OPEN ACCESS

International Journal Of Modern Engineering Research (IJMER)

Speed Control of PFC Quadruple Lift Positive Output Luo Converter fed BLDC Motor Drive

K. Srinivasa Rao[1], G. Satyanarayana Rao[2], V. L. N. Sastry[3]

[1] (EEE Department, Sasi Institute of Technology & Engineering, Tadepalligudem, A.P, India

[2] (EEE Department, Sasi Institute of Technology & Engineering, Tadepalligudem, A.P, India

[3] (EEE Department, Sasi Institute of Technology & Engineering, Tadepalligudem, A.P, India

ABSTRACT: *This paper gives analysis and simulation performance of Brushless DC motor (BLDC) with quadruple lift positive output Luo converter. A quadruple lift positive output Luo converter is used to supply the required voltage to drive the BLDC motor. The performance of the BLDC motor drive in closed loop is analyzed using the PI controller in terms of speed. The speed of the BLDC motor is varied by a low frequency switching of the Voltage Source Inverter (VSI). The switching of VSI in turn controls the DC link voltage at the output of the inverter. Diode Bridge Rectifier (DBR) at the input side is eliminated, which reduces the conduction losses. Also the Power Factor Correction (PFC) is obtained at the front end of the AC source by controlling DC- link voltage in closed loop. The proposed system has high voltage transfer gain and very less ripple content in output voltage. Further the performance of the BLDC motor drive using a PI controller is verified through MATLAB simulation. The proposed drive provides a solution for low power applications with less cost.*

Keywords: *BLDC motor, Hall sensor, PFC control, PI controller, Quadruple lift positive output Luo converter.*

I. Introduction

In traditional DC motors, the brushes are used for implementing mechanical commutation. Due to this many problems like mechanical friction arises which produces noise, electrical sparks, radio interference and reduces the life span of the machine. Keeping in mind the high cost of production and inconvenient maintenance, the use of these DC motors is confined to large size applications. The urgency in higher performance motors for small and medium applications leads to the development of Brush Less Direct Current (BLDC) motors.

The Permanent Magnet Synchronous Motor (PMSM) is similar to that of BLDC motor. The PMSM motor uses sinusoidal waveform to control each winding back emf waveforms while the BLDC motor uses trapezoidal waveforms. In a BLDC motor, the windings are taken on the stator and the magnet is incorporated on the rotor. As there are no brushes present in the BLDC motor, the commutation is achieved electronically with a drive consisting of semiconductor switches which changes the current in the winding with respect to the feedback from rotor through position sensors.

The BLDC motors find fistful because of simple construction, low electromagnetic pollution, relatively high reliability, least cost, more efficiency, maximum power density and negligible maintenance. In recent years Brushless DC motors are widely used in low power applications like ship propellers, aerospace, textile industries, manipulators, robotic arms and Automotives.

In [2], the converter is used after the DBR which corrects power factor correction at input side single phase AC mains and voltage is controlled at the DC link which reduces the THD in the converter. The concept of the front end PFC converter with DBR fed from single phase AC mains is discussed [3] and the speed of the air conditioner is controlled to save energy by controlling the DC link voltage as it is proportional to the required speed of the PMBLDC motor.

For lower power application with cost saving technique is discussed with PFC based Cuk converter for obtaining unity power factor at the AC mains [4]. Bridgeless (BL) - Canonical Switching Converter (CSC) partially eliminates the DBR at the input which reduces the conduction losses, thereby increases the efficiency of the scheme [5].

The PFC BL-buck boost converter completely eliminates the DBR thereby reducing the conduction losses to a large extent and increases the efficiency. Also the PFC is obtained at the input side by controlling DC- link voltage [6]. BL-Zeta converter employs the reduced sensor with fundamental frequency switching of the VSI to reduce the switching losses. Also, due to elimination of DBR, conduction losses decrease thereby achieving PFC at input side [7].

The paper is organized as section II describes the detailed analysis and operation of proposed Quadruple Lift positive output Luo converter. Section III presents the modeling of Brushless DC motor with electronic commutation process with the help of Hall Effect sensors. Section IV gives the brief description of the Quadruple Lift positive output Luo converter fed BLDC motor drive with simulation results and section V concludes the paper.

II. QUADRUPLE LIFT POSITIVE OUTPUT LUO-CONVERTER

Quadruple lift positive output Luo converter circuit is shown in Fig.1 and it consists of two switches S_1 and S_2, five inductors L_1, L_2, L_3, L_4, and L_5 with six capacitors C, C_1, C_2, C_3, C_4 and C_0 and seven freewheeling diodes[8].

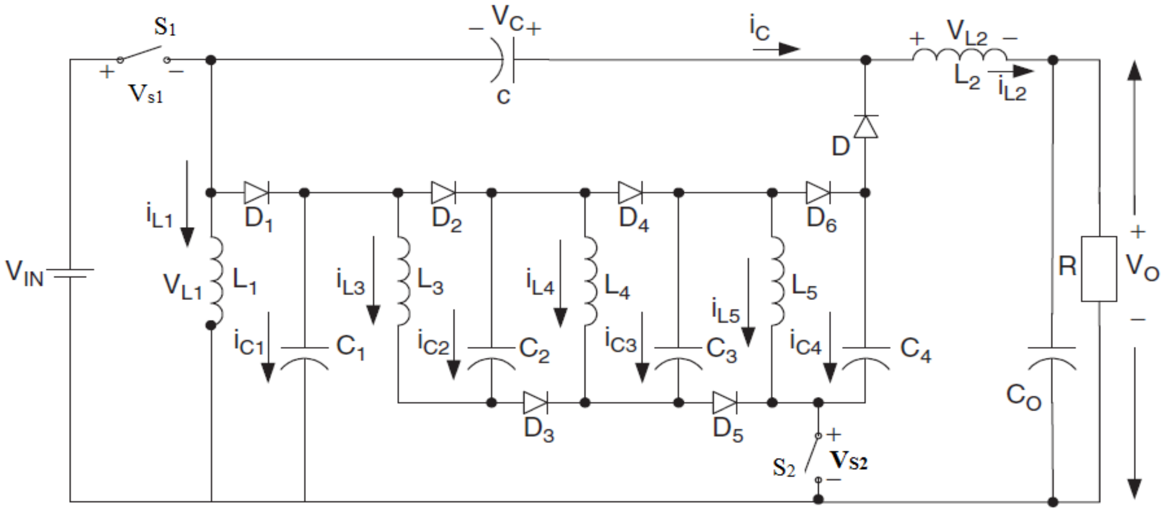

Fig.1: Quadruple Lift Positive Output Luo Converter

Capacitors C_1, C_2, C_3 and C_4 perform the process to lift the capacitor voltage V_C by four times the applied input voltage V_{IN} and L_3, L_4 and L_5 perform the operation as ladder joints to line the four capacitors C_1, C_2, C_3, C_4 and lift up the capacitor voltage V_C.

It is assumed that all the components are ideal and positive output quadruple lift converter operates in a CCM.

When the switches S_1 and S_2 are in ON state, the diodes D_1 to D_6 are in ON state and diode D is in OFF state. While the switches S_1 and S_2 are in OFF state, the diodes D_1 to D_6 are in OFF state and diode D is in ON state [9].

The current Ic_2 increases when the switches are in ON state for a period of DT and it decreases when the switches are in OFF state for a period of (1-DT).

The output voltage and currents are given as

$$V_O = \frac{4}{1-D} V_{in} \quad (1)$$

$$I_O = \frac{1-D}{4} I_{in} \quad (2)$$

The high voltage transfer gain is obtained by

$$M_Q = \frac{V_O}{V_{in}} = \frac{4}{1-D} \quad (3)$$

Inductor average currents are given as

$$I_{L_1} = \frac{D}{1-D} I_O \quad (4)$$

$$I_{L_2} = I_O \quad (5)$$

$$I_{L_3} = I_{L_4} = I_{L_5} = I_{L_1} + I_{L_2} = \frac{1}{1-D} I_O \quad (6)$$

The modes of operation of the converter are shown in Fig.2 and Fig.3.

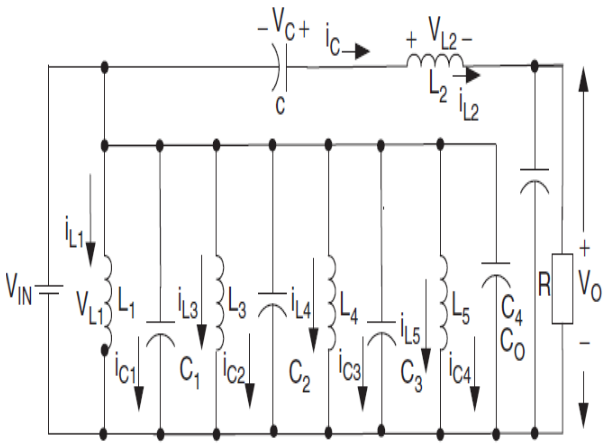

Fig.2: when the switches are in ON State

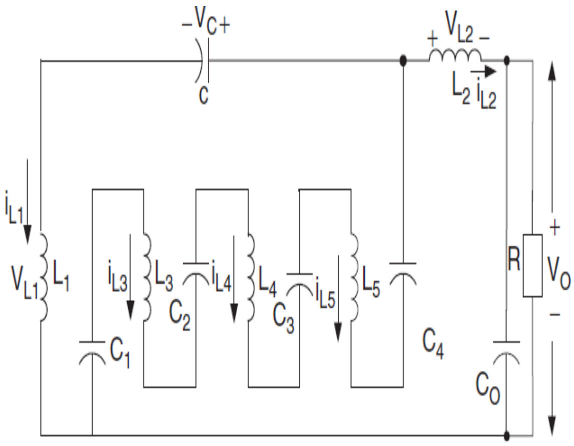

Fig.3: when the switches are in OFF State

Assuming that f = 50 KHz, $L_1 = L_2 = 1mH$, $L_3 = L_4 = L_5 = 0.5mH$, $C = C_1 = C_2 = C_3 = C_4 = C_O = 20\mu F$ and duty ratio, D = 33%. The output voltage of Luo converters is almost a real DC voltage with very small ripple.

III. Modelling Of BLDC Motor

A BLDC motor drive comprises of 3-Φ inverter circuit whose output is given to BLDC motor and the inverter is controlled by switching pulse signals obtained from the electronic commutation circuit which has 6- step commutation with each phase conducting span of 120^0 in electrical degrees. The sequence of commutation is like ab-ac-bc-ba-ca-cb. The cross section and phase sequence of BLDC motor are shown in Fig.4 while the basic BLDC motor model is shown in Fig.5.

The DC link voltage is given to an inverter which converts the DC voltage to AC voltage and the output of the inverter is supplied to the BLDC motor. Assuming the inverter has no power loss and the connection of 3-Φ BLDC motor is in star [10].

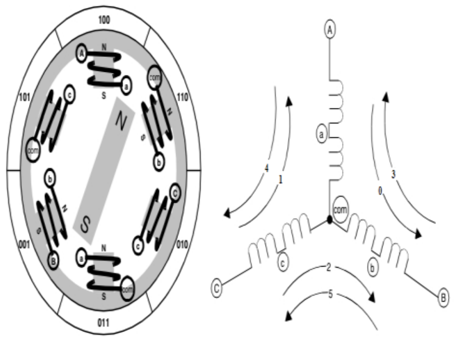

Fig.4: Cross section and phase sequence of BLDC motor

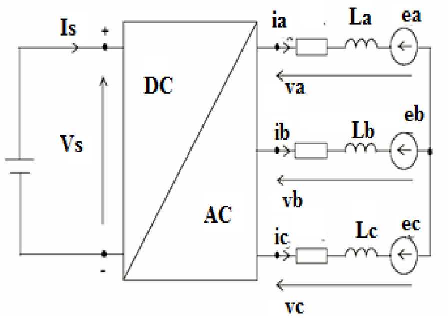

Fig.5: Simple BLDC Model

Applying KVL for the 3-Φ stator loop winding circuitry gives:

$$v_a = R_a + L_a \frac{di_a}{dt} + M_{ab}\frac{di_b}{dt} + M_{ac}\frac{di_c}{dt} + e_a \qquad (7)$$

$$v_b = R_b + L_b \frac{di_b}{dt} + M_{bc}\frac{di_a}{dt} + M_{ba}\frac{di_c}{dt} + e_b \qquad (8)$$

$$v_c = R_c + L_c \frac{di_c}{dt} + M_{ca}\frac{di_a}{dt} + M_{cb}\frac{di_b}{dt} + e_c \qquad (9)$$

Where e_a, e_b, e_c are the back-EMF waveforms which are functions of angular velocity (w_m) of the rotor shaft and is given by,

$$e = K_b \omega_m \qquad (10)$$

Where K_b is the back-emf constant

So, from the above equations the mathematical model of the BLDC motor can be expressed in matrix form as:

$$\begin{bmatrix} L_a & M_{ab} & M_{ac} \\ M_{ba} & L_b & M_{bc} \\ M_{ca} & M_{cb} & L_c \end{bmatrix} \frac{d}{dt} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} = \begin{bmatrix} v_a \\ v_b \\ v_c \end{bmatrix} - \begin{bmatrix} R & 0 & 0 \\ 0 & R & 0 \\ 0 & 0 & R \end{bmatrix} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} - \begin{bmatrix} e_a \\ e_b \\ e_c \end{bmatrix} \quad (11)$$

Let us consider that the stator self inductances don't depend on the rotor position and the mutual inductances will be given as:

$$L_a = L_b = L_c = L \quad (12)$$

$$M_{ab} = M_{ac} = M_{ba} = M_{ca} = M_{cb} = M \quad (13)$$

Assuming a 3-Φ phase balanced system, all the phase resistances are equal and is given as

$$R_a = R_b = R_c = R \quad (14)$$

Rearranging the equation (11) yields

$$\begin{bmatrix} L & M & M \\ M & L & M \\ M & M & L \end{bmatrix} \frac{d}{dt} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} = \begin{bmatrix} v_a \\ v_b \\ v_c \end{bmatrix} - \begin{bmatrix} R & 0 & 0 \\ 0 & R & 0 \\ 0 & 0 & R \end{bmatrix} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} - \begin{bmatrix} e_a \\ e_b \\ e_c \end{bmatrix} \quad (15)$$

Where the symbols e , v and i denote the phase back-emf , phase voltages and phase currents respectively, with the three phases as a, b and c. R is the resistance per phase and L is the inductance per phase values and T_e, T_L, J and w_m are the electrical torque, the load torque, the rotor inertia and the rotor speed.

The back emf and the electrical torque can be expressed as

$$e_a = \frac{k_b}{2} w_m F(\theta_e) \quad (16)$$

$$e_b = \frac{k_b}{2} w_m F\left(\theta_e - \frac{2\pi}{3}\right) \quad (17)$$

$$e_c = \frac{k_b}{2} w_m F\left(\theta_e - \frac{4\pi}{3}\right) \quad (18)$$

The electromechanical torque is expressed as

$$T_{em} = J\frac{d\omega_r}{dt} + B\omega_r + T_L \quad (19)$$

$$T_{em} = \frac{1}{\omega_m}(e_a i_a + e_b i_b + e_c i_c) \quad (20)$$

The electrical torque is given by

$$T_e = \frac{k_t}{2}\left[F(\theta_e) i_a + F\left(\theta_e - \frac{2\pi}{3}\right) i_b + F\left(\theta_e - \frac{4\pi}{3}\right) i_c\right] \quad (21)$$

where K_b and K_t are the back-emf constant and the torque constant respectively.

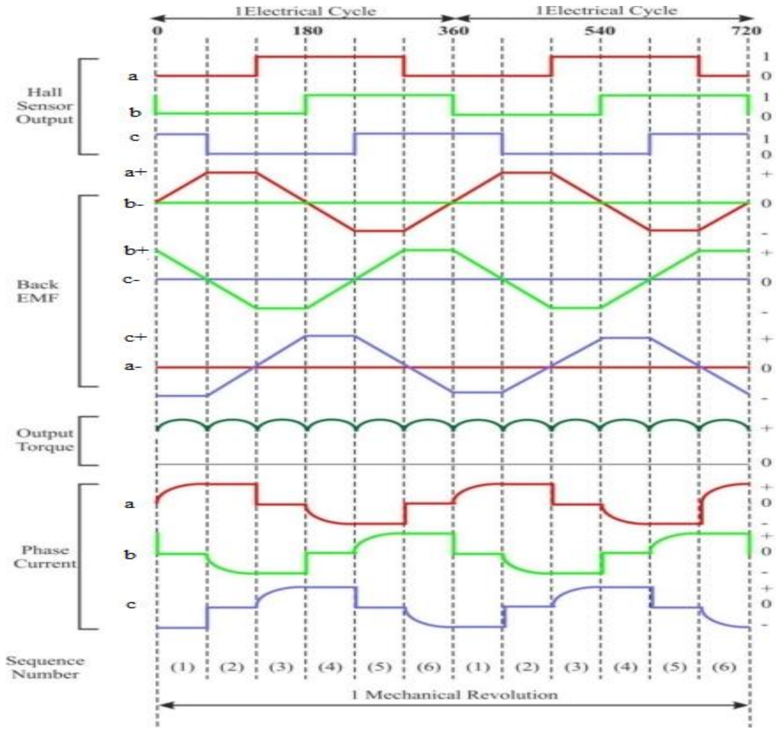

Fig.6: Hall Sensor Signal, Back Emf, Output Torque and Phase Current

The Hall position sensors are installed in the motor to detect the rotor position and transform it into an electrical signal on a span of 60^0, providing the correct commutation for the logic switch circuit. Therefore, the proper current commutation for the windings is obtained from the rotor position information and the PM rotor will rotate continuously because of the stepping rmf generated by the current in the air gap. The commutation timing to switch the appropriate switches is determined by the rotor position, which can be detected by Hall sensors H_a, H_b and H_c as shown in the Fig.6.

IV. QUADRUPLE LIFT POSITIVE OUTPUT LUO-CONVERTER FED BLDC MOTOR DRIVE

Fig-7 shows the proposed Quadruple Lift Positive Output Luo Converter fed BLDC motor drive. The filter at the input side eliminates the DBR which acts as a voltage converter from AC mains to DC at C_f. The converter operates in DCM using the concept of voltage follower for the dual operation of PFC and DC link voltage control. The proposed converter eliminates the DBR thereby reduces the conduction losses to a large extent and increases the efficiency. Also the PFC at the front end of the AC source is obtained at the input side by controlling DC- link voltage. The converter converts the source voltage into a higher output voltage with high power efficiency and high power density.

Voltage follower approach:

With the use of Voltage follower approach, the front-end PFC converter generates the PWM pulses for the PFC Luo converter switches (S_{w1} and S_{w2}) for DC link voltage control with PFC operation at AC mains.

A reference dc link voltage (V_{dc}^*) is generated as

$$V_{dc}^* = k_v \, w^* \qquad (22)$$

Where k_v and w^* are the motor voltage constant and the reference speed respectively.

The voltage error signal (V_e) is generated by comparing the reference DC link voltage (V_{dc}^*) with the sensed DC link voltage (V_{dc}) as

$$V_e(k) = V_{dc}^*(k) - V_{dc}(k) \qquad (23)$$

Where k represents sampling instant.

This error voltage signal (Ve) is given to the voltage proportional–integral (PI) controller to generate a controlled output voltage (Vcc) as

$$V_{cc}(k) = V_{cc}(k-1) + k_p\{V_e(k) - V_e(k-1)\} + k_p \qquad (24)$$

Where k_p and k_i are proportional and integral gains of the voltage PI controller.

Now the output of the voltage controller is compared with a saw tooth signal (m_d) of high frequency to generate the PWM pulses as

$$\text{For } V_s > 0; \quad \left\{\begin{cases} if\ m_d < V_c\ then\ S_{w1} = ON \\ if\ m_d \geq V_c\ then\ S_{w1} = OFF \end{cases}\right\}$$

$$\text{For } V_s < 0; \quad \left\{\begin{cases} if\ m_d < V_c\ then\ S_{w2} = ON \\ if\ m_d \geq V_c\ then\ S_{w2} = OFF \end{cases}\right\}$$

Where S_{w1} and S_{w2} are given to the PFC converter switches as switching signals.

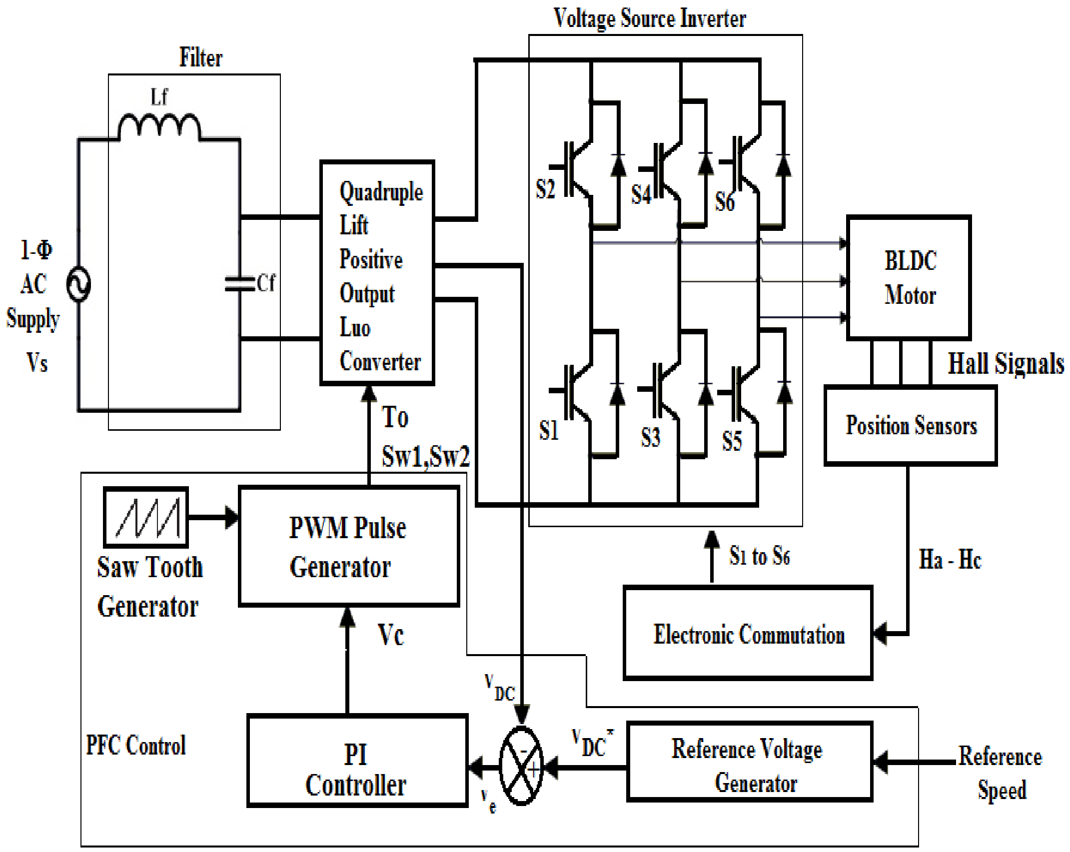

Fig.7: Proposed Quadruple Lift Positive Output Luo Converter fed BLDC Drive

Electronic Commutation:

The switching sequence for BLDC motor is obtained from Hall sensor signals is given in Table.1 and emf relation with hall signals is given in Table.2

Table.1: Switching Sequence for BLDC motor

Switching Interval	Sequence	Hall Sensor input			Switches Closed		Phase Current		
		a	b	c			a	b	c
0^0-60^0	0	0	0	1	S_1	S_4	a+	0	c-
60^0-120^0	1	0	0	0	S_1	S_2	a+	b-	0
120^0-180^0	2	1	0	0	S_5	S_2	0	b-	c+
180^0-240^0	3	1	1	0	S_5	S_0	a-	0	c+
240^0-300^0	4	1	1	1	S_3	S_0	a-	b+	0
300^0-360^0	5	0	1	1	S_3	S_4	0	b+	c-

Table.2: Back Emf's from hall sensor signals

Hc	**Hb**	**Hc**	**EMF e_a**	**EMF e_b**	**EMF e_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	0	0

At a particular instant two of the three phases of BLDC motor are connected and the sequence of switching is obtained from hall sensor outputs. The Simulink implementation of the decoder circuit for Back Emf's from hall sensor signals is shown in Fig.8 and the Simulink model for generating switching pulse signals is shown in Fig.9.

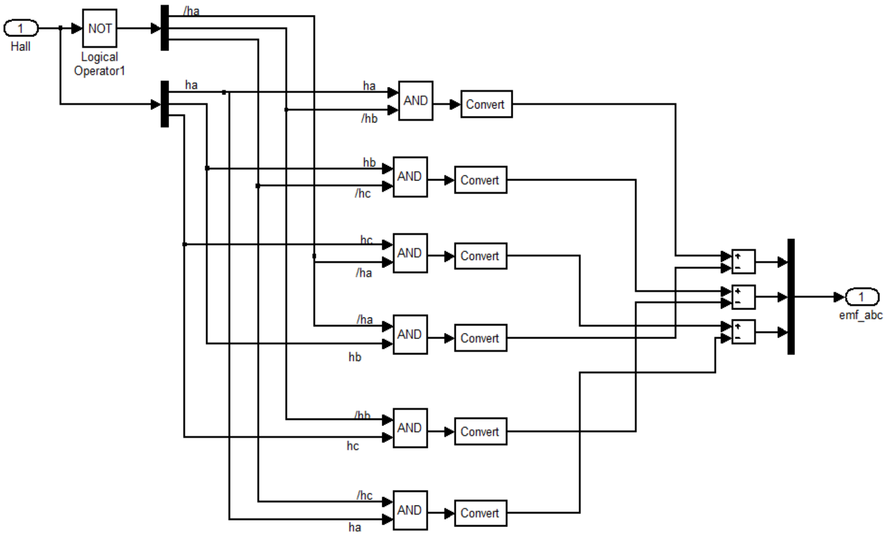

Fig.8: Simulink implementation of decoder circuit for Back Emf's from hall sensor signals

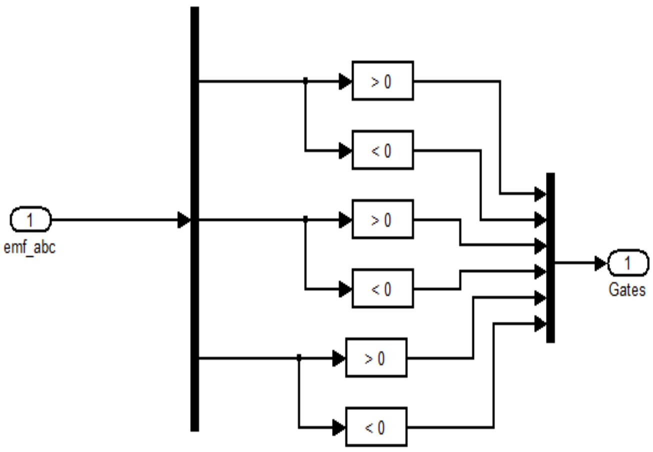

Fig.9: Simulink model for switching pulse generation

The simulation of the proposed model is considered with the load variation at 0.1 Sec and 0.3 Sec. The stator current and induced emf of the BLDC motor is shown in Fig.10 and the switching signals for VSI is shown in Fig.11

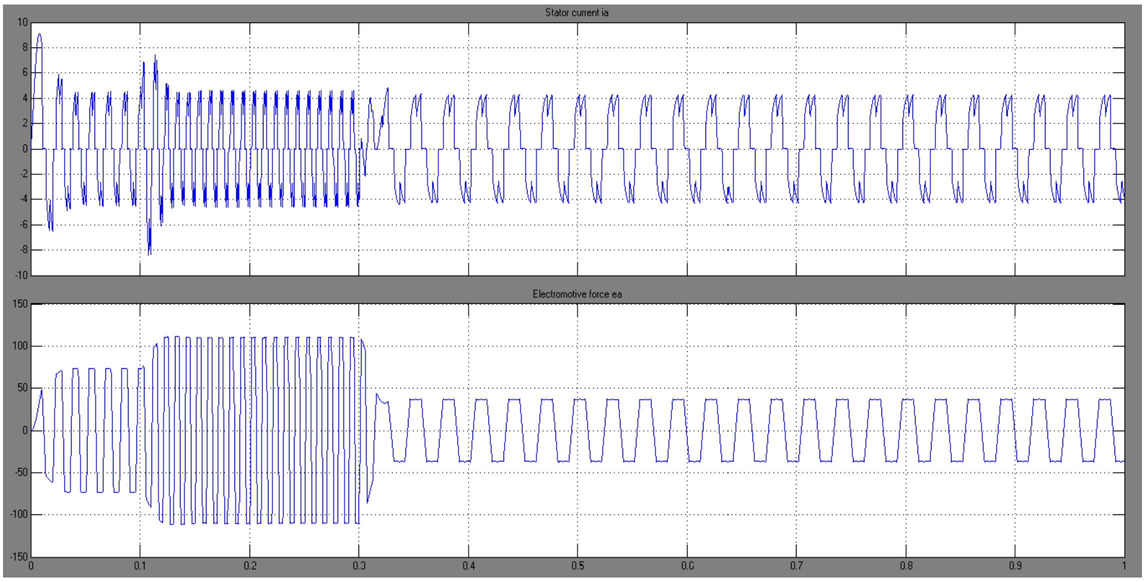

Fig.10: Induced Emf and Stator current waveforms

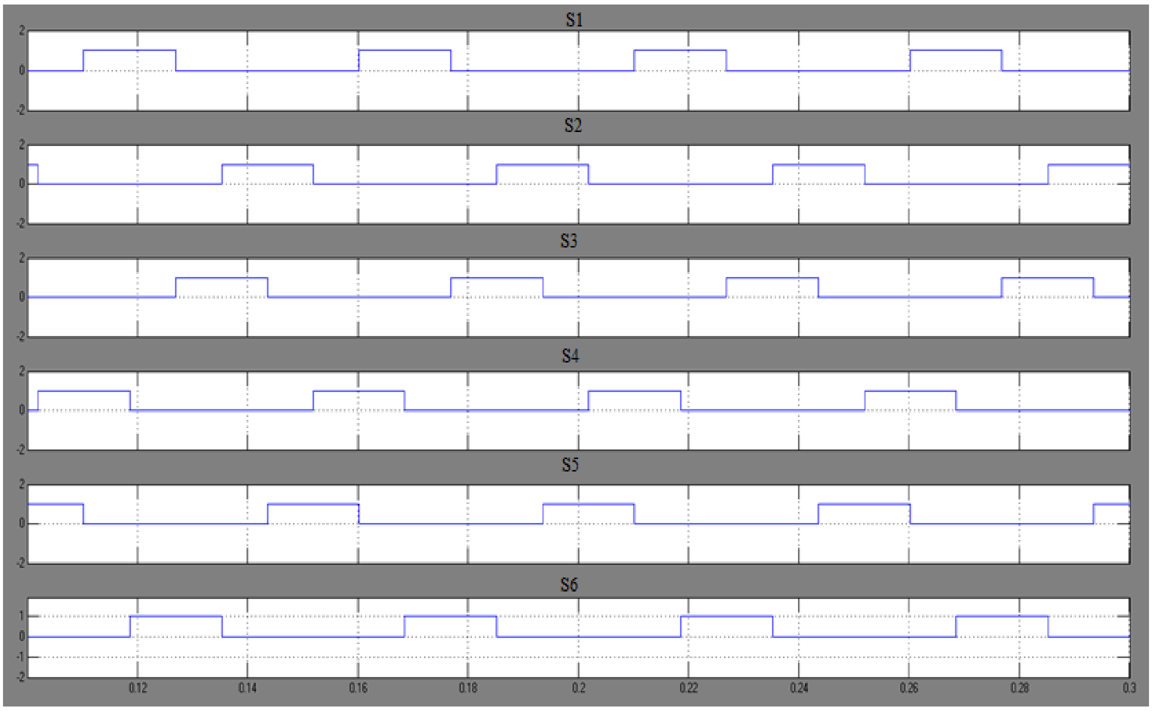

Fig.11: Switching Signals for VSI

The BLDC motor ratings are 4 pole, V_{rated} (rated DC link voltage) = 416V, T_{rated} (rated torque) = 2.2 Nm, ω_{rated} (rated speed) = 1500 rpm, K_v (back EMF constant) = 146 V/krpm, K_t (torque constant) = 1.4 Nm/A, R_{ph} (phase resistance) = 2.8750 Ω, L_{ph} (phase inductance) = 8.5 mH, J (moment of inertia) = 1.25 kg cm^2.

The BLDC motor speed is controlled with the use of PI controller and the speed is adjusted automatically adjusted to rated 1000 rpm during the time period 0 to 0.1 sec. and after application of the load at 0.1 Sec the speed tracks the load and automatically adjusted to rated 1500 rpm and at 0.3 Sec the load is decreased to 500rpm and the speed is automatically adjusted to 500rpm. So with the use of PI controller the BLDC motor speed is controlled and the simulation results of speed and electromagnetic torque is shown in Fig.12 while the source voltage, source current and DC link voltages are shown in Fig.13 with the variation of load at 0.1 Sec and 0.3 Sec.

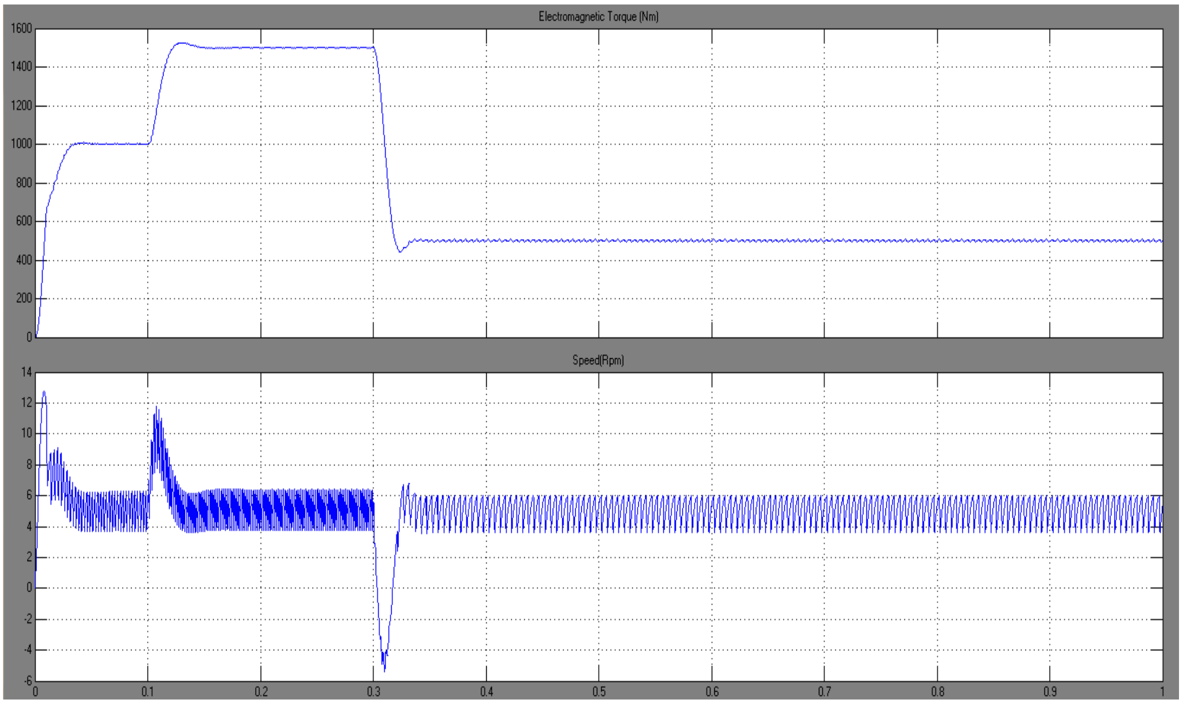

Fig.12: Electromagnetic Torque and Speed variation with load change at 0.1 sec and 0.3 sec.

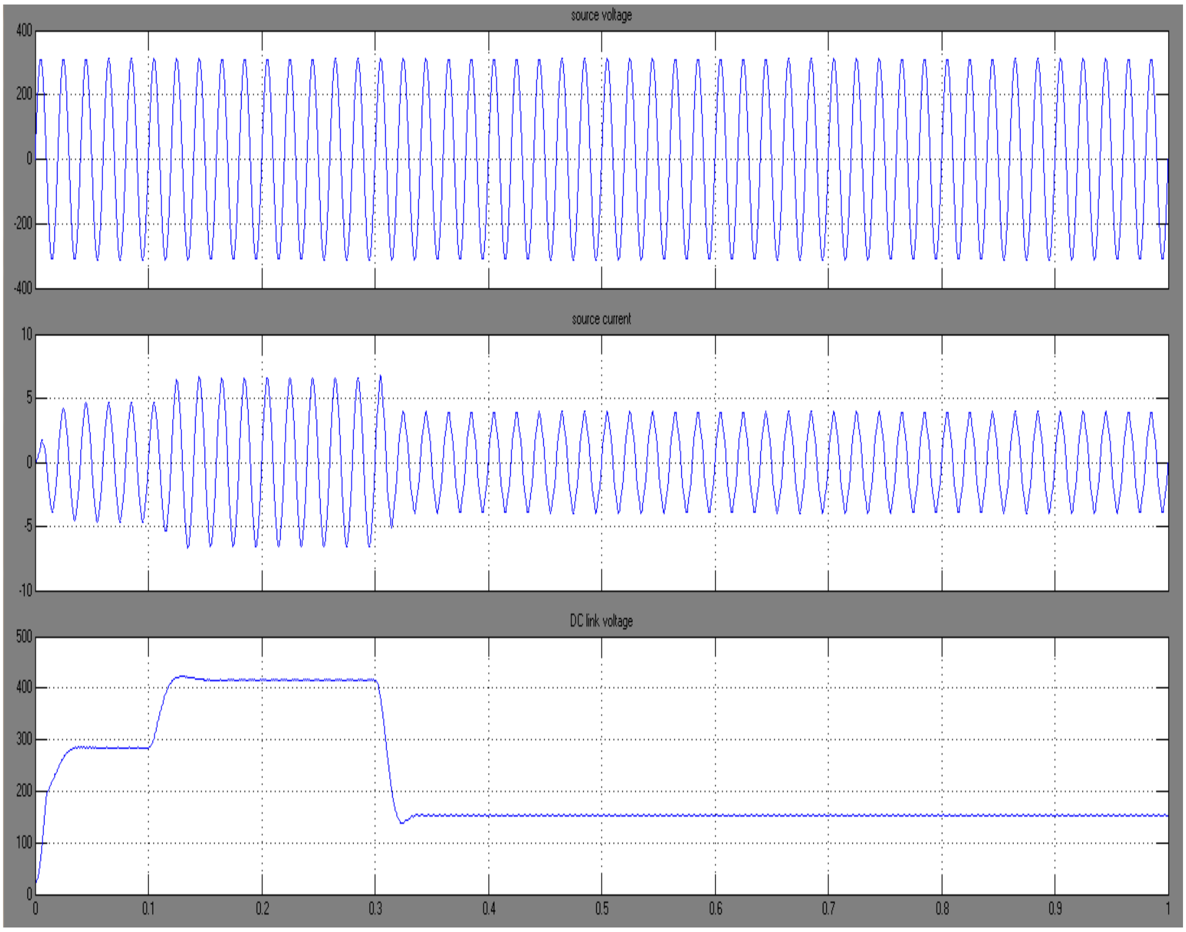

Fig.13: Source voltage, source current and DC link voltage waveforms

V. CONCLUSION

A Quadruple Lift Positive Output Luo Converter for VSI fed BLDC motor drive has been modelled to maintain a unity power factor at the supply mains for the lowest cost PFC motor for low power equipments like blowers, fans, water pumps, etc. By varying the DC link voltage of VSI, the speed of the BLDC motor drive has been controlled which employs the reduced sensor with fundamental frequency switching of the VSI to reduce the switching losses. Also by completely eliminating the DBR the conduction losses are reduced to a large extent and increase the efficiency. The operating modes of the converter are also presented. Finally, the proposed converter has been simulated with load variations at 0.1 Sec and 0.3 Sec with time of operation of 1Sec and the satisfactory results has been obtained.

REFERENCES

[1]. C.L.Xia, *Permanent Magnet Brushless DC Motor Drives and Controls*. Hoboken, NJ, USA: Wiley, 2012.

[2]. R.Geshma Kumari, Dr .S.Tara Kalyani , " Modeling and Control of PMBLDCM Using PFC Half &Full Bridge Converter," *International Journal of Engineering and Innovative Technology, Volume 3, Issue 2*, August 2013.

[3]. S. Singh and B. Singh "A power factor corrected PMBLDCM drive for air-conditioner using bridge converter," *IEEE Trans. Power Electron.*, July 2010, pp.1-6.

[4]. Vashist Bist, Bhim Singh,"PFC Cuk Converter Fed BLDC Motor Drive," *IEEE Trans. Power Electron., vol. 30, no. 2*, pp. 871–887, Mar. 2014.

[5]. Vashist Bist, Bhim Singh," A BL-CSC Converter Fed BLDC Motor Drive with Power Factor Correction," *IEEE Trans. on Industrial Electron., Vol. 62, no. 1*, pp. 172-183, May 2014.

[6]. Vashist Bist, Bhim Singh, "An Adjustable-Speed PFC Bridgeless Buck–Boost Converter-Fed BLDC Motor Drive," *IEEE Trans. on Industrial Electron., Vol. 61, no. 6*, pp. 2665– 2677, June 2014.

[7]. Vashist Bist, Bhim Singh," A PFC Based BLDC Motor Drive Using a Bridgeless Zeta Converter," *IEEE,Industrial Electronics Society*, pp. 2553– 2558, Nov-2013.

[8]. F.L.Luo and H.Ye, "Positive output super lift converters," *IEEE Transaction on power electronics, Vol.18, No. 1*, pp. 105-113, January 2003.

[9]. Fang Lin Luo and Hong Ye. *Advanced DC/DC Converters*. CRC Press 2004, London, U.K.

[10]. A Taskori et al, "Modelling of BLDC motor with ideal back emf for automotive application," *Vol II, WCE 2011*, July 6 - 8, 2011, London, U.K.