

A PFC Based Four Switch BLDC Motor

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ABSTRACT: A BLDC Motor is well suited in large number of applications because of its high efficiency, high reliability, high torque and watt per unit weight, long life time. In conventional control method of BLDC motor a bridge rectifier with a 6 switch VSI were used. But the major problem involved in this method is that the current wave form become distorted and the supply power factor reduced. In this paper a PFC (Power Factor Corrected) bridgeless zeta converter based VSI (Voltage Source Inverter) fed BLDC motor drive. The major function of this research is to control the brushless DC motor with sensorless control of four switch three phase inverter. This system simplified the topological structure of the six switch 3 phase inverter.

KEYWORDS: BLDC brushless dc motor; PFC power factor correction

I. INTRODUCTION

development of an efficient and low cost motor drive is required which focuses on low and medium power equipments like air conditioner refrigerators, fans and many appliances used in medical field and industrial applications. The cost reduction involves reducing the number of sensors, using simple control and requirement of low amount of signal processing which in turn requires a low cost DSP (Digital Signal Processor). also, requirement of high efficiency in reducing the losses in the drive system components such as DBR (Diode Bridge Rectifier), front end converter and VSI (Voltage Source Inverter). The development of such motor drive which can fit for the above mentioned applications with high efficiency and minimum cost is the main objective of this work. A BLDC (Brushless DC) motor is well suited in large number of applications because of its high efficiency, high reliability, high torque and watt per unit weight, low noise level, low EMI (Electro-Magnetic Interference), low maintenance requirements and long lifetime. This motor is also known as an ECM (Electronically Commutated Motor) since it has no brushes and commutator, rather an electronic commutation through VSI is used with switching sequence of VSI's switches depending upon the rotor position as sensed by Hall Effect position sensors. The BLDC motor is a trapezoidal back-emf motor having permanent magnets on the rotor and three phase windings on the stator. A single phase supply feeding a DBR with DC link capacitor followed by a VSI draws peaky supply current which have high amount of harmonics. This leads to a high value of THD (Total Harmonic Distortion) of supply current and thus a low power factor at the AC mains which is not acceptable by International power quality standards such as IEC-61000-3-2 [1]. Many configurations are reported in the literature regarding harmonic reduction in a single phase supply system. A two stage PFC converters have been widely used, in which two different stages i.e. a boost PFC stage and a buck/ buckboost stage for voltage control [2]. This suffers from a major disadvantage of high number of components thus high losses and two independent control circuits for PFC and voltage control. Single stage PFC converters have gained importance due to simplicity in design and low amount of losses due less count of components [3,4]. Single stage isolated PFC converters use high frequency isolation transformer which is compact in size and thus reducing the space requirement of the PFC converter and provides isolation between input and output [4]. Bridgeless converters have gained importance due to elimination of DBR at the input which consequently reduce the conduction losses of diodes and thus improve the overall efficiency of the converter. Elimination of two diodes or complete elimination of diodes in a DBR depends upon the configuration of the converter. A bridgeless topology utilizing SEPIC and Cuk converter have been widely used for the development of the PFC converter with improved power quality at the AC mains [5]. An isolated Zeta converter operating in CCM (Continuous Conduction Mode) or DCM (Discontinuous Conduction Mode) is widely used for PFC applications. DCM is preferred for low and medium power applications because it utilizes an approach of voltage follower which requires a single voltage sensor for DC link voltage control and PFC operation. CCM uses a current multiplier technique, which

requires three sensors (one current and two voltage sensors) for operation and thus increases the overall cost of drive system. This paper explores the potential of Zeta converter for BLDC motor drive targeting special class of applications. Moreover, possibilities of employing a bridgeless configuration in Zeta converter are still unexplored. The drive system is needed to be developed which must incorporate features like low cost, high efficiency and satisfactory performance with improved power quality at the AC mains for a wide range of speed control. This work is targeted to achieve all these objectives in the proposed drive.

II. PROPOSED BRIDGELESS ZETA CONVERTER

Figure 1 shows the proposed bridgeless Zeta converter based VSI fed BLDC motor drive. A single stage, bridgeless Zeta converter is used for the DC link voltage control and PFC operation. A front-end converter operating in DCM utilizes a voltage follower approach which requires a single voltage sensor for PFC and voltage control. This eventually, reduces the cost of the drive system on behalf of sensor reduction. Since, the speed is controlled by controlling the DC link voltage of the VSI, hence fundamental frequency switching of the VSI (through electronic commutation of BLDC motor) is used which offers low switching losses [8]. Moreover, the conduction losses of the DBR are reduced to half by using a bridgeless topology which also offers improved thermal utilization of the converter's switches. The performance of the proposed drive is evaluated for wide range of speed control with improved power quality at AC mains. Performance is also evaluated for wide variation in supply voltages to demonstrate the performance for practical supply systems. The power quality indices thus obtained are observed within the prescribed limits by international power quality standards such as IEC-61000-3-2 [1].

Operation of Bridgeless Zeta Converter

A bridgeless topology is designed such that two switches conduct independently for the positive and negative half cycle of the supply voltage [5-7]. The conduction losses of the DBR are reduced to half as compared to conventional topology due to the bridgeless configuration. Moreover, this also improves the thermal utilization of switches since switch rms current is divided into two switches.

A. OPERATION DURING COMPLETE CYCLE OF SUPPLY VOLTAGE

Figure 2 (a) and (b) show the operation of bridgeless Zeta converter for a positive and negative half cycle of the supply voltage respectively. As shown in Figure 2(a), switch Sw1 and diode D1 conduct for the positive half cycle of the supply voltage and diode D2 remains reverse biased during this period. Similarly for the negative half cycle of the supply voltage, switch Sw2 and diode D2 conduct and no current flows through switch Sw1 and diode D1 as shown in Figure 2(b). The energy is transferred through HFT (High Frequency Transformer) which turns ratio is given as $N1:N1:N2$. The magnetizing inductance (L_m) is designed to operate in DCM such that a discontinuous conduction is achieved for a wide range of DC link voltage control to achieve an inherent power factor correction.

B. OPERATION DURING COMPLETE SWITCHING CYCLE

Figure 2(a), (c) and (d) show three different modes of operation during a complete switching cycle for positive half cycle of supply voltage. When switch Sw1 is on (Fig. 2(a)), the energy is stored in the HFT, intermediate capacitor C1 and inductor L_o ; whereas DC link capacitor C_d supplies the required energy to the load. When switch is turned off (Fig. 2(c)), the HFT discharges through Diode D and inductor L_o supplies the required energy to the DC link capacitor. In the DCM mode of operation (Fig. 2(d)), the HFT is completely discharged, whereas inductor L_o continues to supply the required energy to the DC link capacitor. Variation of different parameters such as HFT current (i_{Lm}), inductor current (i_{L_o}), intermediate capacitor's voltage (V_{C1}) and DC link voltage (V_{dc}) is shown in Fig. 2(e).

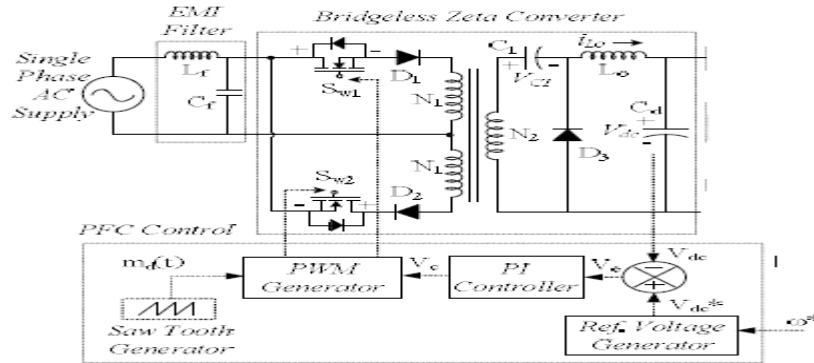


Figure 1 Proposed bridgeless Zeta converter

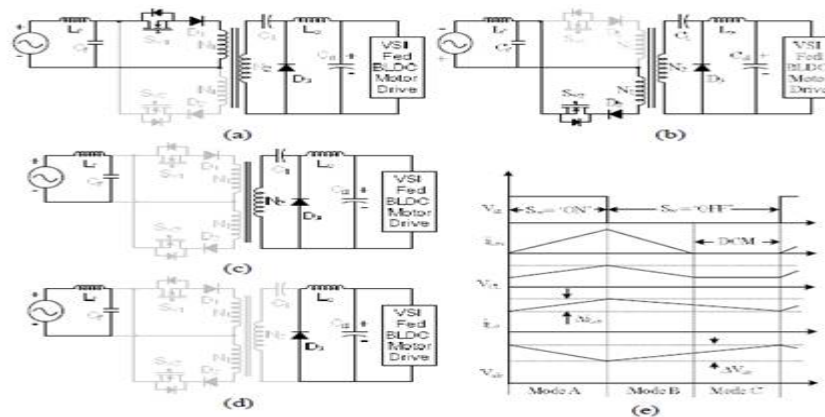


Figure 2 (a-d) Different modes of operation of the proposed bridgeless Zetaconverter fed BLDC motor drive and the (e) associated waveforms

C.DESIGN OF BRIDGELESS ZETA CONVERTER FED BLDC MOTOR DRIVE

A 500W PFC bridgeless Zeta converter is designed for VSI fed BLDC motor drive with the following specifications; Po (output power) = 500W, Vs (supply voltage) = 220V, Vdc (DC link voltage) = 130V, fL (line frequency) = 50 Hz, N2:N1 (transformation ratio of HFT) = 1:2, ΔiLo (permitted ripple current in inductor Lo) = 10% of Io, ΔVc1 (permitted ripple voltage in intermediate capacitor C1) = Vm (peak of input voltage), ΔVdc (permitted DC link voltage ripple) = 2% of Vdc, fS = 45kHz. (Complete specifications of BLDC motor are given in Appendix). The input voltage Vs is given as,

$$V_s = V_m \sin(2\pi f_L t) = 311 \sin(314t)$$

where Vm is peak input voltage, fL is line frequency i.e. 50 Hz. The input average voltage is given and calculated as [2],

$$V_{in} = \frac{2V_M}{\pi} = \frac{2 \times 311}{\pi} = 197.98V \approx 198V$$

The output voltage, Vdc of isolated Zeta converter is given as [12],

$$V_{dc} = \left(\frac{N_2}{N_1}\right) \frac{D}{(1-D)} V_{in}$$

where D is the duty ratio. From equation (3), duty ratio D is calculated as,

$$D = \frac{V_{dc}}{V_{dc} + (N_2/N_1)V_{in}} = \frac{130}{130 + 0.5 \times 198} = 0.5677$$

The value of equivalent load resistance (RL) is calculated as,

$$R_L = \frac{V_{dc}^2}{P_0} = \frac{130^2}{500} = 33.8\Omega$$

The critical value of magnetizing inductance Lm(critical) of HFT to operate at boundary of CCM and DCM is given as [12],

$$L_{mc} = \frac{R_L(1-D)^2}{2Df_s(N_2/N_1)^2} = \frac{33.8 \times (1-0.5677)^2}{2 \times 0.5677 \times 45000 \times 0.5^2} = 494.5\mu H$$

The value of magnetizing inductance Lm is selected such that,

$$L_m \ll L_{mc}$$

Hence from equation (6), the value of Lm is selected as 300μH for its operation in DCM. The value of output inductor Lo is calculated as [12],

$$L_0 = \frac{V_0(1-D)}{f_s \Delta i_{L0}} = \frac{130 \times (1-0.5677)}{45000 \times 0.1 \times 3.846} = 3.247mH$$

Hence a value of 3.3mH is selected for output inductor Lo. The value of intermediate capacitor C1 is given and calculated as [4]

$$C_1 = \frac{V_{dc}D}{\Delta V_{Cin} R_L f_s} = \frac{V_{dc}D}{V_m R_L f_s} = \frac{130 \times 0.5677}{311 \times 33.8 \times 45000} = 56nF$$

The value of intermediate capacitor is selected as 150nF. The value of DC link capacitor is given and calculated as [12],

$$C_d = \frac{I_{dc}}{2\omega_L \Delta V_{dc}} = \frac{3.846}{2 \times 314 \times 0.02 \times 130} = 2355.55 \mu F$$

Hence the value of DC link capacitor is selected as 2200μF. An EMI filter is designed to avoid the reflection of high switching frequency in the supply system [9]. The maximum value of filter capacitance Cmax is given and calculated as [21],

$$C_{max} = \frac{I_{peak}}{\omega_L V_{peak}} \tan(\theta) = \frac{500 \sqrt{2}/220}{314 \times 311} \tan(1) = 574.5nF$$

Where

Ipeak is the peak input current, Vpeak is the peak input voltage and θ is the displacement angle. The value of filter capacitance Cf is selected such that Cf is lower than Cmax, hence the value of Cf is selected as 330nF. The expression for the calculation of filter inductance Lf is given as [21]

$$L_f = \frac{1}{4\pi^2 f_c^2 C_f} = \frac{1}{4\pi^2 \times 4500^2 \times 330 \times 10^{-9}} = 3.79mH$$

where fc is the cut-off frequency such that fc=fs/10 [21]. Hence the filter inductance is selected as 4mH

D.CONTROL OF BRIDGELESS ZETA CONVERTER

A bridgeless Zeta converter working in DCM and controlled using a voltage follower approach; acts as an inherent power factor pre-regulator. The PFC control unit as shown in **Figure 1** is used for the generation of PWM signals to the switches Sw1 and Sw2 of the front end converter to maintain a desired DC link voltage of VSI and near unity power factor at AC mains. The control scheme of the proposed bridgeless Zeta converter fed BLDC motor drive consists of a reference voltage generator, voltage error generator, voltage controller and a PWM generator

E.CONTROL OF BLDC MOTOR FOR ELECTRONIC COMMUTATION

The three-phase inverters with only four switches, as shown in **Figure 3** is striking solution for Six-Switch Inverter to reduce mechanical Strength and Switching Losses. In addition to that with the normal three-phase voltage-source inverter with Four switches, the most important descriptions of this proposed converter plays dual role i) the first is the

reduction of Switches and Freewheeling diode count; ii) the second is the reduction of conduction losses. They used Position sensors to achieve commutation (Mechanical) control of Brushless DC motors.

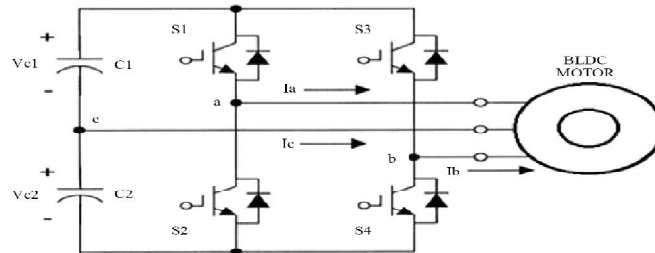


FIGURE 3.PROPOSED FOUR-SWITCH THREE PHASE INVERTER BRUSHLESS DC MOTOR DRIVE SYSTEMS

Among the implements, the three phase inverters have only four switches, the main description of these proposed inverter are reduction of switches and conduction losses. Until now, reduced components have been applied in AC induction motor drives, however now a day the Brushless DC motor drives are using due to its high power factor, high speed, high torque, simple control and lower maintenance. The Four-Switch Three Phase Inverter (Four-switch Three Phase Inverter) used in six commutation modes based on current control and Senso less control schemes. [10] developed Brushless DC motor drives with trapezoidal back electromotive force (EMF) using the Four-Switch Three-Phase Inverter. The four-space-vector scheme was used in the six commutation modes based on current control. In these Brushless DC drive configuration, the DC supply given to Fourswitch inverter it converts DC power to three phase AC power. In proposed method single phase to three phase converter back end consists of four switches (T1 to T6). In three phase Brushless DC motor, two phases A and B are connected to the two legs of the Four-switch Three phase inverter and the third phase C is connected to the centre point of the capacitor. Phase C is directly connecte to the Brushless DC motor, so the phase C current is not directly controlled [11]

$$S_a + S_b + S_c = 0$$

$$S_c = -(S_b + S_a)$$

Therefore, phase C indirectly controlled by phase A and phase B. For Brushless DC motors with a trapezoidal back EMF, is required to produce a constant electric torque. The proposed voltage Pulse Width Modulation(PWM) scheme for Four-switch three phase inverter requires six commutation modes which are (X, 0), (1, 0), (1, X), (X, 1), (0, 1) and (0, X) [12]. Here “X” stands for Don’t care conditions.

III. EXPERIMENTAL RESULTS

Total harmonic distortion and input supply currents are shown in the **Figure 4**. The simulation of proposed research four-switch BrushlessDC Motor is carried by Simulink and its Simulink model are shown if **Figure 5**. To generate the pulse width modulation signals subsystems are proposed which is shown in **Figure 6**. The reference speed is set and rotor position sensor speed sensed are given to the controller if it is equal it is send to the controller or error is generated and rectified and it is given to the controller then the switches generates the Pulses. The Pulse width modulation signals generated by the switches from the output of controller are shown in **Figure 7**. It is carried out by voltage and timeperiod and the results are taken from simulink environment. The DC voltage which is fed an input supply gives the output after then rectification which is prese inbuilt

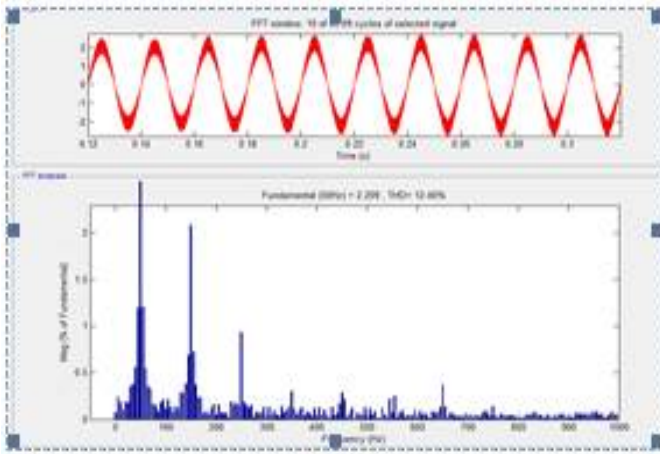


Figure 4 Harmonic spectra of AC mains current, IIN
(a) at 270 V AC mains and 100% load.
(b) at 170 V AC mains and 100% loa

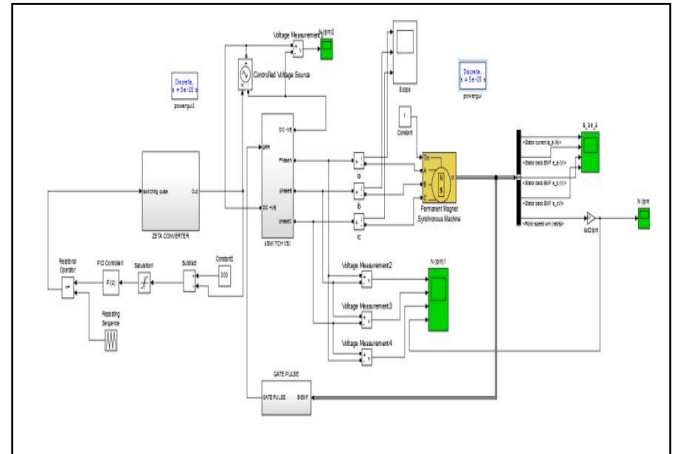


Figure 5: Simulation model of proposed four-switch three phase inverter system

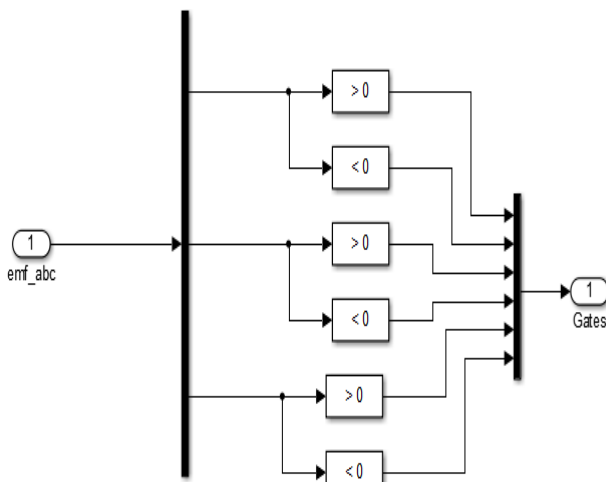
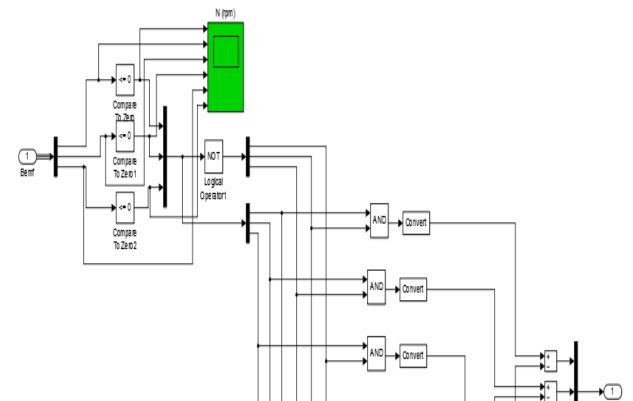


Figure 6.Subsystem of Pulse width modulation generation for switches (T1-T4)



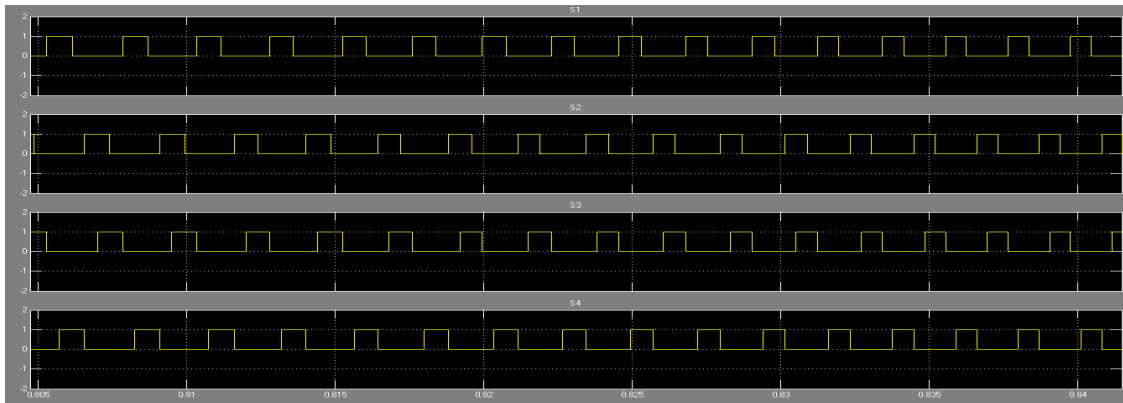


Figure 7. pulse generation for switches (T1-T4)

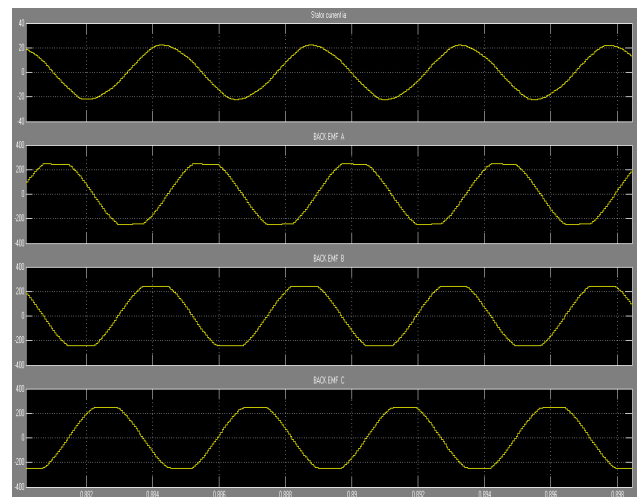
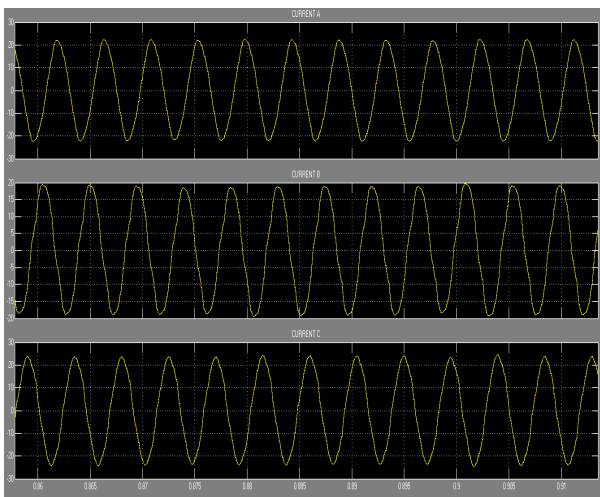


Figure 8 & 9Phase current of the Sensorless four switch three phase inverter Brushless DC motor Back EMF of brushless DC motor

IV. CONCLUSION

Single stage PFC converters have gained importance due to simplicity in design and less amount of losses due less count of components. In this research, we significantly use sensorless control, so for angle position hall sensing fully avoided. Brush- less DC drives which is preferable for compact, low maintenance and high reliability system in order to reduce the mechanical strength so it proposed and convenient simulation results are carried out. In this the back electromotive force compensating and direct current controlling for brushless DC motor drives analyzed. In this scheme, the pulse width modulation is applied to high side switches of the converter. The power factor correction operation is carried out by using bridgeless zeta converter and PF controller. This proposed converter used sensorless control operation. There are no hall sensors, therefore, the system becomes robust, optimized design of the brushless DC. motor achieves higher efficiency and better speed, current is formulated.

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