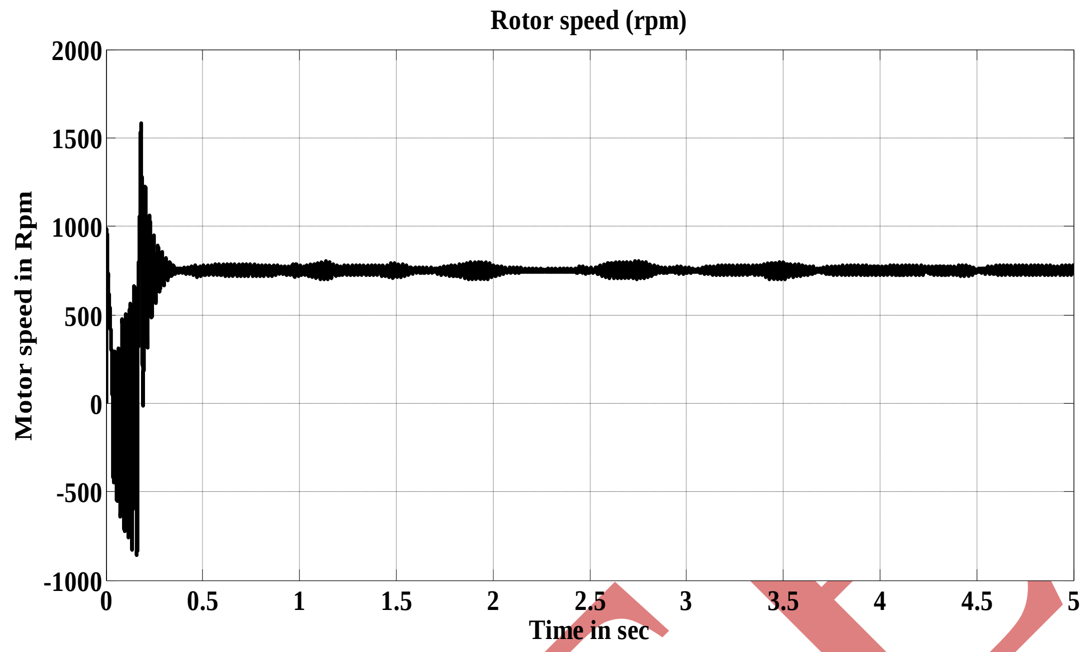

Figure.5: Rotor speed for three phase BLDC drive.

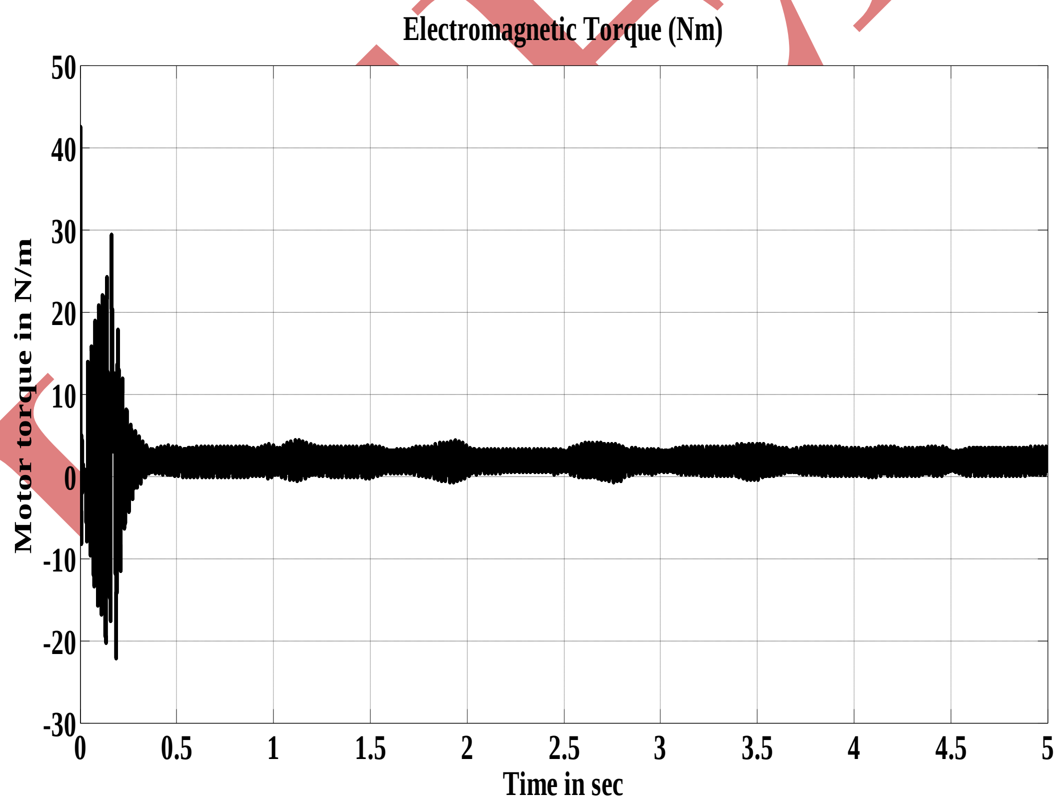

Figure.6: Motor torque for three phase BLDC drive.

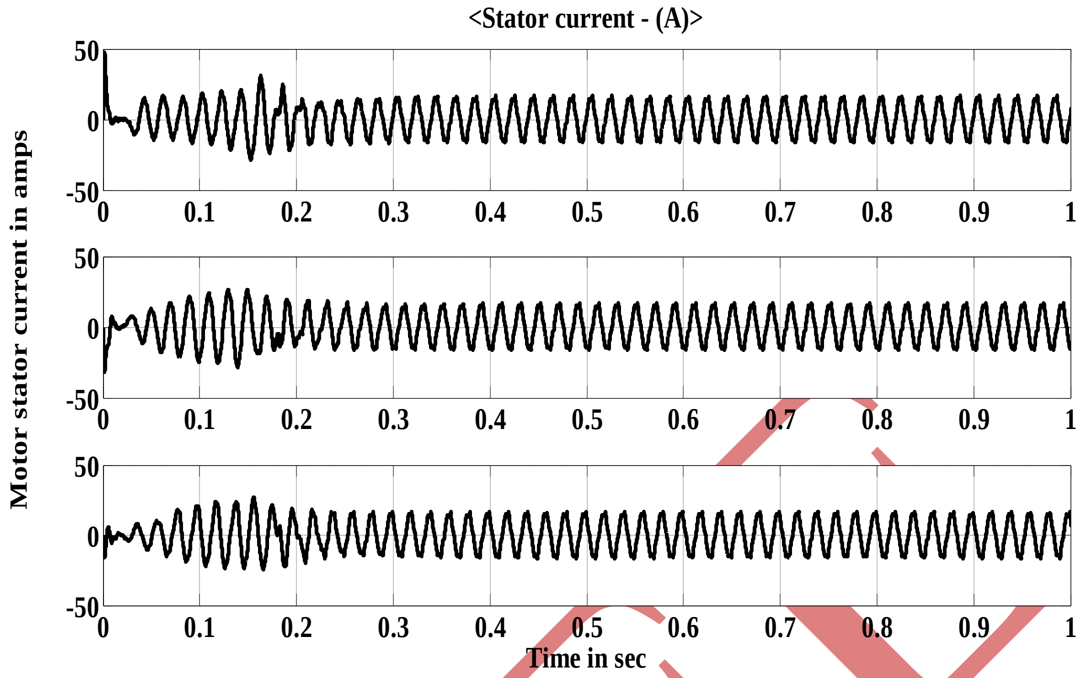

Figure.7: Stator current for three phase BLDC drive.

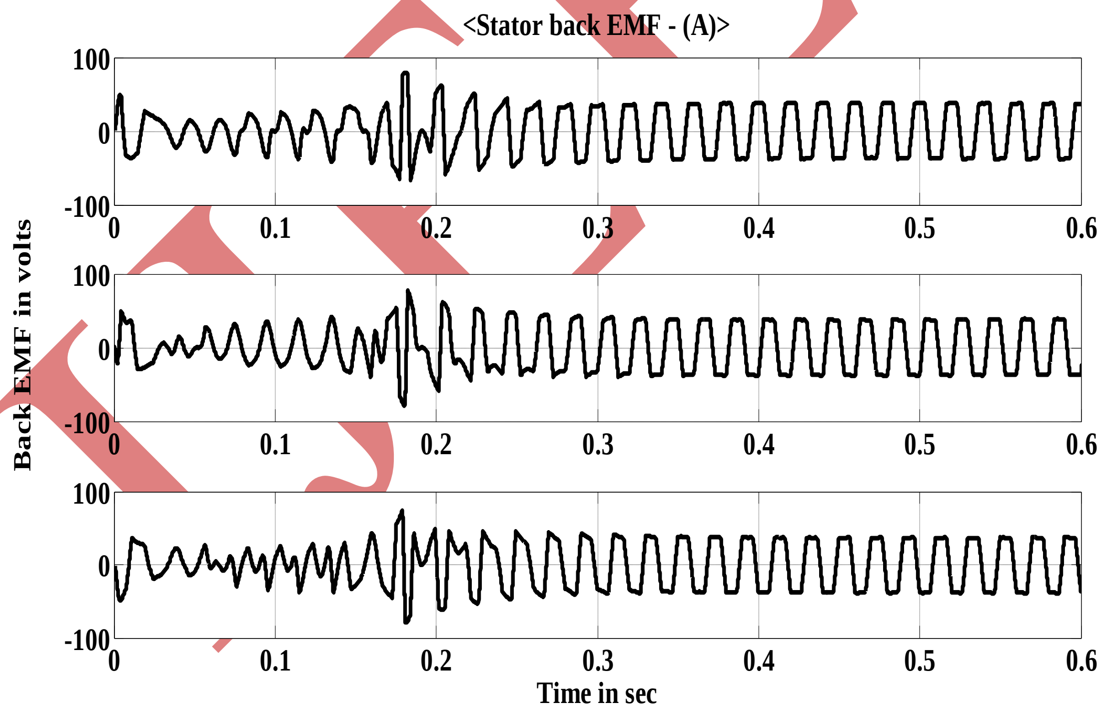

Figure.8: Back EMF for three phase BLDC drive.

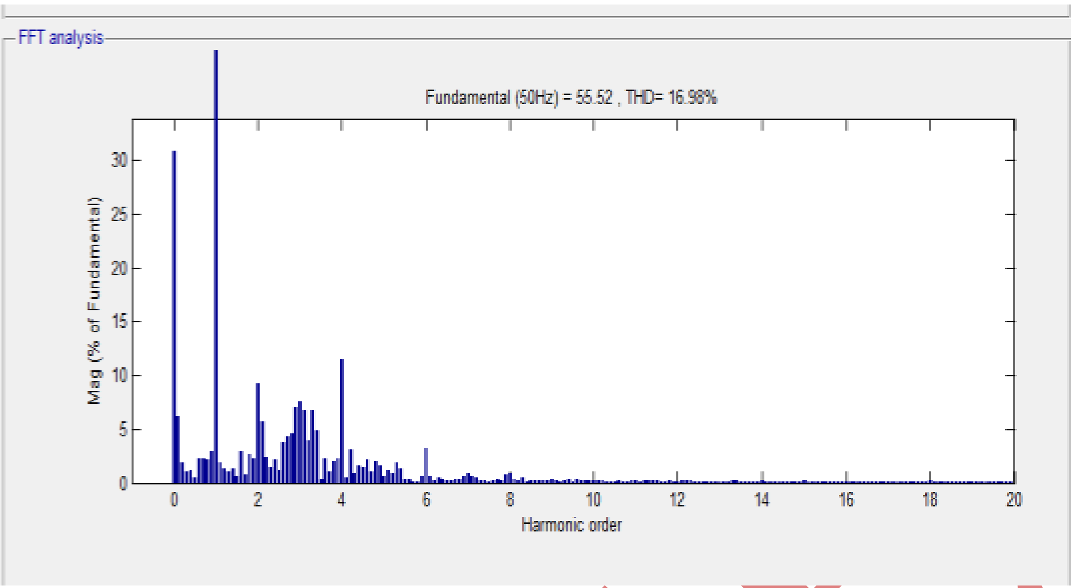

Figure.9: Stator current T.H.D for three phase BLDC drive

Figures 5 & 6 show that the BLDC motor speed is settled at 800 rpm and the BLDC motor torque is about 5 N/m. Figures 7 & 8 show that the BLDC motor stator current is about 15 Amps and the BLDC motor back emf voltage is about 40 Volts.Figure.9 shows that the stator current T.H.D of three phase BLDC drive which is about 16.98%.

V CONCLUSION

A proposed sensor less technique to detect back EMF zero crossings for a BLDC motor using the terminal voltages is proposed and the motor terminal voltage sensed to estimate the rotor position and then operate the BLDC drive. In this method, the zero crossing points of back EMF are detected and made 30 degree electrical angle lag to get six discrete rotor position signals in each electrical cycle, from which commutation information is obtained by the logical switch circuit, and then the sensor less operation is implemented. Considering a BLDC motor with three stator phase windings connected in star, the motor is driven by a three-phase voltage source inverter in which the switches are triggered with respect to the rotor position. Therefore, the performance and reliability of BLDC motor drivers have been improved because the conventional control sensing techniques have been improved through sensor less technology.

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