CHAPTER 6

SL-QZS INVERTER FED BLDC MOTOR USING IFOC AND BACK EMF ESTIMATION METHOD

The previous chapter is discussed about reducing multiple power conversion system of PV fed BLDC motor drives and extracting high power from such system with improved control performance of BLDC motor. In general vector control schemes use three voltage and current sensors to implement the controller for any motors, voltage and current sensors are necessary for any vector control algorithm. Hence speed or position sensor in any vector controlled drive increases cost of the drive system and also increases the overall size of the drive. Speed or position sensors increases complexity in construction of the motor, and vibrations occur in motors due to poor control techniques. Therefore, the installed speed or position sensor do not give accurate results, and extra electronic circuits are required for compensating noises in speed sensor output caused due to vibration. Jiang, D et al., 2011 presented a speed sensor less approach is made for control of BLDC motor where speed is estimated using an algorithm. Kumar, R., Singh, B 2014 introduced the BLDC motor is driven from a switched inductor quasi Z-source inverter fed from a PV source, and a simplified IFOC control scheme is applied to enhance motors performance over previous approaches. Speed estimation algorithm involving a back EMF observer and then calculating the speed of BLDC motor based on the relation between back EMF and speed. The estimated speed is same as speed measured using a sensor, and this method has negligible settling time, gives accurate results even for varying load conditions. To match the current characteristics of given BLDC motor rotor angle is obtained from estimated speed at any instant of time and hall position signals are estimated with rotor angle value. Then commutation signals are obtained using the conventional hysteresis single band current controller. In this control technique by estimating hall signals back EMF wave shape tends to be trapezoidal whereas sinusoidal, Space vector PWM methods do not originate trapezoidal back EMF. The conventional pi controller acts as an excellent speed regulator and creates reference torque for IFOC scheme. This ensures accurate control over torque developed by BLDC motor and hysteresis current controller generates switching pulses in the frequency range under nominal frequency. Thus torque ripples occurring due to high switching frequencies and inappropriate control technique is minimized.

6.1 Overall structure of sensor less BLDC control using back EMF observer

The goal of the proposed sensor less control technique is to mitigate the factors affecting the motors performance, maintaining efficiency and minimizing ripples occurred in torque. J. E. Muralidhar and P. V. Aranasi 2014 introduced every sensor less algorithm speed estimation is the initial task, there are various algorithms available to estimate the speed of BLDC motor which depends on the motor mathematical model. Kim et al., 2008 has explained control scheme back EMF observer method is used which estimates the back EMF of the motor by using the mathematical model of BLDC motor and the maxima of back EMF is obtained. Then by utilizing the maximum back EMF value, electrical speed of the motor can be estimated using the relationship between flux linkages constant. Then mechanical or actual rotor speed of the motor can be obtained from the relation between a number of pole pairs and electrical speed. In the proposed scheme solar module is modeled as a conventional single diode equivalent circuit. This model is simple and is efficient as compared to two diode structures. Then incremental conductance MPPT technique varies the amplitude of reference current generated from IFOC scheme. In this control system simplified IFOC is used because conventional IFOC regulates both torque and flux linkages associated with BLDC motor is explained by. S. Park and K. D. Lee 2017. But in this method, only torque is regulated, and the number of pi controllers used in conventional IFOC scheme is decreased. This makes the proposed control technique much simpler because tuning process of multiple pi controllers is a difficult task. The Pi controller generates the reference torque of the motor based on the error between reference speed and actual speed. From the generated reference torque value reference current is calculated which is then fed to a single band hysteresis current controller. In any control scheme using sensor three hall sensors is place at an interval of 120^0 around the stator of BLDC motor. Likewise in sensor less control, three hall signals are estimated based on the angle at which rotor is aligned at any instant of time. Then these hall signals are multiplied with the reference current. Hysteresis controller generates appropriate gating signals with proper commutation instants for BLDC motor. The overall topology of proposed scheme with back EMF observer based sensor less technique is shown in Figure 6.1.

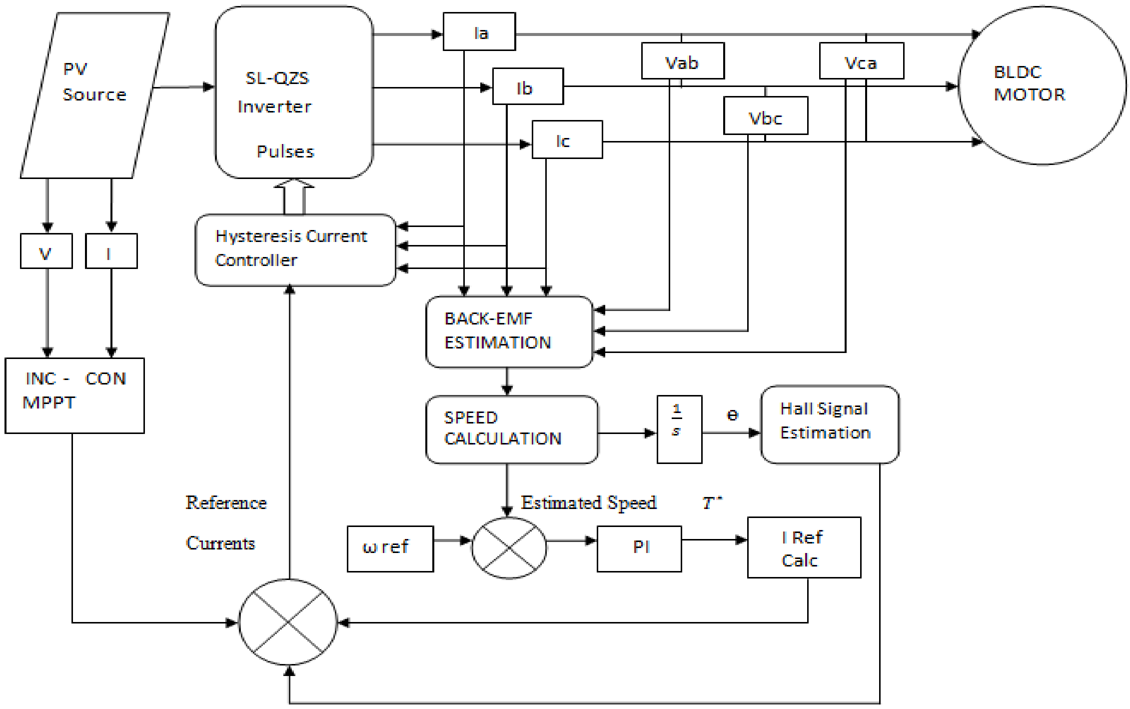

Figure 6.1 Proposed Sensor less of BLDC motor with back EMF observer and simplified IFOC technique

6.2 Operating Principles of Switched Inductor Quasi Z-Source Inverter

The modified form of conventional quasi z source inverter by the addition of three diodes and two inductors in the Z-source network is known to be switched inductor quasi Z-source inverter. Circuit diagram of switched inductor quasi Z-source inverter is shown in Figure 6.2. There is no high inrush current during starting in this topology which makes it an excellent scheme for motor drives where the starting current is to be limited. The SLQZS inverter employs only smaller and less value of passive elements and still has high voltage gain when compared to the classical quasi Z-source inverter is explained by M. R. Feyzi et al., 2010. The other advantages of this circuit topology are working in continuous current mode, lower voltage stress on capacitors involved in the network and switching losses are also reduced by generating the pulse at nominal or grid frequency.

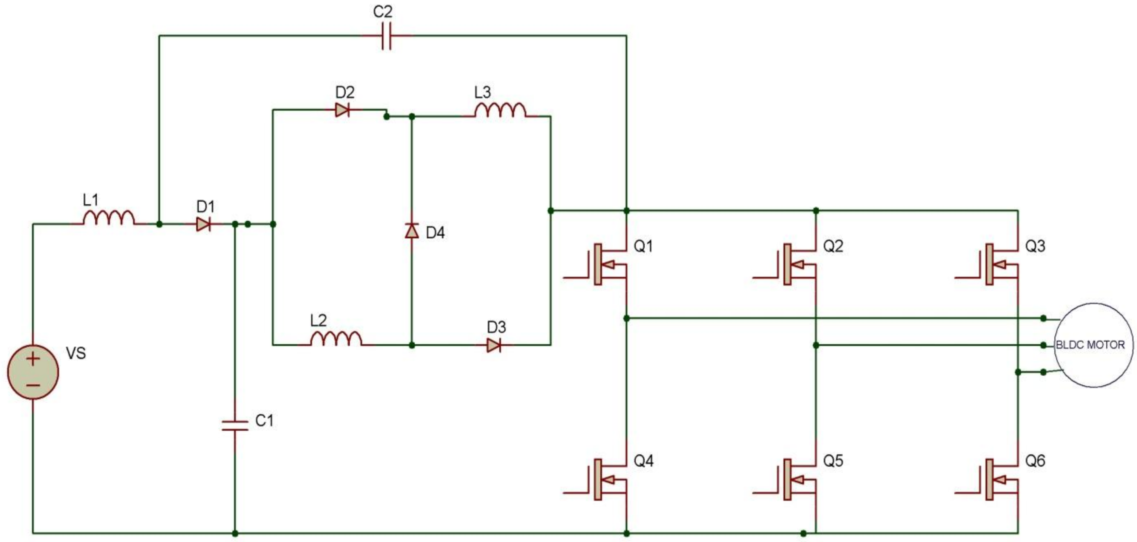

Figure 6.2 Circuit diagram of switched inductor quasi Z-source inverter

6.2.1 Mode of operation

In general Z-source inverter has two different switching states active and zero switching states. During zero switching states of Z-source inverter there is no power flow from source to load and the energy stored in inductor and voltage in the capacitor. Similarly, during active switching state of Z-source inverters functions is similar to the normal inverter and utilizes DC-link voltage and to deliver power to the load.

Shoot through state

In this mode of operation, there is no power transfer from source to load. Normally in any inverter, both the switches of a particular leg are not turned on simultaneously to avoid damaging the source. Here to charge the capacitors and inductors to the supply energy one top and other bottom switch of the same inverters leg are turned on for a particular time interval during every conduction period. During shoot through state, both D_1 and D_4 are turned off while remaining diodes are turned on. This makes the two inductors (L_1, L_2) to be connected in parallel with the source and capacitor circuit. In this mode the capacitors (C_1, C_2) get discharged to get the inductors to be charged that is it will store energy from the source.

Non-shoot through state

During this mode of operation energy stored in the inductor during shoot through the state is transferred to the load and the capacitor (C_1, C_2) gets charged to the supply voltage. In this mode conventional inverter operation is carried out normally any conduction mode of the inverter is applied according to the requirement of the load. During shoot through state, both D_1 and D_4 are turned on while remaining diodes are turned off., in this mode inductors will discharge.

6.3 Control Scheme Using Simplified IFOC

In this control methodology, a simplified Indirect Field Oriented Control technique is used where the speed of BLDC motor is estimated rather than obtaining from a sensor, back EMF observer method is in use to estimate speed which is explained in detail in the following section. T. L. Chern et al., 2011 discrete PI controller is used as a speed regulator in this sensor less control scheme once speed is estimated error between speed reference given as per demand and estimated speed is fed as input to the discrete pi controller, and pi controllers output is reference torque. The actual reference current is calculated from the estimated value of reference torque from the pi controller using its relationship with torque from equation (6.4). By using a simple integral operator rotor position of the permanent magnet brushless DC motor is obtained in angles based on estimated speed. Then from rotor angle, we can estimate three hall signals equivalent to the hall position sensor signals placed at 120^0 intervals in the motor. These hall signals are product with estimated reference current of motor and MPPT reference voltage obtained using incremental conductance algorithm.

6.3.1Back-EMF Estimation

To calculate the back EMF of BLDC motor three phase voltage and phase currents flowing from inverter to BLDC motor have to be measured. Next step of the algorithm is to calculate line voltages and line currents from measured values is discussed by S. Sashidhar and B. G. Fernandes, 2017. In MATLAB simulation BLDC motor is modeled using machine mathematical model (6.1), and from that relation back EMF can be estimated for all three phases and then absolute back EMF is calculated. Then for attaining the exact value of the speed estimation maximum value of back EMF is computed and by using equation (6.2) mechanical rotor speed of BLDC motor can be calculated and explained by S. B. Ozturk and H. A. Toliyat 2007.

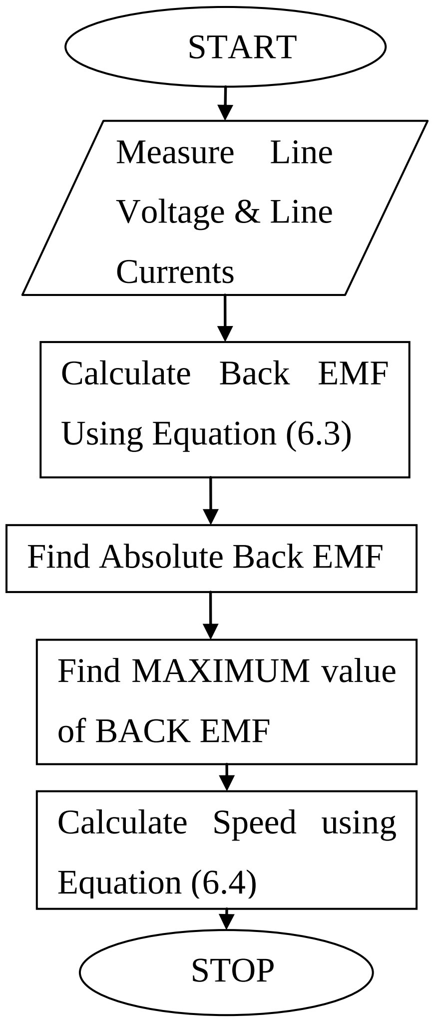

Figure 6.3 Flow Chart of back EMF observer based Speed Estimation Method

$$\begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} = \begin{bmatrix} R & 0 & 0 \\ 0 & R & 0 \\ 0 & 0 & R \end{bmatrix} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} + \begin{bmatrix} L-M & 0 & 0 \\ 0 & L-M & 0 \\ 0 & 0 & L-M \end{bmatrix} \frac{d}{dt} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} + \begin{bmatrix} e_a \\ e_b \\ e_c \end{bmatrix} \quad (6.1)$$

$$\omega_r = \frac{E_{max}}{2*p*flux} \quad (6.2)$$

$$\theta = \int \omega_r \ dt \quad (6.3)$$

$$I_{ref} = \frac{T_{ref}}{2*p*flux} \quad (6.4)$$

Where V_a, V_b, V_c are three phase voltages, I_a, I_b, I_c are three phase currents, e_a, e_b, e_c are back EMF of BLDC motor. ω_r is the rotor speed of BLDC motor and p is the number of pole pairs. Flux is the flux linkage established by magnets. Theta θ is the rotor angle or position of the rotor. T_{ref} Is estimated using pi speed regulator. Flow chart of the proposed speed estimate method is shown in Figure 6.3.

6.3.2 Current Controller

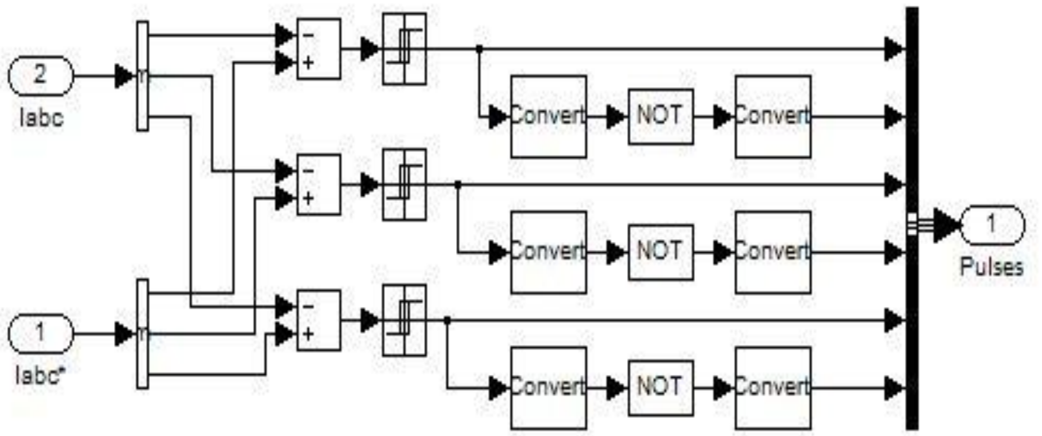

Figure 6.4 Simulink Design of Hysteresis current controller

For proper operation of current controller hysteresis bands, that is an upper band and lower band of comparator relay must be defined correctly. The input of the hysteresis current controller is an error in actual current and reference current. The hysteresis comparator will produce a high pulse for switching device only if the error in current is within the specified band limits and the hysteresis comparator will produce a low pulse for switching device only if the error in current is exceeded the specified band limits. A typical hysteresis current controller based on single band implemented in MATLAB simulation is shown in Figure 6.4. To keep the switching frequency of pulse obtained from a hysteresis current controller within a smaller value band limit chosen must be small. This helps in reducing the switching losses of SLQZS inverter by switching at relatively lower frequencies. In our control scheme, only single band hysteresis controller is used for higher efficiency and improving inverters performance double band controllers are used.

6.4 Simulation Results and Discussion

Photovoltaic source fed switched inductor quasi Z-source inverter is simulated in Simulink software and the implementation of proposed scheme is shown in Figure 6.5. Parameters applied in proposed inverter circuit and simulation parameters used for sensor less BLDC motor is shown in Table 6.1. Back EMF observer technique estimates the speed of sensor less BLDC motor in sensor less technique and an Indirect Field Oriented Control with hysteresis current controller is applied for closed loop control of brushless DC motor. The performance of proposed SLQZS inverter BLDC motor drive with sensor less control scheme is shown from Figure 6.6 to Figure 6.13.

TABLE 6.1 Simulation Parameters

Motor Parameters	
Name	Range
Stator Resistance (Rs)	0.7 ohms
Stator Inductance (Ls)	2.72mH
Rotor Speed	500 rpm
Flux Linkage	0.019099 V.s
Poles	4

Torque Constant	0.15279N.m/A
Circuit Parameters	
Impedance source inductors (L_1, L_2, L_3)	0.1mH, 1mH, 1mH
Impedance source capacitors(C_1, C_2)	1000F
DC-Link Voltage (V_{DC})	24v
PV SPECIFICATIONS	
Voltage	24v
Current	6.4A
Power	150W

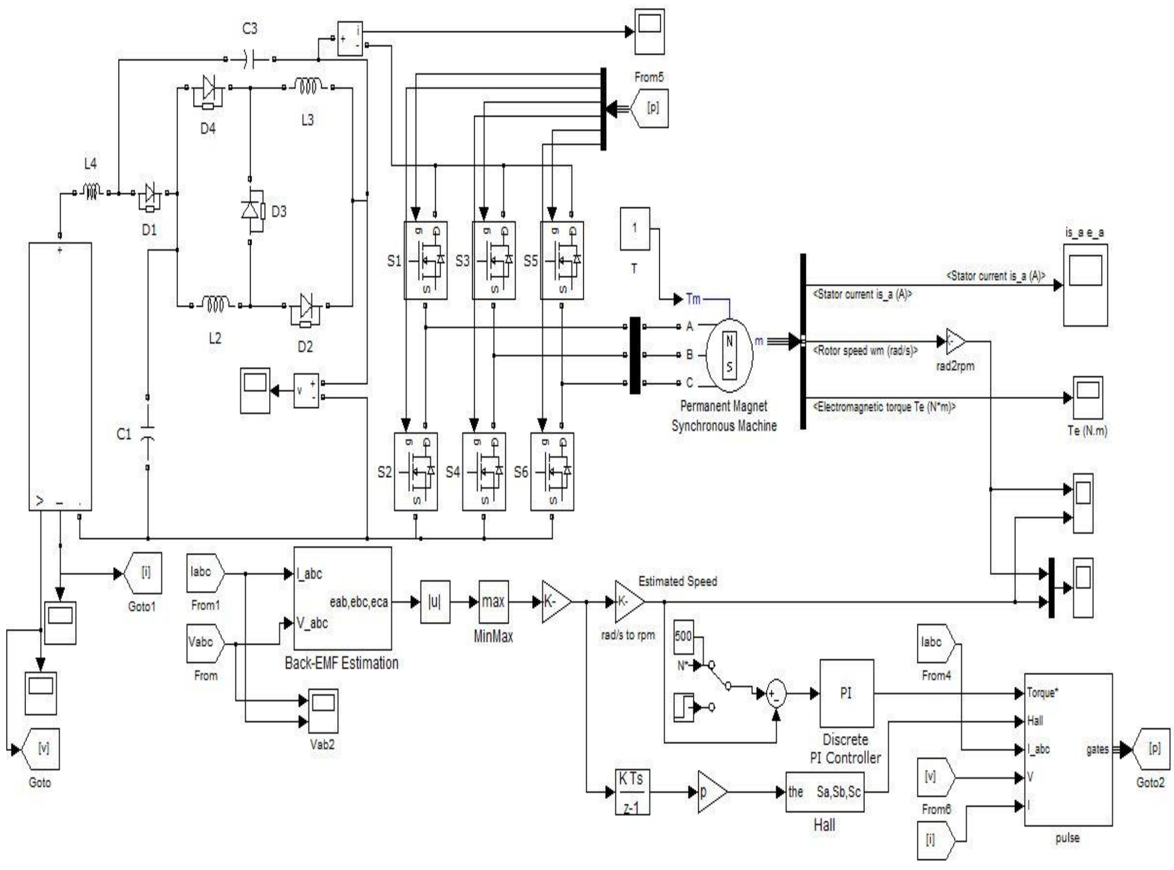

Figure 6.5 MATLAB Implementation of proposed sensor less BLDC motor drive

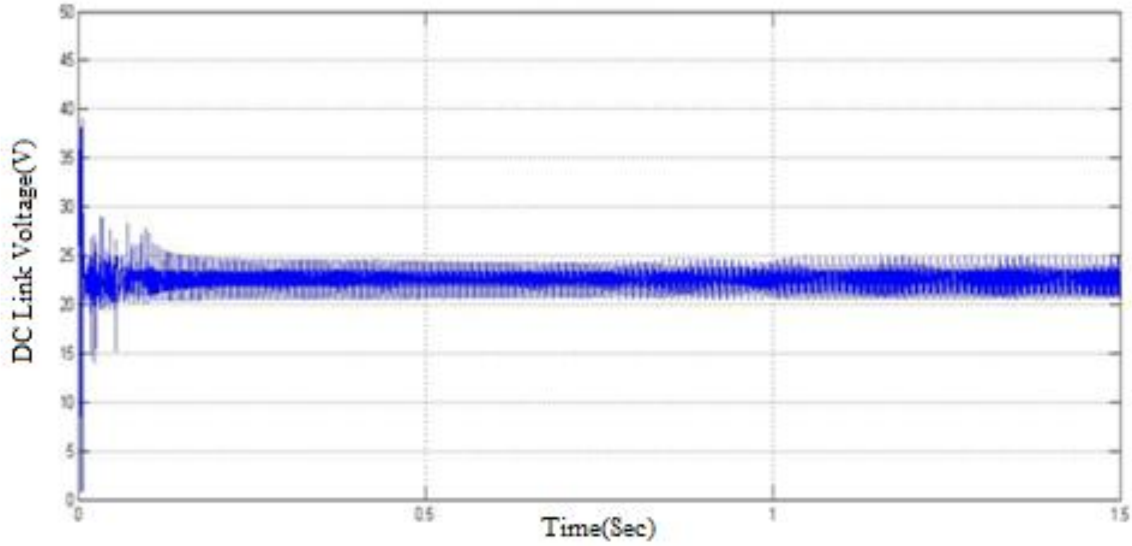

Figure 6.6 DC Link voltage waveform of SLQZS inverter

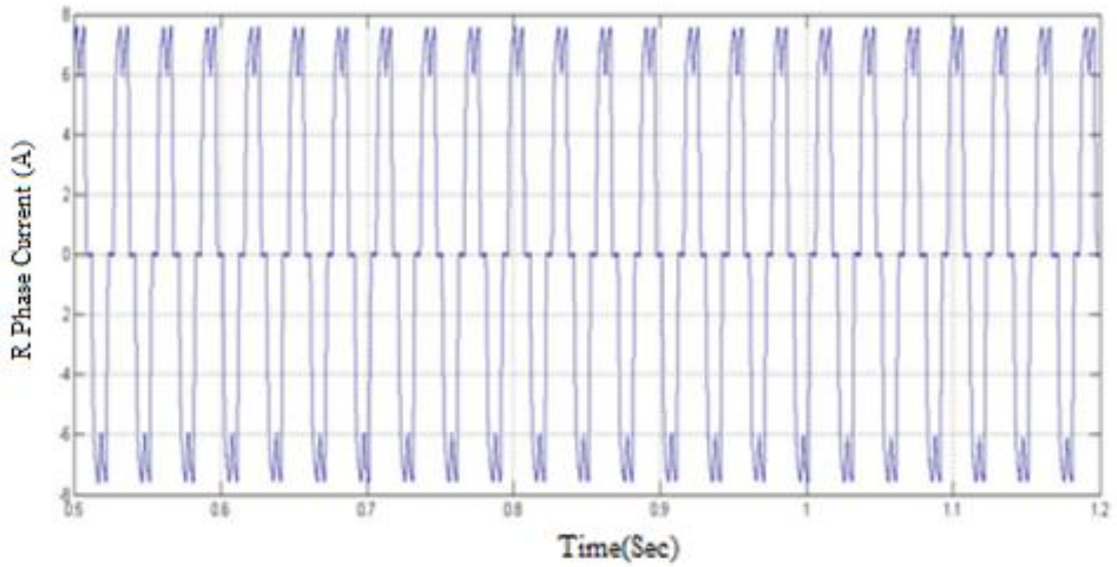

Figure 6.7 R Phase Current waveform of BLDC motor

The dc link voltage is shown in Figure 6.6. The R phase current of BLDC motor is shown in Figure 6.7. Figure 6.8 BLDC motors Stator current waveform for varying speed reference. The FFT analysis of stator current using indirect field oriented control is shown in Figure 6.9.

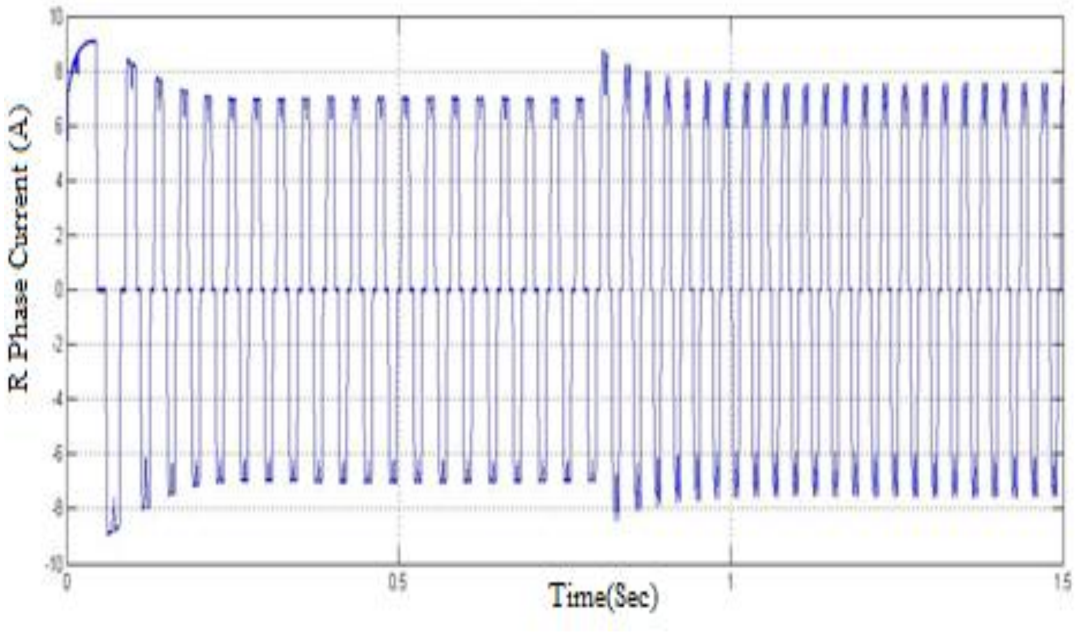

Figure 6.8 BLDC motors Stator current waveform for varying speed reference

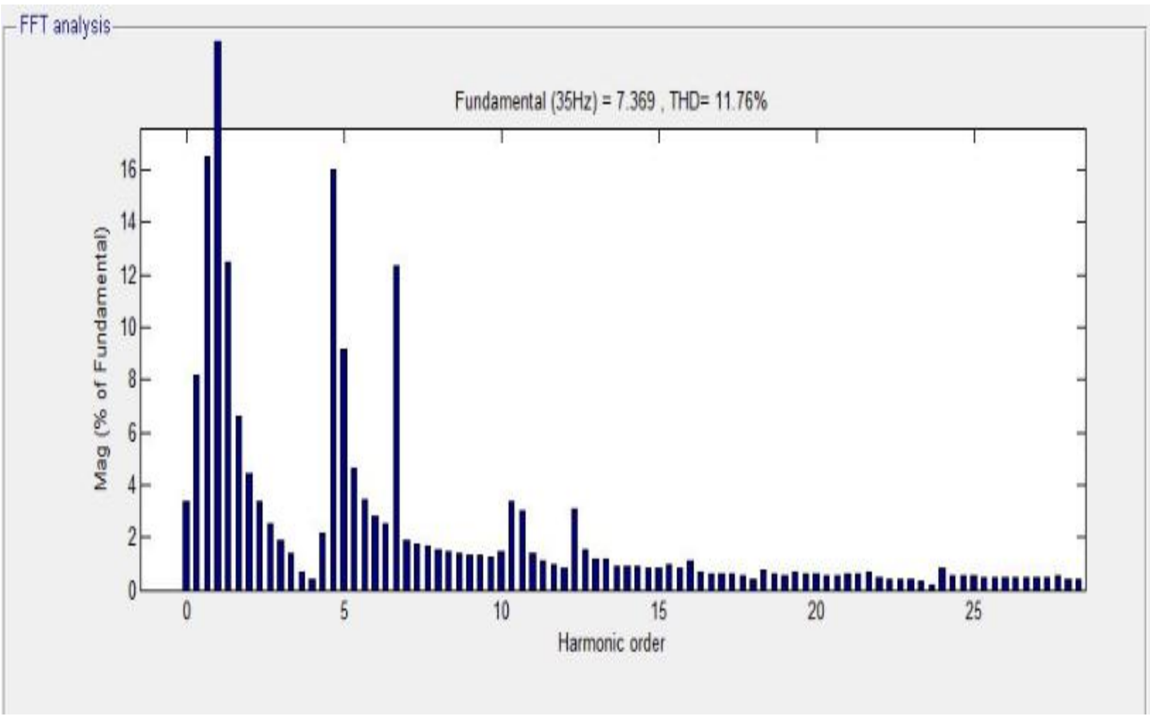

Figure 6.9 FFT Analysis on Stator Current using IFOC Technique

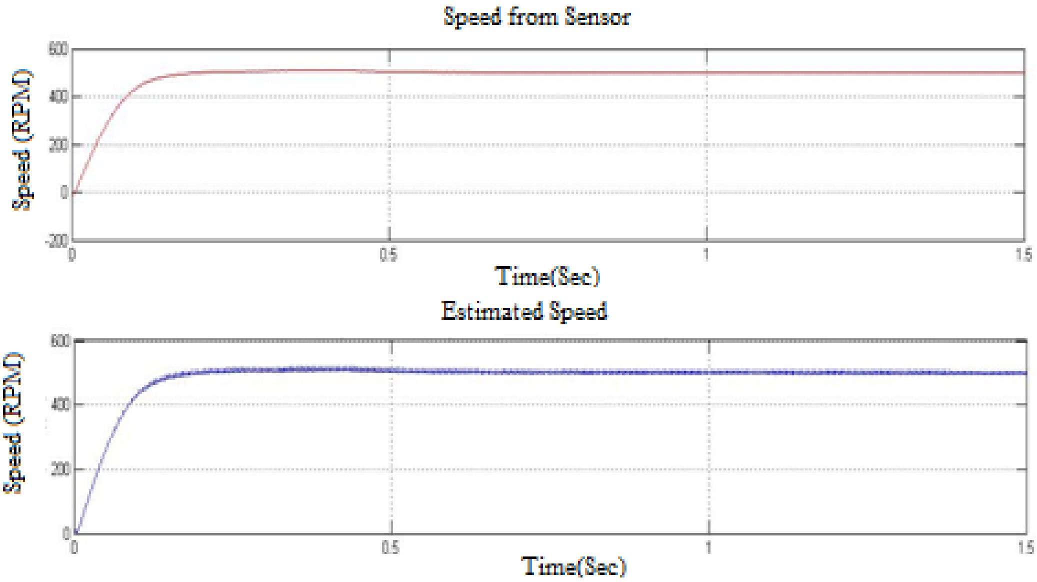

Figure 6.10 Speed Response of BLDC motor

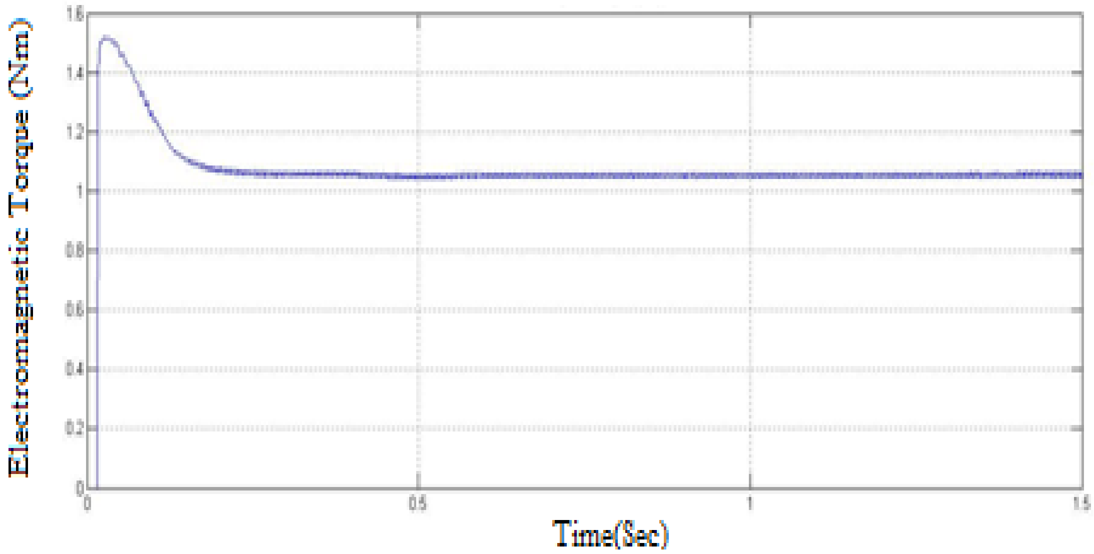

Figure 6.11 Electro-magnetic Torque waveform

The BLDC motor performance for the proposed sensor less control scheme for changing speed command with time is shown from Figure 6.10 to Figure 6.13. During the simulation time interval at 0.8 seconds, the speed reference set at the input of pi controller is varied from 400rpm to 500 rpm and the response of proposed control scheme motor speed, electro-magnetic torque and stator current is given below which validates the improved performance of proposed BLDC drive for varying system parameters.

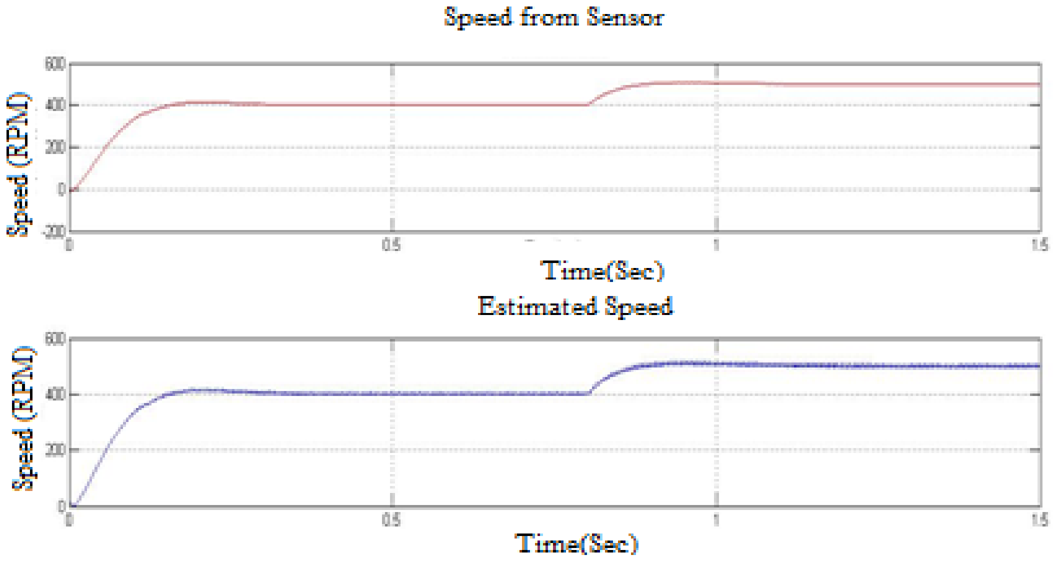

Figure 6.12 Speed response from speed measurement and estimated speed for step change of speed reference at t=0.8s

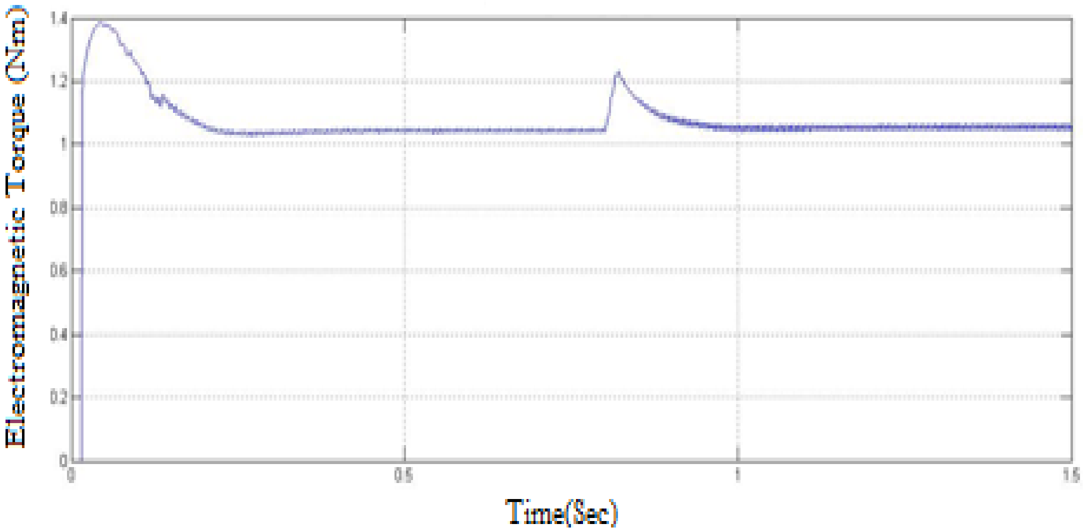

Figure 6.13 BLDC motors Electromagnetic torque waveform for varying speed reference

6.5 Summary

A BLDC motor is proposed in this chapter where the use of position and speed sensor is neglected. The speed or position signal of the rotor of the motor is estimated from back-EMF observer method. This method estimates the speed of the motor with a high degree of accuracy and suitable for the motor with different parameters, it does not involve any tuning strategy in speed estimation rather involves simple computation. For regulation of motors speed conventional pi controller is used and it generates the reference torque for indirect field oriented control. The IFOC vector control methodology reduces the torque ripples and to provide smooth starting torque. The stator current performance of BLDC motor has attained trapezoidal shape in this vector control scheme by estimating hall signals from estimated speed of the motor. The improved performance of proposed scheme using sensor less IFOC control of BLDC motor using back EMF observer method is verified by simulating in MATLAB/Simulink environment.