Fuzzy Based Bridgeless Sepic Rectifier Fed Four Switch Three Phase BLDC Motor Drive

Manisha Emmanuel, Sreepriya R

Abstract— **This paper presents a fuzzy controlled bridgeless-single ended primary inductance converter (BL-SEPIC) fed four switch three phase (FSTP) brushless DC (BLDC) motor drive for low power household applications. Bridgeless configuration offers lower conduction losses due to the elimination of diode bridge rectifier (DBR) at the front end. Other merits of bridgeless PFC topology are: less component counts, simple structure, electrical isolation, and simple control circuitry. Fuzzy logic control has been implemented for converter switching control. The BLDC motor is excited by a Four Switch Three Phase Inverter with minimum number of switches which in turn reduce the associated switching losses. It results in low electromagnetic interference, less complexity of control. The speed of the BLDC motor is controlled by adjusting the DC link voltage of the VSI feeding a BLDC motor. The VSI feeding BLDC motor is used for achieving an electronic commutation of the BLDC motor and operates in a low frequency switching for reduced switching losses in it. The entire control concept has been implemented using MATLAB/ Simulink model.**

Index Terms— ***Bridgeless-SEPIC, Brushless DC (BLDC) Motor, Power Factor Correction (PFC), Voltage Source Inverter (VSI), Four Switch Three Phase (FSTP), Diode Bridge Rectifier (DBR), Fuzzy logic control.***

I. INTRODUCTION

The BLDC motors find wide applications in industry due to their high power density and ease of control. The BLDC motors have high efficiency, low maintenance and low rotor inertia for their increased demand in servo, robotic and domestic applications. The BLDC motor is an AC synchronous motor with permanent magnets on the rotor and windings on the stator. Permanent magnets create the rotor flux and the energized stator windings create electromagnet poles. The rotor is attracted by the energized stator phase. By using the appropriate sequence to supply the stator phases, a rotating field on the stator is created and maintained. This action of the rotor chasing after the electromagnet poles on the stator is the fundamental action used in brushless permanent magnet motors. These motors are also referred as electronically commutated motors, since it require the rotor position information for achieving the electronic commutation of BLDC motor via a three-phase VSI. Power converters are employed with solid state devices which are commonly used as on/off switches. These switches are not ideal and have switching losses and conduction losses which in turn reduce the efficiency of the drive. These losses can be minimized by reducing the number of switches in converters or by using high performance processors. Conventional BLDC motors are excited by six switch three phase inverter. However a low cost drive system is an important consideration in the design and development of modern motor control drives. Consequently, we found that one leg (two switches) in the conventional six-switch converter is not necessary to drive a 3Ø BLDC motor. It results in the possibility of the four-switch configuration instead of the six switches. The main features of FSTPI are reduction of switches and conduction losses. The use of electronic commutation eliminates problems such as sparking, noise and EMI. Due to the absence of brushes and commutators, BLDC motors require less maintenance and operate much more quietly than DC motors. This leads to their use in modern motor control applications.

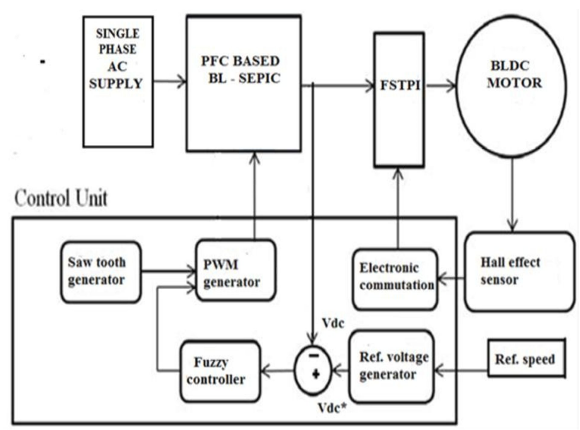

Fig1: Proposed system block diagram.

In the conventional system there is a front end DBR which causes high conduction loss, this loss can be reduced by bridgeless configuration of SEPIC converter. In Bridgeless converters, the absence of an input diode bridge and the presence of only two semiconductor switches in the current flowing path during each switching cycle result in less conduction losses and improved thermal management compared to the conventional Sepic and Cuk PFC converters.

Fuzzy logic has rapidly become one of the most successful technology for developing sophisticated control systems. Several studies show, both in simulations and experimental results that fuzzy logic control yields superior results with respect to those obtained by conventional control algorithms. Thus, in industrial electronics the fuzzy logic control has become an attractive solution in controlling the electrical motor drives. In this paper, a simulation model with the fuzzy logic controller is presented. The fuzzy logic toolbox in MATLAB is used to design fuzzy logic controller, which is integrated into simulations with Simulink.

II. PROPOSED SYSTEM

Fig 1. shows the proposed PFC based BL-SEPIC fed four switch three phase BLDC motor drive. A single-phase supply is used to feed a DBR followed by a filter and a bridgeless SEPIC feeding BLDC motor. The filter is designed to avoid the reflection of

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switching ripples in the DBR and the supply system. This bridgeless-SEPIC is designed to operate in discontinuous inductor current mode (DICM) such that a single voltage sensor is required for voltage control and inherent power factor correction is achieved at AC mains. This combination of DBR and PFC converter is used to feed a BLDC motor drive via a FSTPI as shown in Fig. 1. The speed of BLDC motor is controlled by adjusting the DC link voltage of the VSI via the PFC converter. The VSI is operated in a fundamental frequency switching mode to achieve an electronic commutation of the BLDC motor. The Four switch configuration of inverter helps in reduction of switching and conduction losses.

II.a. PFC BASED BRIDGELESS SEPIC CONVERTER

The operation of proposed PFC BL-SEPIC is divided into two different sections corresponding to its operation for a complete line cycle (i.e. positive and negative half cycles of supply voltage) and complete switching cycle.

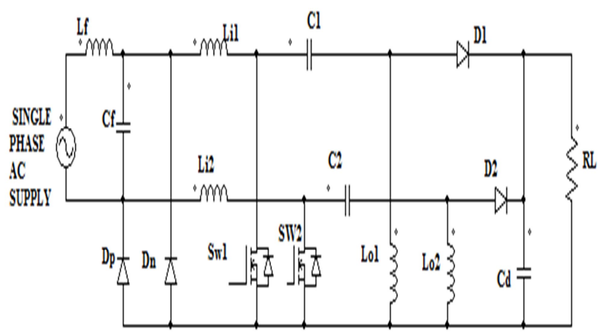


Fig 2: PFC based BL-SEPIC.

The proposed BL-SEPIC is designed such that switches Sw1 and Sw2 operate for positive and negative half cycles of supply voltage, respectively. During the positive half cycle of supply voltage; switch Sw1, input inductor Li1, output inductor Lo1, intermediate capacitor C1 and diode D1 are in state of conduction and vice-versa for negative half cycles of supply voltage.

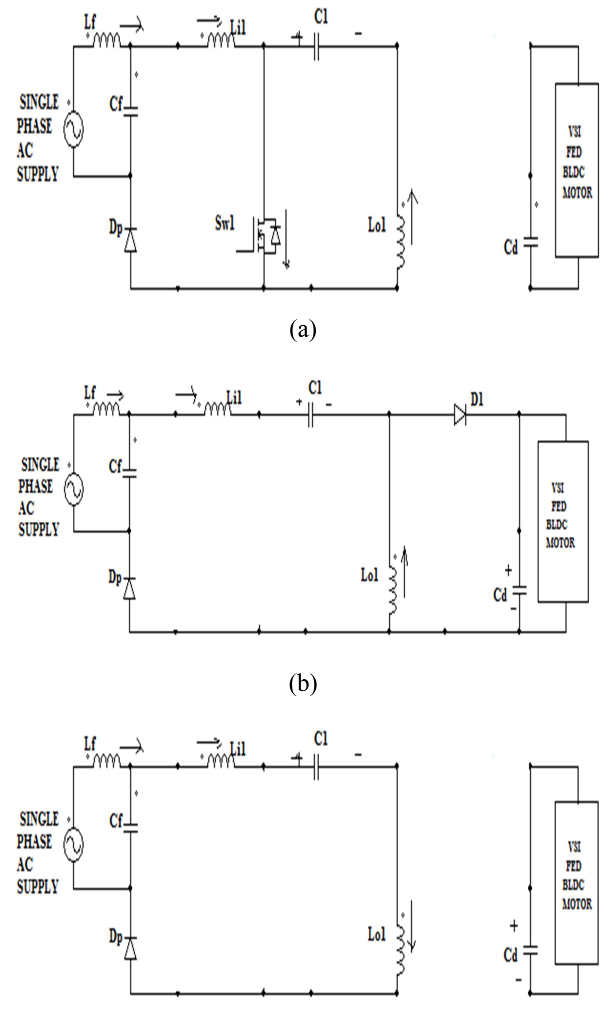
Three modes of operation in a complete switching cycle are given as follows. Fig.3. show three modes of operation for positive half cycle of supply voltage.

Mode I: In this mode, when switch (Sw1) is turned-on, the input inductor (Li1) and output inductor (Lo1) start charging as shown in Fig. 3(a). The intermediate capacitor (C1) discharges via output side inductor (Lo1) and the voltage across it decreases as shown in Fig. 4. The diode (D1) remains in non-conducting state and the DC link capacitor (Cd) supplies the required energy to the VSI fed BLDC motor.

Mode II: When switch (Sw1) is turned-off, the input inductor (Li1) and output inductor (Lo1) start discharging via diode (D1) as shown in Fig. 3(b). Moreover, the intermediate capacitor (C1) charges in this mode of operation as shown in Fig.4. The DC link capacitor (Cd) charges in this interval and the DC link voltage (Vdc) increases in this mode as shown in Fig. 3(b).

Mode III: During this interval, the output side inductor (Lo1) is completely discharged and the input inductor (Li1) continues to discharge as shown in Fig. 3(c). The intermediate capacitor (C1) continues to charge via input inductor (Li1) and the DC link capacitor (Cd) supplies the required energy to the VSI fed BLDC motor drive as shown in Fig. 4.

In a similar way, the operation for the negative half cycle of the supply voltage can be explained.



(a) (b) (c)

Fig. 3: Different modes of operation of a BL-SEPIC during (a-c) positive half cycle of supply voltage.

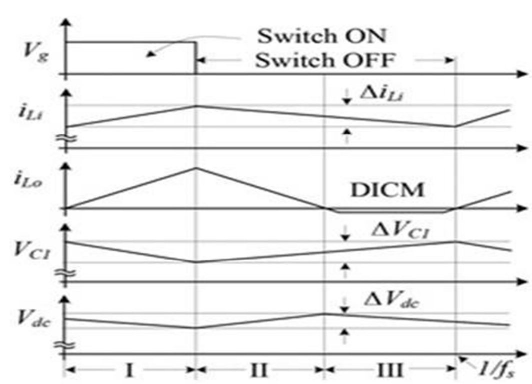


Fig. 4: Waveforms of BL-SEPIC during complete switching cycle.

II. b. FUZZY LOGIC CONTROLLER

FLC is one of the most successful applications of fuzzy set theory, introduced by Zadeh in 1965. Its major features are the use of linguistic variables rather than numerical variables.

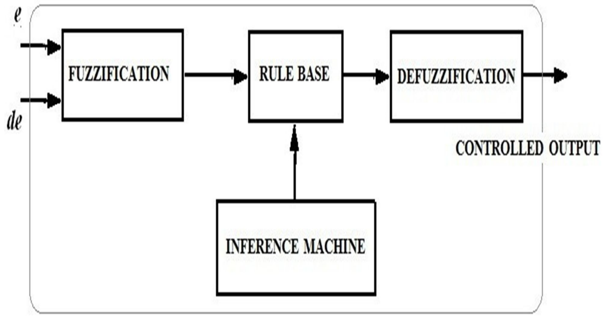


Fig.5: Structure of Fuzzy Logic Controller.

A fuzzy controller consists of four stages, namely fuzzification, knowledge base, fuzzy inference mechanisms and defuzzification. The knowledge base is composed of a data base and a rule base, and is designed to obtain good dynamic responses under uncertainty in process parameters and external disturbances. The data base, consisting of input and output membership functions, provides information for appropriate fuzzification operations, the inference mechanism and defuzzification. The inference mechanism uses a collection of linguistic rules to convert the input conditions into a fuzzified output. Finally, defuzzification is used to convert the fuzzy outputs into control signals.

The conventional PI controller is replaced by a fuzzy controller. In a Fuzzy controller, control action is determined from the evaluation of simple linguistic rules.

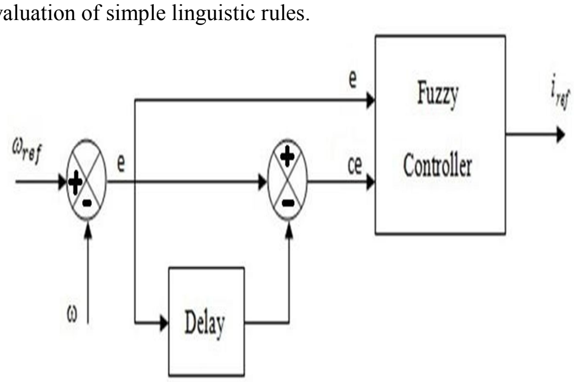


Fig.6: Block diagram of fuzzy control system.

Fuzzy logic controller has two input and one output. Two inputs are error in speed (e) and change in error (ce). The error (e) and change in error (ce) are used as numerical variables from the real system. To convert these numerical variables into linguistic variables, the following seven sets are used: NB, NM, NS, ZO, PS, PM, PB.

TABLE I. Rule base table used in the system.

e/ce	NB	NM	NS	Z	PS	PM	PB
NB	NB	NB	NB	NB	NM	NS	Z
NM	NB	NB	NB	NM	NS	Z	PS
NS	NB	NB	NM	NS	Z	PS	PM
Z	NB	NM	NS	Z	PS	PM	PB
PS	NM	NS	Z	PS	PM	PB	PB
PM	NS	Z	PS	PM	PB	PB	PB
PB	Z	PS	PM	PB	PB	PB	PB

The advantages of fuzzy logic controllers over conventional PI controllers are that they :

- Do not need an accurate mathematical model,
- Can work with imprecise inputs and
- Can handle non-linearities and are more robust than conventional PI controllers.

II .c. FOUR SWITCH THREE PHASE INVERTER

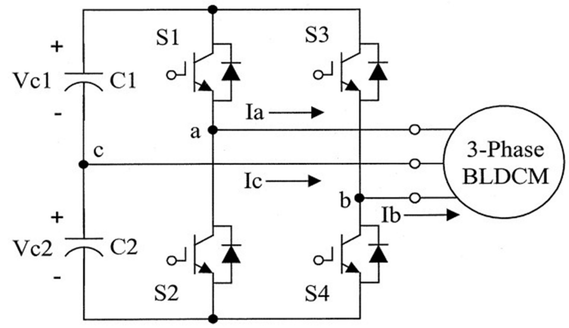


Fig 7: Four switch three-phase inverter.

In single phase to three phase converter back end consists of four switches (S1 to S4). In three phase BLDC motor, two phases A and B are connected to the two legs of the FSTPI and the third phase C is connected to the centre point of the capacitor.

As shown in Fig. 7, two common capacitors, instead of a pair of bridges, are used, and phase *c* is out of control because it is connected to the midpoint of the series capacitors. A conventional PWM scheme for the six-switch inverter is not used for the four-switch inverter topology of the BLDC motor drive. Whole working process of the BLDC motor is divided into six modes, as shown in Table II.

TABLE II. Working mode of the four-switch three phase BLDC motor.

Mode	Hall values	Working Phase	Current restraint	Conducting devices
Mode 1	101	+a,-b	$I_a=I^*, i_b=-I^*$	S_1, S_4
Mode 2	100	+a,-c	$I_a=I^*$	S_1
Mode 3	110	+b,-c	$I_b=I^*$	S_3
Mode 4	010	+b,-a	$I_b=I^*, i_a=-I^*$	S_2, S_3
Mode 5	011	+c,-a	$I_a=-I^*$	S_2
Mode 6	001	+c,-b	$I_b=-I^*$	S_4

The BLDC motor needs quasi-square current waveforms, which are synchronized with the back-EMF to generate constant output torque and have 120°conducting and 60° non-conducting regions. Also, at every instant, only two phases are conductive, and the other phase is inactive. Phase *c* involves four modes, including modes 2, 3, 5, and 6. Only one switch should work in the four modes.

III. SIMULATION RESULTS

In order to verify the performance of the proposed system simulation of prototype models is done in MATLAB/ Simulink environment. A single phase AC supply is given. The converter voltage is selected as 200V. The repeating sequence being utilized in the model has an operating frequency of 20 kHz. The simulation parameters are listed in TABLE. III.

TABLE. III. Simulation Parameters.

Input AC Supply	220 V
Line Frequency	50 Hz
Rated DC bus Voltage	200 V
Switching Frequency	20 kHz
Rated Speed	2000 rpm
Rated Power	280 W
Rated Torque	1.4 Nm

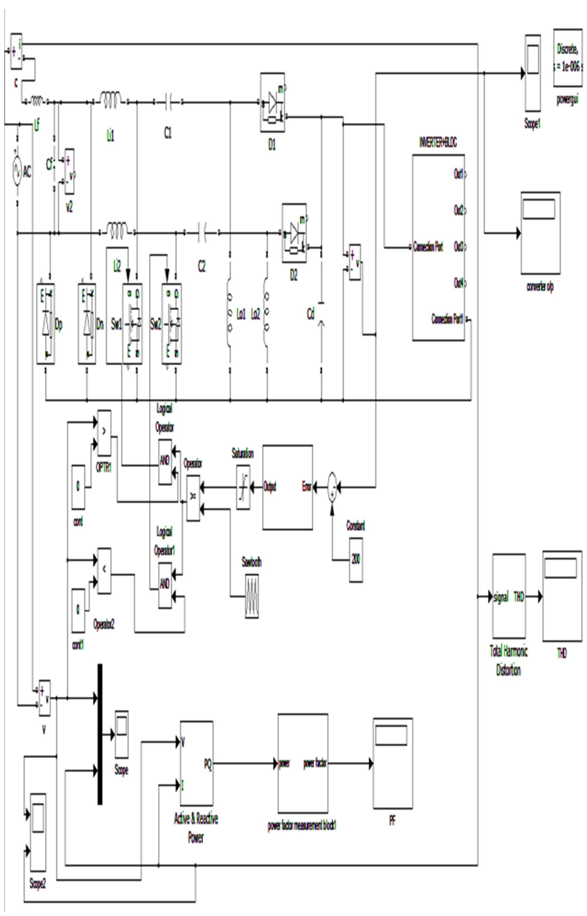


Fig.8: Simulink model of Proposed System.

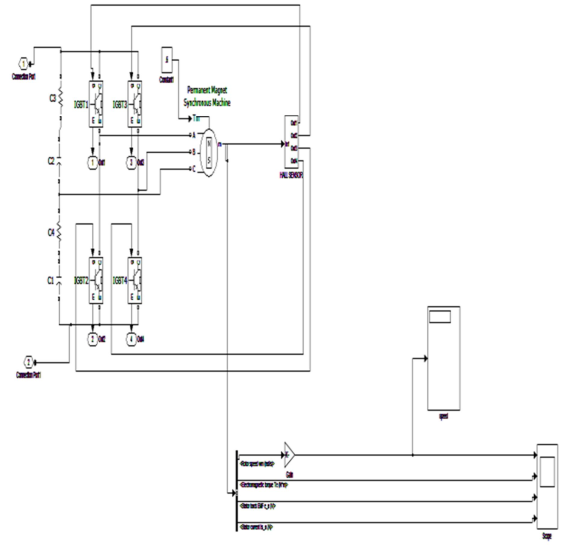


Fig.9: Simulink model of FSTPI fed BLDC motor drive.

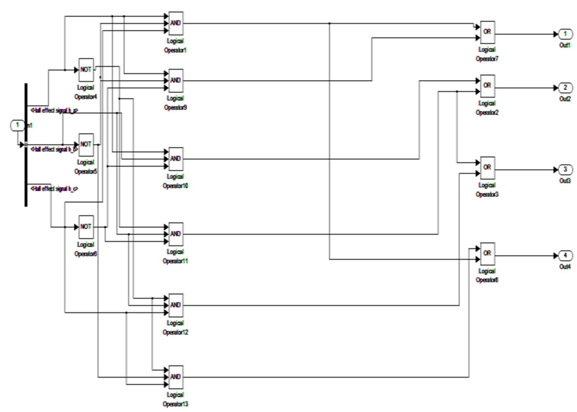


Fig.10: Simulink model of Hall sensor switching sequence.

Using Boolean algebra the hall sensor switching sequence is implemented and given to corresponding switches as per the TABLE II.

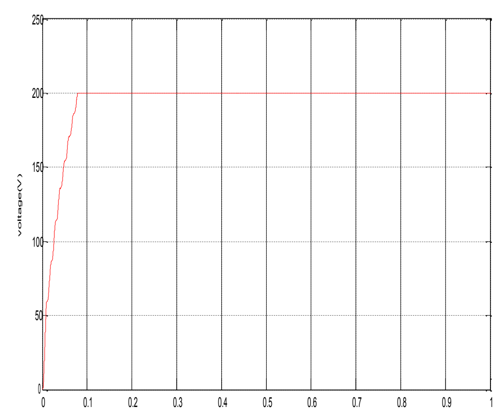


Fig.10. Output waveform of BL-SEPIC converter.

The reference output voltage of converter is set as 200 V and the converter output obtained from simulink model is nearly same as that of reference value .

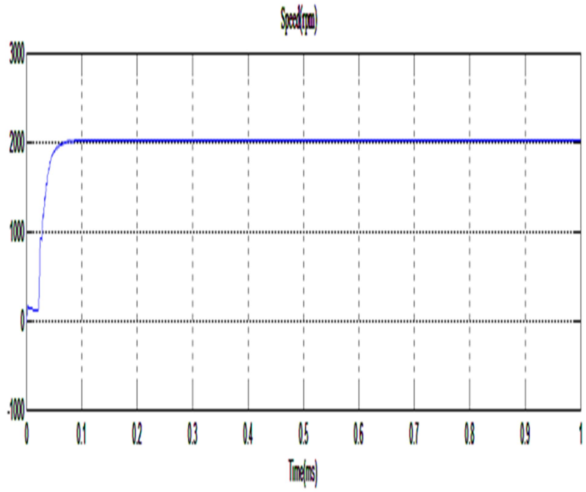


Fig.11. Motor speed.

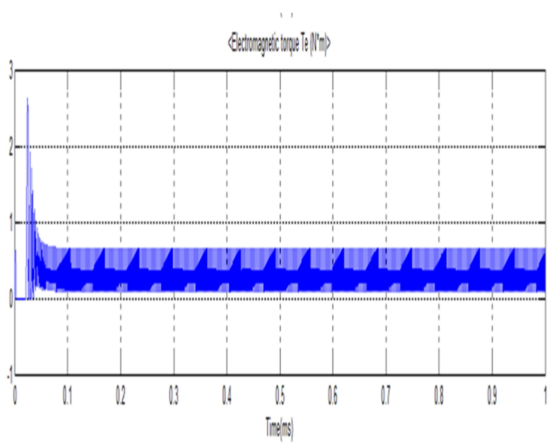


Fig. 12. Electromagnetic torque (Nm).

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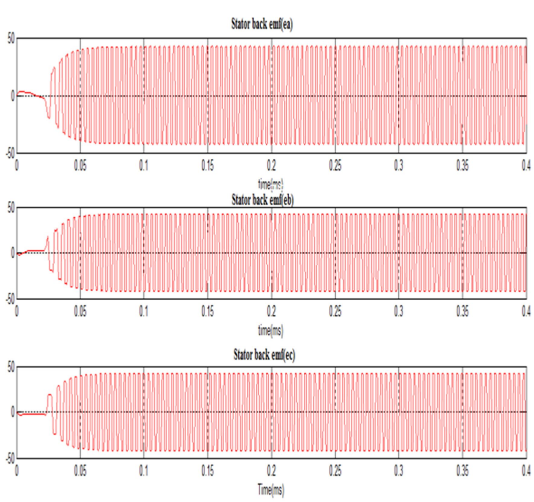

Fig. 13. Back emf waveform.

The no load speed obtained is 2000 rpm. After 0.025 ms the effect of initial starting of motor reduces. PF obtained from this circuit is .996.

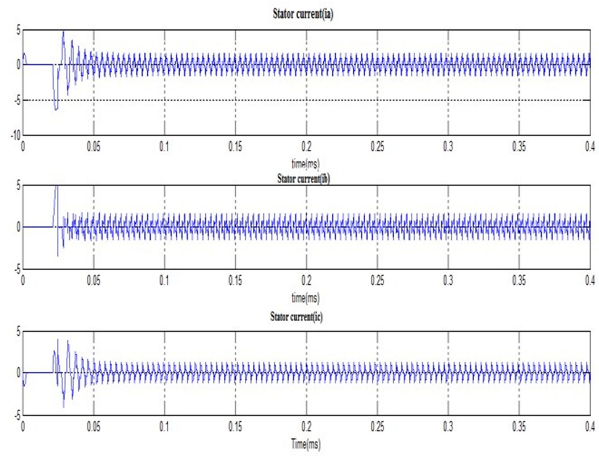

Fig. 14. Stator current waveform.

III. CONCLUSION

In this paper a drive system is proposed to low power household applications. The front-end BL-SEPIC converter has been operated in DICM for achieving an inherent PFC at AC mains. Moreover, a fundamental switching frequency of VSI is employed for reduction of its switching losses by operating the BLDC motor in electronic commutation. Fuzzy logic control is used instead of PI for fast error correction. Four switch three phase inverter helps in reduction of switching and conduction losses. Another advantage of proposed system is that it uses a single voltage sensor.

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