International Journal of Advanced Information Science and Technology (IJAIST) ISSN: 2319:2682
Vol.4,No.7, July 2015 DOI:10.15693/ijaist/2015.v4i7.24-29

A PFC Bridgeless Buck-Boost Converter Fed BLDC Motor with Sensorless Control

Ms Remya V V
PG Scholar, Power Electronics
KMEA Engineering College
Edathala, Kerala, India

Ms Ann Mary Thomas
Assistant Professor, EEE Department
KMEA Engineering College
Edathala , Kerala, India

Abstract— **This paper discusses a position sensorless brushless direct current (BLDC) motor drive fed by a bridgeless(BL) buck-boost converter. The BL buck-boost converter act as a power factor correction (PFC) stage and a variable dc link voltage provider for the BLDC motor fed from a single phase AC supply. BL configuration of the converter contributes to the efficiency improvement and discontinuous conduction mode (DCM) operation of the BL buck-boost converter has inherent PFC capability through voltage follower control. The voltage source inverter (VSI) feeding the BLDC motor allows fundamental frequency switching which reduces switching losses. A sensorless control of BLDC motor is used based on detection of back electromotive force (back EMF) zero crossing from the terminal voltages. The proposed method relies on a difference of line voltages measured at the terminals of the motor. Simulation of this position sensorless BLDC drive fed from a PFC, BL buck - boost converter has done in MATLAB and the validity is proved.**

Indexterms —Bridgeless,Power factor correction,Discontinuous conduction mode,Sensorless control,Back EMF

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 as their architecture is suitable for any safety critical applications. The increase in energy prices spurs higher demands of variable speed PM motor drives. Also, recent rapid proliferation of motor drives into the automobile industry, based on hybrid drives, generates a serious demand for high efficient PM motor drives, and this was the beginning of interest in BLDC motors. A BLDC motor has three phase windings on the stator and permanent magnets on the rotor.The BLDC motor is also known as an electronically commutated motor because an electronic commutation based on rotor position is used rather than a mechanical commutation which has disadvantages like sparking and wear and tear of brushes and commutator .

BLDC motors are usually fed by a diode bridge rectifier followed by a dc link capacitor .But this practice results in various power quality disturbances such as high total harmonic distortion (THD) and low power factor (PF). . Single stage PFC converter has gained importance because of high efficiency as compared to two-stage PFC converters due to low component count and a single switch for dc link voltage control and PFC operation. For improvement in efficiency, bridgeless (BL) converters are used which allow the elimination of DBR in the front end. A buck–boost converter configuration is best suited among various BL converter topologies for applications requiring a wide range of dc link voltage control (i.e., bucking and boosting mode).

The DC-DC converter which is a general solution for total harmonic reduction and power factor improvement can have either continuous conduction mode(CCM) or discontinuous conduction mode(DCM). To get rid of the complicated control circuit invoked by CCM shaping technique and to reduce the cost of the electronic interface, DCM input technique can be adopted in low power to medium power level applications. The benefit of using DCM input circuit for PFC is that no feed forward control loop is required. This is also the main advantage over a CCM PFC circuit, in which multi loop control strategy is essential.

The BLDC motors are generally controlled using a three-phase inverter, requiring a rotor position sensor for starting and for providing the proper commutation sequence to control the inverter switches. These position sensors can be Hall sensors, resolvers, or absolute position sensors. A typical BLDC motor control system with position sensors will increase the cost and the size of the motor, and a special mechanical arrangement needs to be made for mounting the sensors. These sensors, particularly Hall sensors, are temperature sensitive. On the other hand, they could reduce the system reliability because of the components and wiring. In some applications, it even may not be possible to mount any position sensor on the motor. The sensorless operation of BLDC motor is quite attractive as it provides a low-cost way to extract rotor position information from the motor-terminal voltages. In the excitation of a three- phase BLDC motor, except for the phase-commutation periods, only two of the three phase windings are conducting at a time and the non conducting phase carries the back-EMF.As the back-EMF is a measure of rotor position, it can be measured to determine the switching sequence for commutation of switches in the inverter.

II. Block Diagram Of The Proposed System

The proposed system consists of a bridgeless buck – boost converter in DCM mode acting as a front end PFC stage feeding a BLDC motor. As a lower loss alternative, the input bridge rectifier has been eliminated to develop the dual use circuit. The DCM input technique of the converter is adopted which require a single voltage sensor for dc link voltage control.

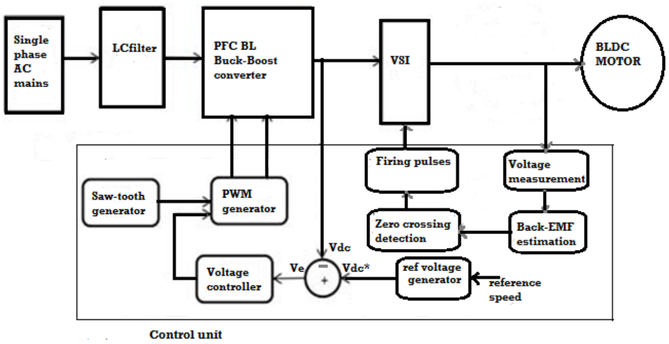

Figure 1: Block diagram of proposed system

In DCM, the input current is normally a train of triangle pulses with nearly constant duty ratio. Therefore, an input filter is necessary for smoothing the pulsating input current. The input inductor operating in DCM cannot hold the excessive input energy because it must release all its stored energy before the end of each switching cycle. As a result, a bulky capacitor is used to balance the instantaneous power between the input and output. In each of the half cycle the dc link capacitor is feeding the drive through different modes. The VSI ,electronic commutator of the BLDC motor is provided with the gate signals from sensorless control scheme. Back-EMF Zero Crossing Detection method is employed to determine the rotor position for electronic commutation.

III. BL Buck-Boost Converter And Operating Modes

The circuit consists of Lf and Cf as the filter inductance and capacitance at the input stage .This low pass filter helps in reducing the switch stress as the DCM mode of the converter has high peak current.

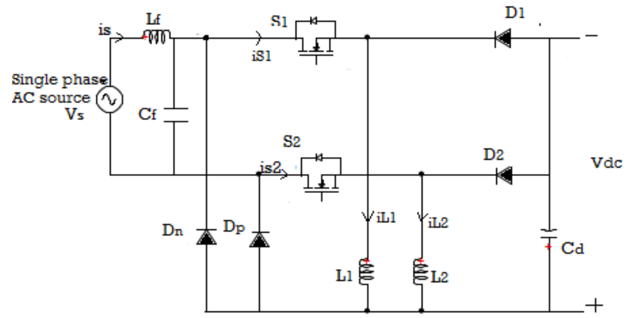

Figure 2: BL Buck-Boost converter

S1,L1and D1 are the buck-boost converter components operating in the positive half cycle of supply voltage and S2,L2 and D2 are the buck-boost components operating in the negative half cycle. The BLDC motor is fed through a high value DC link capacitor Cd.
The circuit is operating in three modes in each switching cycle.

A. *Operation during positive half cycle*

Mode I: The switch S1 is conducting for a period of ton to charge the inductor L1.Inductor current iL1 increases and diode Dp completes the input side circuit. The left over charge in the DC link capacitor is feeding the BLDC motor. It is shown in Figure 3(a).

Mode II : In this mode the switch S1 is turned off and the stored energy in the inductor is completely transferred to the load via the DC link capacitor. Hence inductor current completely decreases to zero in this mode as shown in Figure3(b).

Mode III : In this mode none of the switches and diodes are conducting as the inductor L1 is discharged completely in the previous mode. The DC link capacitor continues to feed the motor in this mode also as shown in Figure 3(c).

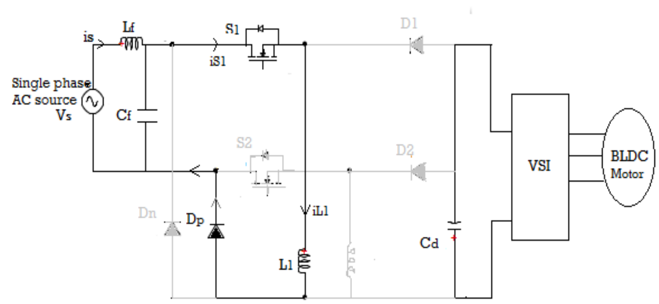

Figure 3(a): ModeI during positive cycle

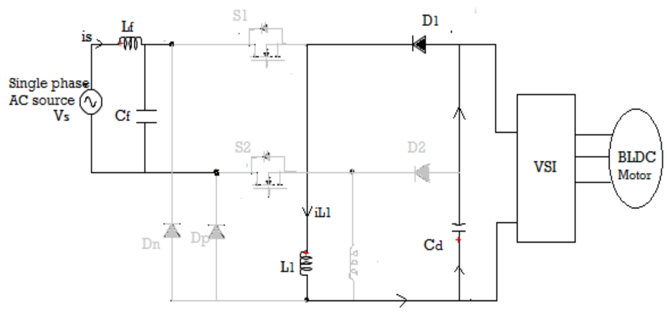

Figure 3(b):ModeII during positive cycle

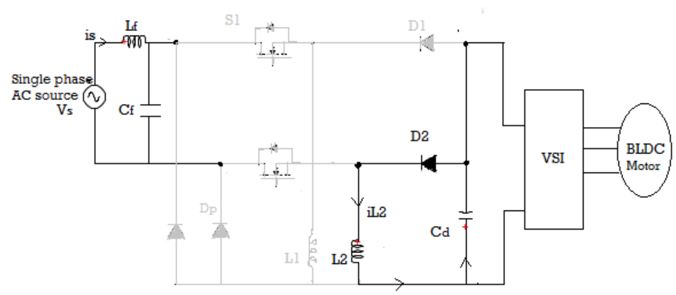

Figure 4(b): Mode II during negative cycle

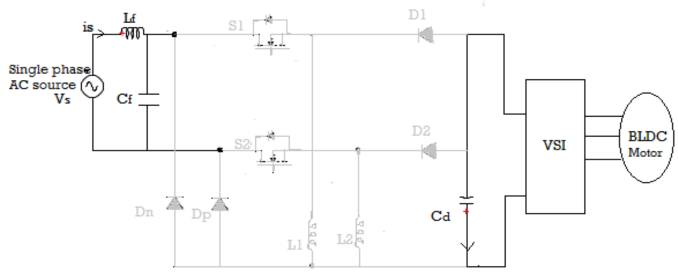

Figure 3(c): Mode III during positive cycle

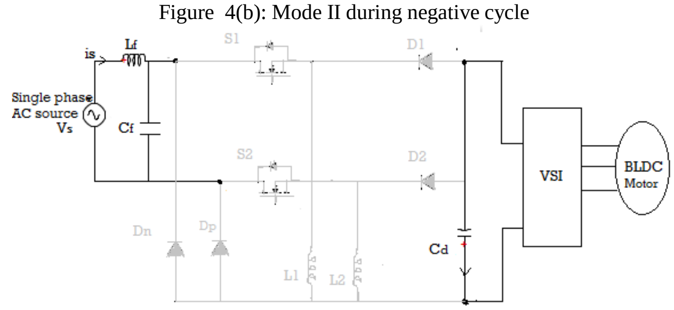

Figure 4(c): Mode III during negative cycle

B .Operation during negative half cycle

During this half cycle of operation the switch S2, inductor L2 and the diodes Dn, D2 are operated to transfer energy from input to the load.

Mode I: The switch S2 is conducting to charge the inductor L2.Inductor current iL2 increases and diode Dn completes the input side circuit. The left over charge in the DC link capacitor is feeding the BLDC motor.It is shown in Figure4(a).

Mode II: In this mode the switch S2 is turned off and the stored energy in the inductor is completely transferred to the load via the DC link capacitor. Hence inductor current completely decreases to zero in this mode as shown in Figure4(b).

Mode III : In this mode none of the switches and diodes are conducting as the inductor L2 is discharged completely in the previous mode. The DC link capacitor continues to feed the motor in this mode also as shown in Figure4(c).

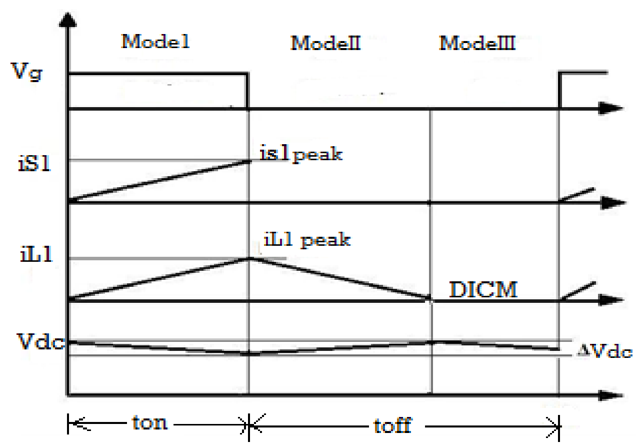

Figure 5(a): Waveform during a switching cycle

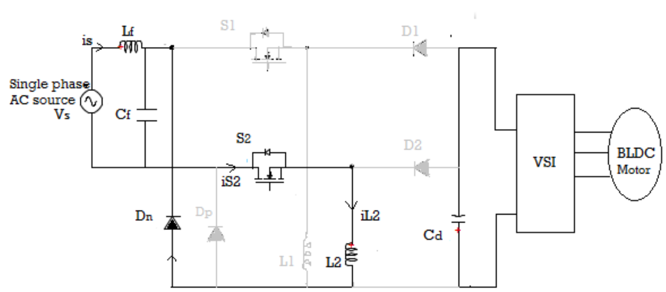

Figure 4(a): ModeI during negative cycle

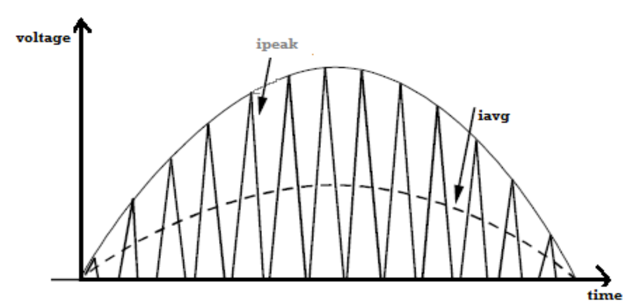

Figure 5(b): current envelope in voltage follower control

The envelop of current in voltage follower control is depicted in Figure 5(b) which uses the DCM operation of the converter i.e. the current becomes zero in each switching cycle. And the inductor current is independent of the previous value.

IV VOLTAGE SOURCE INVERTER FEEDING THE BLDC

The inverter changes the DC input voltage of the converter to a symmetrical AC output voltage with desired magnitude and frequency. The converter provides variable DC input so that the inverter switches can be driven at a fixed frequency. And variable output voltage can be obtained.

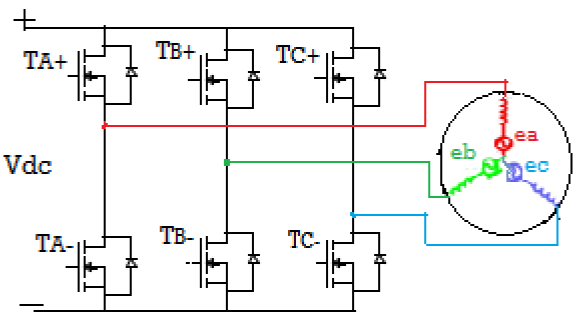

Figure 6:Voltage source inverter

V CONTROL OF BL BUCK BOOST CONVERTER

The control unit generates the switching pulses for S1 and S2. Since the converter is a DCM input circuit ,which is also called "voltage follower" or "automatic controller." ,in which the input current follows the input voltage automatically, only a single voltage loop is required for the DC link voltage control. The control unit consists of a reference voltage generator such that

$$Vdc^* = kv\ w^* \quad (1)$$

Where ,kv is the motors voltage constant and w* is the reference speed. The reference voltage is compared with the feedback voltage to generate an error signal Ve.

$$Ve = Vdc^* - Vdc \quad (2)$$

This error signal is given to the PI controller to produce the control output voltage.This output control voltage is compared with a sawtooth wave of high frequency to generate the PWM pulses with a condition that if Vs> 0, S1 operates and if Vs< 0 S2 operates.

VI SENSORLESS OPERATION OF BLDC MOTOR

For reducing the cost and size of the motor assembly , a position sensor less control of BLDC motor is used. Since back emf is a function of rotor position, here the line back- emf is used for position detection using zero crossing detector.

A.Open loop starting

The back-EMF detection methods cannot be applied well when the motor is at a standstill or low speed, since back-EMF is zero at that conditions. Hence a starting procedure is needed to start the motor from standstill. The procedure starts by exciting two arbitrary phases for a preset time. At the end of the present time, the open-loop commutation advancing the switching pattern by 120° is done. , and then, the polarity of the motor line current is altered. Then, the rotor turns to the direction corresponding to the exited phases. Next, the commutation signal that advances the switching pattern by 120° is given. After the next commutation the position sensorless drive is attained.

B.Sensorless operation

The sequence of operation of the sensorless scheme is shown in Figure 7.

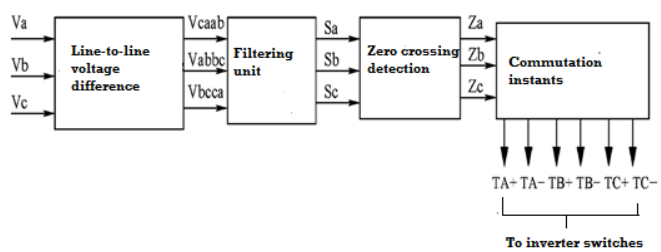

Figure 7:sensorless operation block diagram

Here the back emf is estimated indirectly from the terminal voltage differences. ea, eb and ec are obtained from Vcacb,Vabbc,Vbcca respectively as they match their zero crossing instants. To avoid any false zero-crossing detection these signals are filtered and exact zero crossing is detected to gate the inverter switches. Sample and hold circuit can be used for filtering the voltage spikes in the line voltage difference.

VII SIMULATION RESULTS

The performance of the drive is simulated in MATLAB/Simulink environment using the Sim-Power-System toolbox. The performance of the drive is categorized as power quality achieved due BL Buck-Boost converter at the input side. The parameter associated with BLDC motor such as speed, torque, stator current and back-emf are evaluated. Parameters such as supply voltage, supply current, DC link voltage, inductor current and switch currents are also evaluated to ensure its proper functioning.

The simulation results are shown below. Here the drive is analyzed for two different speeds. Figure 8(a) and 8(b) shows simulation result of the speed and dc link voltage corresponding to a reference speed of 800 rpm. Figure 9(a) and 9(b) shows the simulated waveform of the speed and DC link voltage for a reference speed of 1000rpm.

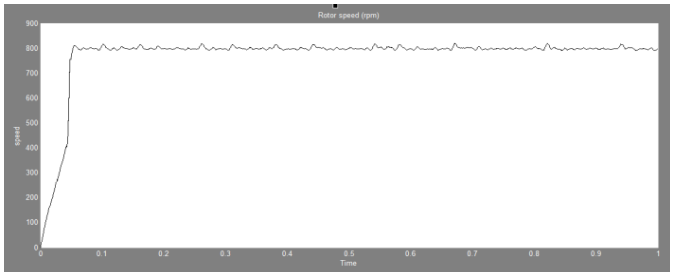

Figure 8(a): Speed control for a reference speed of 800 rpm

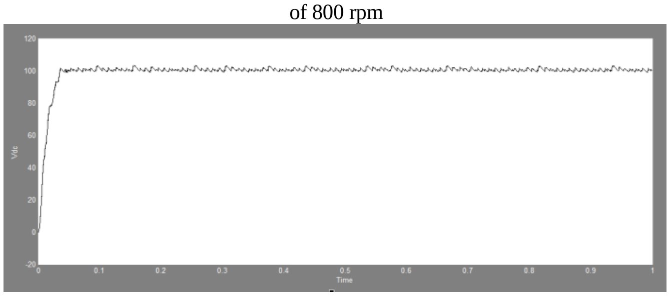

Figure 8(b):DC link voltage level at 800 rpm

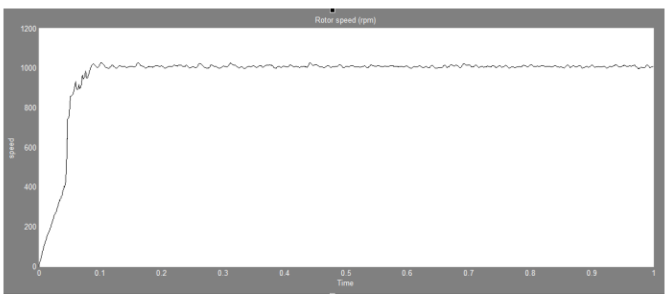

Figure 9(a): Speed control for a reference speed of 1000 rpm

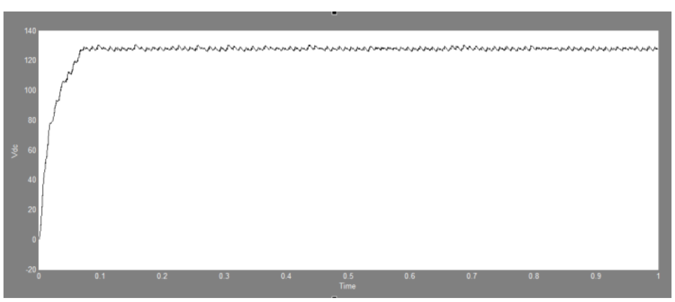

Figure 9(b): DC link voltage level at 1000 rpm

Figure 10 shows the simulated inductor currents iL1 and iL2 corresponding to the positive and negative half cycle of supply voltage. The power quality at the AC mains can be checked by analyzing the input voltage and current waveforms in Figure11(a). The improvement in the power factor and hence the reduction in total harmonic distortion can be detected from Figure 11(b).

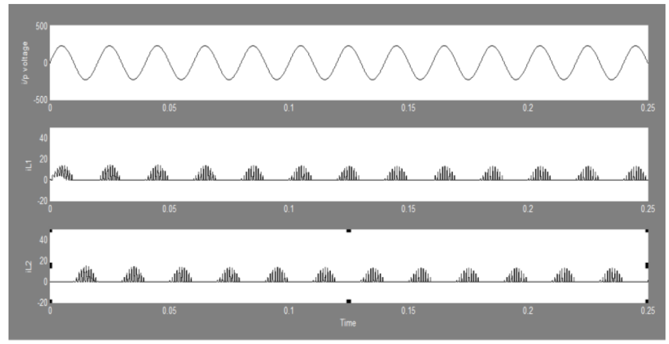

Figure 10: Inductor current for positive and negative half cycle of supply voltage

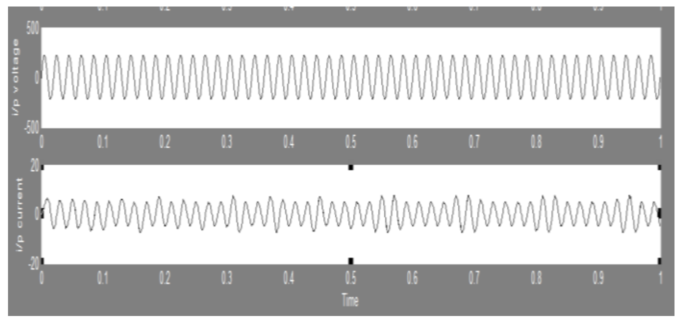

Figure 11(a): Input voltage and current of the BL Buck-Boost converter

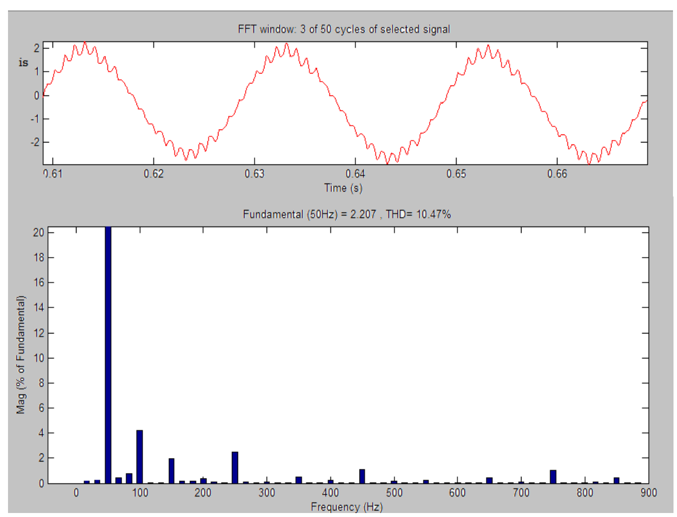

Figure 11(b):THD spectrum of input current

Figure 12 shows simulated stator current and back emf in three phases. The back emf waveforms are displaced by 120degree.

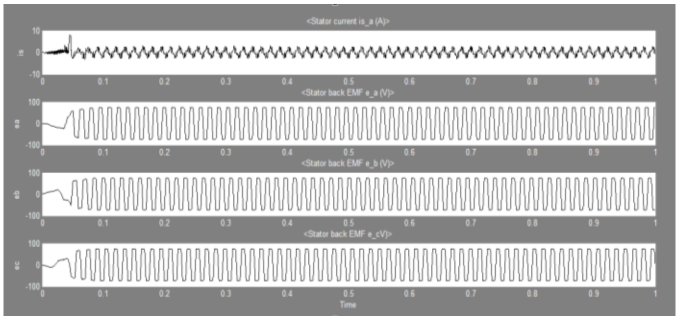

Figure 13:Motor stator current and back_emf

VIII CONCLUSION

A PFC BL buck–boost converter fed BLDC drive with sensorless control has been presented targeting low-power applications. A single-stage PFC converter, bridgeless buck-boost converter is used for power factor correction at the input side. The converter is designed to operate in discontinuous conduction mode to achieve inherent power factor correction. The control of BLDC motor by eliminating the Hall Effect position sensor is proposed. Back-emf zero crossing detection method of sensorless approach is utilized here. This method is based on detecting the instant at which the back-EMF in the unexcited phase crosses zero. The power factor and THD obtained are within the acceptable limits of international standards. Speed of the motor can be varied by varying DC link voltage.

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Authors Profile

Remya VV received her **BTech degree** in electrical & electronics engineering from Govt. College of Engineering, Kannur, Kerala,India. She is currently pursuing **M Tech** in Power Electronics from KMEA Engineering College (under M G University), Kerala . Her areas of interest are Power electronic converters and Electric drives.

Ann Mary Thomas received her Bachelor **degree** in electrical and electronics from DMI College of Engineering Chennai, India. She completed M **Tech** in VLSI Design from RMK Engineering College, Tamilnadu in 2009. Now she is working as an Assistant Professor in KMEA Engineering College.Her interested area also include Power quality and Power electronics.