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Reduction of Current Harmonics with FLC based CSC for Synchronous Drive

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ABSTRACT: This paper presents a performance of the canonical switching cell (CSC) converter fed brushless DC (BLDC) motor drive for power quality (PQ) improvement. The use of CSC not only controlled the DC link voltage but also make the inverter to operate at low frequency so that switching losses are minimized. Moreover the use of front end CSC improves the power factor at AC mains. The system needs only a single voltage sensor for the DC bus voltage sensing; hence the system cost is reduced. The performance was analyzed on the basis of PQ terms of the proposed system under steady state and dynamic conditions. The performance graph has been plotted for the total harmonic distortion (THD) and the power factor (PF). A front end Canonical switching cell converter operating in Discontinuous Inductor Current Mode (DICM) is proposed for PFC operation at AC mains. Fuzzy logic is introduced in order to suppress the chattering and enhancing the robustness of the PFC control system. The results show that the system gives a good PF and the supply current THD as per PQ standard IEC 61000-3-2 for wide range of the motor speed and the supply voltage. The performance has been evaluated using MatLab-Simulink.

KEYWORDS*:* Diode Bridge Rectifier (DBR), Canonical switching cell (CSC) converter, discontinuous inductor current mode (DICM), Power factor correction (PFC).

I.INTRODUCTION

In recent years the BLDC motor is widely used in many low and medium power applications, because of its high energy density, high torque /inertia ratio, high efficiency and low maintenance due to the absence of the commutator and brush assembly. The BLDC motors are used in household appliances like washing machine, water pumping and air conditioning etc. and also in industries like robotics and industrial tools and motion control equipment. In the BLDC motor the commutation is done by using the electronic commutation; it involves hall-effect sensors to sense the rotor position and energizes the corresponding phase windings in the proper sequence by using the voltage source inverter (VSI) [1]. In the conventional scheme the BLDC motor drive system is fed by a diode bridge rectifier (DBR) which draws a current from ac mains with higher harmonic levels, also the power factor has been affected and it is not satisfies the PQ standard IEC 61000-3-2, so the power factor correction (PFC) is required for attaining good PQ parameter. The boost converter is widely used in the BLDC motor drives, in which the DC link voltage is maintained constant and the speed is controlled by controlling the PWM pulses of the VSI. This system has a drawback for the higher amount of the switching losses in the VSI switches due to higher level of the switching frequency at the inverter switches and the higher current levels [2-5]. In the sepic and cuk converter fed BLDC motor drive the speed of the motor is controlled by controlling the DC link voltage, hence the switching losses associated with the VSI switches are reduced, but it has a problem of using two sensors, which increases the system cost [6-7].The CSC converter based system presents a single voltage sensor based BLDC motor drive system, which is a cost effective solution of the low power applications.

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Improving power quality considerations require two factors: achieving high power factor and low harmonics. In fact, a low power factor reduces the power available from the utility grid, while a huge harmonic distortion of the line current causes EMI problems and cross-interferences, through the line impedance, between different systems connected to the same grid. From this point of view, the standard rectifier employing a diode bridge followed by a filter capacitor performs poor. Thus, technologies are being developed to interface systems that improve the power factor of standard electronic loads. Figure 1 shows the conventional system with PFC-boost converter. A front end power factor correction (PFC) is used after the diode bridge rectifier (DBR) for improving the quality of power factor at ac mains [1].

Many topologies of PFC have been reported in the literature surveys. A PFC boost converter has been the most popular configuration [15]. A constant dc-link voltage is maintained at the de-link capacitor for controlling the speed of the drive. Conventional scheme of PFC includes a current multiplier approach which includes voltage and current sensors [2]. The front end SEPIC and Cuk regulator using a variable voltage control have been proposed in [2] and [5], but at the cost of two current sensors. Bridgeless SEPIC regulator of PFC have been proposed in [12], but at the higher cost due to larger inductance. (DBR) for improving the quality of power factor at ac mains This project presents the improvement of power quality using fuzzy based canonical switching cell converter with voltage follower approach.
Figure 1 shows the conventional system with PFC-boost converter. A front end power factor correction (PFC) is used after the diode bridge rectifier.

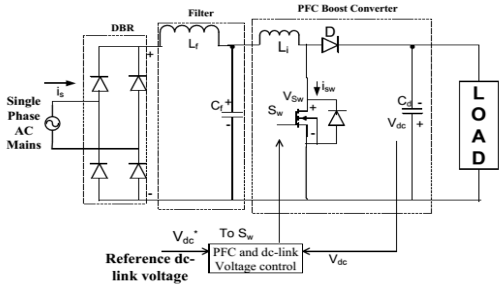

Fig.1 Conventional System with PFC-Boost Converter

II. PROPOSED FUZZY BASED CANONICAL SWITCHING CELL CONVERTER

A front-end power factor correction (PFC) converter is connected after the diode bridge rectifier (DBR) for improving the quality of power and achieving a near unity power factor at ac mains. Figure 2 shows the proposed fuzzy based canonical switching cell (CSC) converter for power quality improvement. A CSC converter operating in DICM acts as an inherent power factor pre-regulator for attaining a power factor of nearer to unity at AC mains. The front end CSC converter is designed and its parameters are selected to operate in a DICM for obtaining a high power factor. A single voltage sensor is required for PFC converter operating in discontinuous conduction mode (DCM) using the voltagefollower approach but at the cost of high stresses on PFC converter’s switch.

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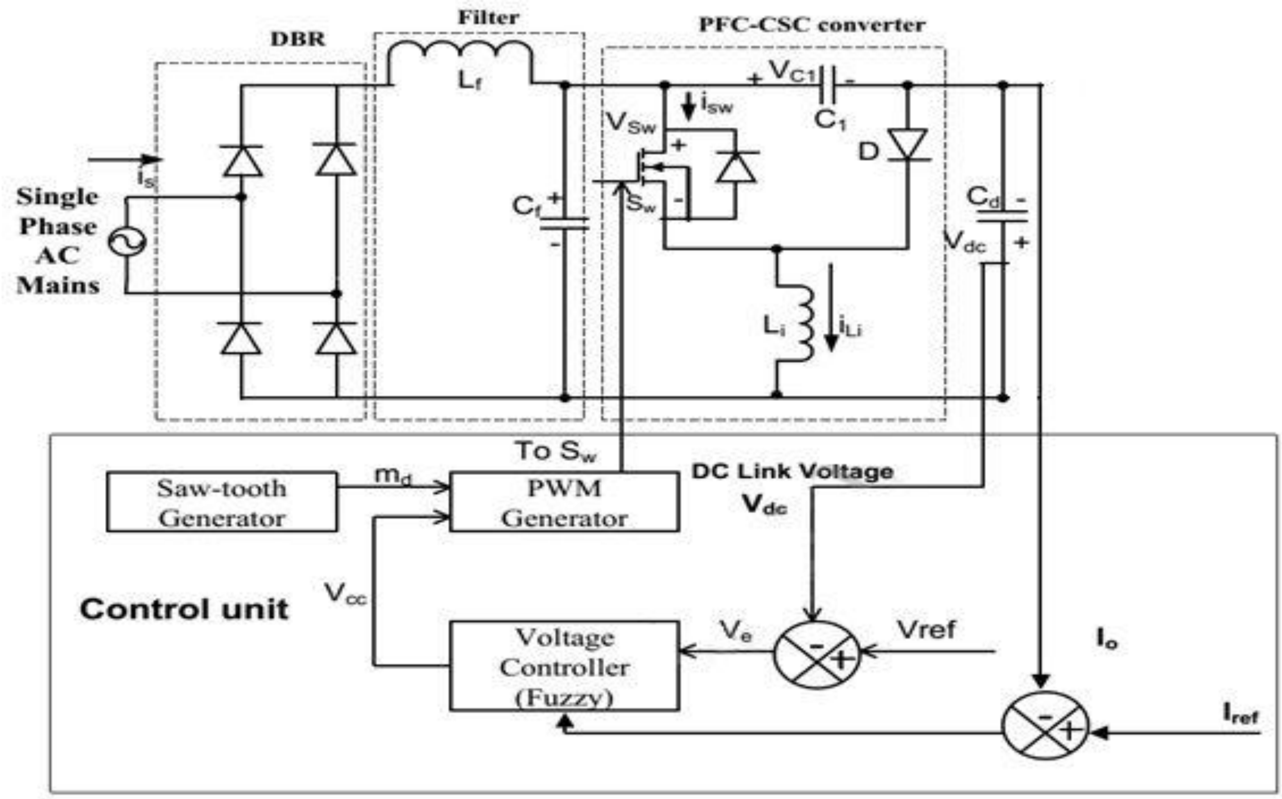

Fig. 2 Proposed Fuzzy Based Canonical Switching Cell Converter

III. OPERATING PRINCIPLE OF PFC-BASED CSC CONVERTER

The proposed PFC based CSC Converter operates in DICM. In DICM, the current in inductor Li becomes discontinuous in a switching period (Ts).

Mode I: Figure 3 shows the operation of Mode I operation of CSC converter. The switch Sw is turned ON, the energy from the supply and stored energy in the intermediate capacitor C1 are transferred to inductor Li. In this process, the voltage across the intermediate capacitor Vc1 reduces, while inductor current iLi and dc-link voltage Vdc are increased. The designed value of intermediate capacitor is large enough to hold enough energy such that the voltage across it does not become discontinuous.

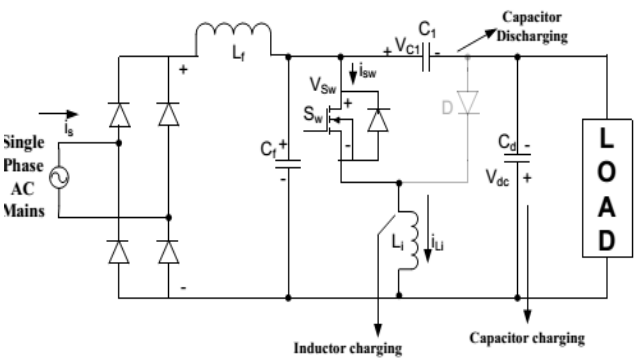

Fig. 3 Mode I

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Mode II: The switch is turned OFF in this mode of operation. The intermediate capacitor C1 is charged through the supply current while inductor Li starts discharging, hence voltage Vc1 starts increasing, while current iLi decreases in this mode of operation. Figure 4 shows the operation of Mode II operation of CSC converter. Moreover, the voltage across the dc-link capacitor Vdc continues to increase due to discharging of inductor Li.

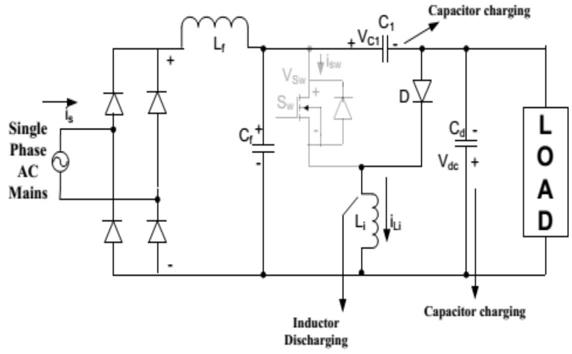

Fig. 4 Mode II

Mode III: This is the discontinuous conduction mode of operation as inductor Li is completely discharged and current iLi becomes zero. Figure 5 shows the operation of Mode III operation of CSC converter. The voltage across the intermediate capacitor C1 to increase, while dc-link capacitor supplies the required energy to the load, hence Vdc starts decreasing.

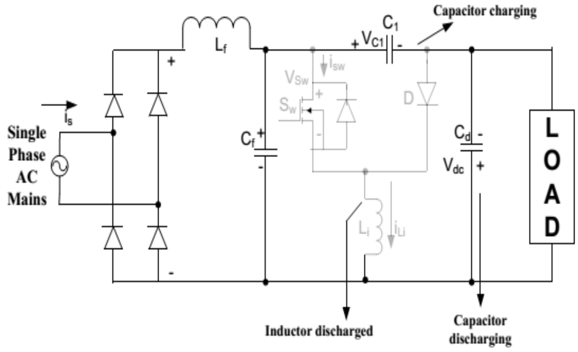

Fig. 5 Mode III

IV. CONTROL OF PFC-BASED CSC CONVERTER

The control of the proposed drive is classified into control of PFC converter and BLDCM.

A. Control of Front-End PFC Converter

The PFC-based CSC converter operating in DICM is controlled via a control of voltage follower. It generates PWM pulses for maintaining the necessary dc-link voltage at the input of VSI. A single-voltage sensor is used for the control of a PFC-based CSC converter operating in DICM.

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

$$V_{dc}^* = k_b \omega^* \tag{1}$$

where K_b and w* are the motor's voltage constant and the reference speed, respectively.

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Now, the reference dc-link voltage (V_{dc}^*) is compared with the sensed dc-link voltage (V_{dc}) to generate a voltage error signal (Ve) at k^{th} sampling instant as

$$V_e(k) = V_{\mathrm{dc}}^*(k) - V_{\mathrm{dc}}(k) \qquad (2)$$

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

where S_w represents the switching signals given to the switch

$$\begin{Bmatrix} \text{if } m_d < V_{cc} \text{ then } S_w = \text{“ON”} \\ \text{if } m_d \geq V_{cc} \text{ then } S_w = \text{“OFF”} \end{Bmatrix} \qquad (3)$$

B. Control of BLDCM: Electronic Commutation

An electronic commutation of the BLDCM includes proper switching of VSI in such a way that a symmetrical dc current is drawn from the dc-link capacitor for 1200 and placed symmetrically at the centre of back electro-motive force (EMF) of each phase. A Hall-Effect position sensor is used to sense the rotor position on a span of 600, which is required for the electronic commutation of BLDCM. The conduction states of two switches (S1 and S4) are shown in Fig3.6. A line current iab is drawn from the dc link capacitor in which magnitude depends on the applied dc-link voltage (Vdc), back-EMF’s (ean and ebn), resistances (Ra and Rb), and self and mutual inductance (La, Lb, and M) of the stator windings. Table I shows the different switching states of the VSI feeding a BLDCM based on the Hall-Effect position signals (H1 – H3).

Table I

Switching states of VSI corresponding to hall-Effect rotor Position signals

Hall signals			Switching states					
H_1	H_2	H_3	S_1	S_2	S_3	S_4	S_5	S_6
0	0	0	0	0	0	0	0	0
0	0	1	1	0	0	0	0	1
0	1	0	0	1	1	0	0	0
0	1	1	0	0	1	0	0	1
1	0	0	0	0	0	1	1	0
1	0	1	1	0	0	1	0	0
1	1	0	0	1	0	0	1	0
1	1	1	0	0	0	0	0	0

Control of Front-End PFC Converter Conventionally, PI, PD and PID controller are most popular controllers and widely used in most power electronic closed loop appliances however there are many researchers reported successfully adopted Fuzzy Logic Controller (FLC) to become one of intelligent controllers to their appliances. A simple fuzzy logic control is built up by a group of rules based on the human knowledge of system behavior.

In this project FLC is introduced to improve the robustness and suppresses the chattering of the load. Furthermore, design of fuzzy logic controller can provide desirable performance which is not possible with linear control technique. Thus FLC has the potential to improve the robustness of dc-dc converters. The PFC-based CSC converter operating in DICM is controlled using a voltage-follower approach. It generates PWM pulses for maintaining the necessary dc link voltage. A single-voltage sensor is used for the control of a PFC-based CSC converter operating in DICM. The output of voltage controller is compared with a high frequency saw-tooth signal to generate PWM pulses which is given to the switch Sw.

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V. INTRODUCTION TO FUZZY LOGIC CONTROLLER

A new language was developed to describe the fuzzy properties of reality, which are very difficult and sometime even impossible to be described using conventional methods. Fuzzy set theory has been widely used in the control area with some application to dc-to-dc converter system. A simple fuzzy logic control is built up by a group of rules based on the human knowledge of system behavior. Matlab/Simulink simulation model is built to study the dynamic behavior of dc-to-dc converter and performance of proposed controllers. Furthermore, design of fuzzy logic controller can provide desirable both small signal and large signal dynamic performance at same time, which is not possible with linear control technique. Thus, fuzzy logic controller has been potential ability to improve the robustness of dc-to-dc converters. The basic scheme of a fuzzy logic controller is shown in Fig 5 and consists of four principal components such as: a fuzzy fication interface, which converts input data into suitable linguistic values; a knowledge base, which consists of a data base with the necessary linguistic definitions and the control rule set; a decision-making logic which, simulating a human decision process, infer the fuzzy control action from the knowledge of the control rules and linguistic variable definitions; a de-fuzzification interface which yields non fuzzy control action from an inferred fuzzy control action [10].

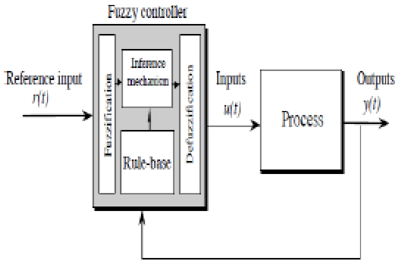

Fig.6. General structure of the fuzzy logic controller on closed-loop system

The fuzzy control systems are based on expert knowledge that converts the human linguistic concepts into an automatic control strategy without any complicated mathematical model [10]. Simulation is performed in buck converter to verify the proposed fuzzy logic controllers.

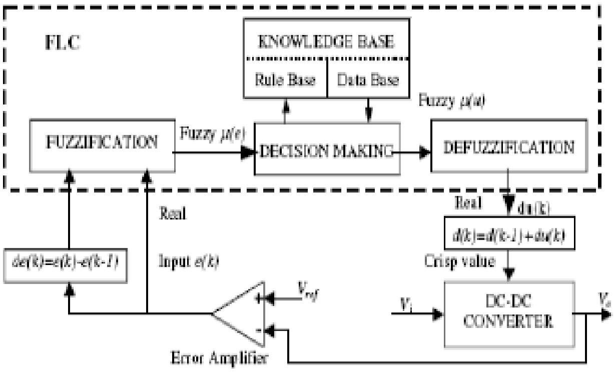

Fig.7. Block diagram of the Fuzzy Logic Controller (FLC) for dc-dc converters

A. Fuzzy Logic Membership Functions:

The dc-dc converter is a nonlinear function of the duty cycle because of the small signal model and its control method was applied to the control of boost converters. Fuzzy controllers do not require an exact mathematical model. Instead, they are designed based on general knowledge of the plant. Fuzzy controllers are designed to adapt to varying operating points. Fuzzy Logic Controller is designed to control the output of boost dc-dc converter using Mamdani style fuzzy inference system. Two input variables, error (e) and change of error (de) are used in this fuzzy logic system. The single output variable (u) is duty cycle of PWM output.

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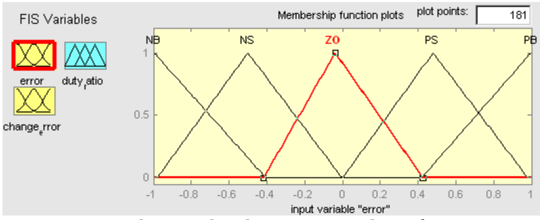

Fig. 8.The Membership Function plots of error

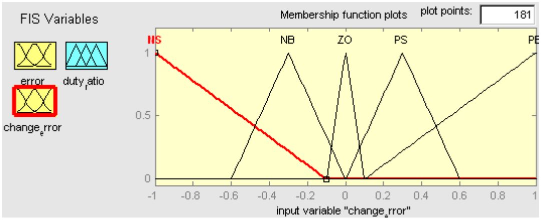

Fig.9. The Membership Function plots of change error

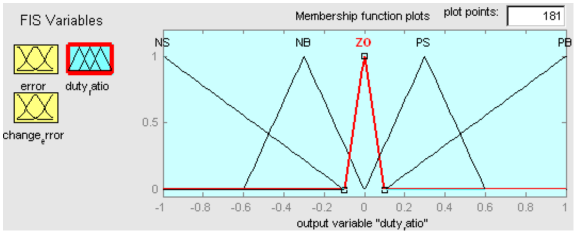

Fig.10. The Membership Function plots of duty ratio

B. Fuzzy Logic Rules:

The objective of this dissertation is to control the output voltage of the boost converter. The error and change of error of the output voltage will be the inputs of fuzzy logic controller. These 2 inputs are divided into five groups; NB: Negative Big, NS: Negative Small, ZO: Zero Area, PS: Positive small and PB: Positive Big and its parameter [10]. These fuzzy control rules for error and change of error can be referred in the table that is shown in Table II as per below:

Table II
Table rules for error and change of error

(de) \ (e)	NB	NS	ZO	PS	PB
NB	NB	NB	NB	NS	ZO
NS	NB	NB	NS	ZO	PS
ZO	NB	NS	ZO	PS	PB
PS	NS	ZO	PS	PB	PB
PB	ZO	PS	PB	PB	PB

VI. SIMULATION OF PROPOSED SYSTEM

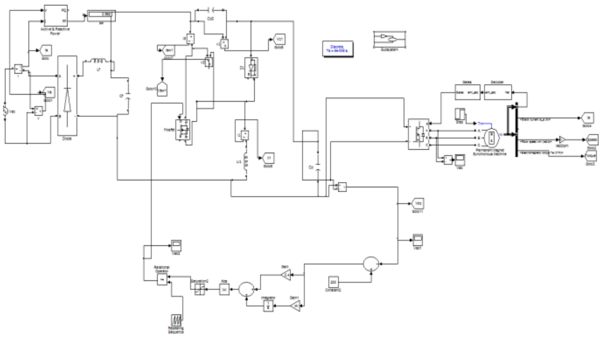

Fig.11.Simulink circuit for proposed BLDC drive system

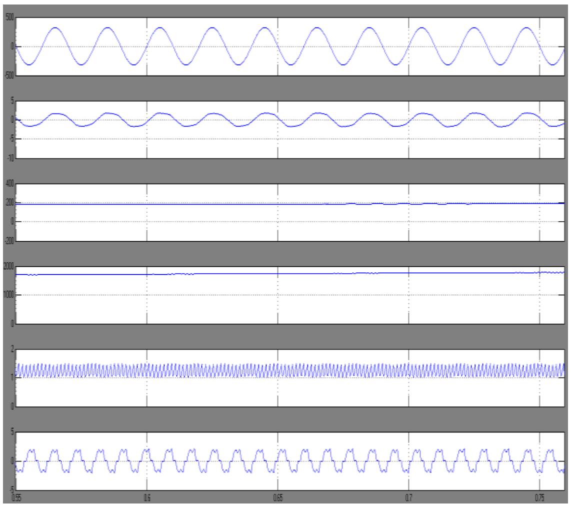

Fig.12.Simulation result for source voltage, source current, dc link voltage, speed of motor, torque of motor and stator current

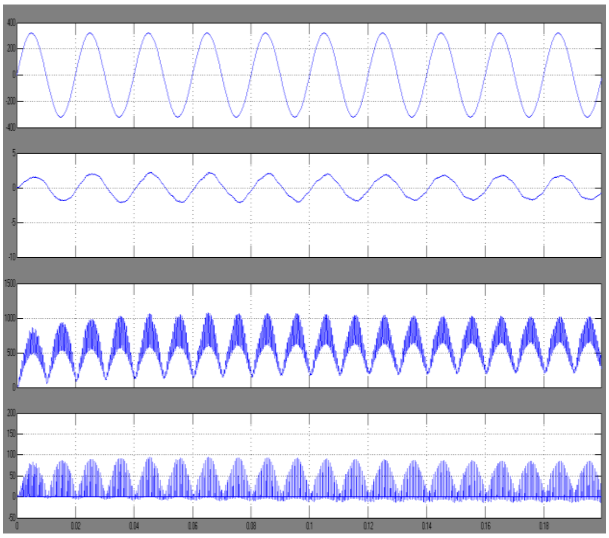

Fig.13.Simulation result for source voltage, current, capacitor voltage and inductor current

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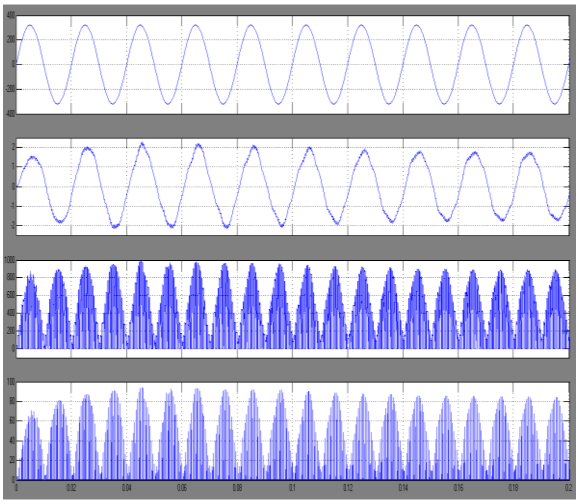

Fig.14.Source voltage, current, voltage stress and current stress of PFC converter

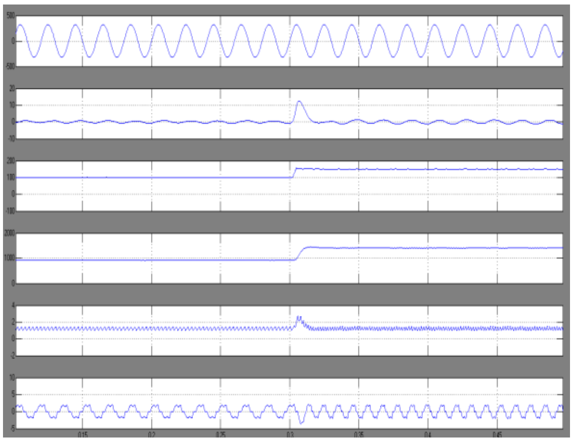

Fig.15.Simulation result for source voltage, current, dc link voltage, speed , torque and stator current of BLDC motor drive when dc link voltage changes from 100 to 150v

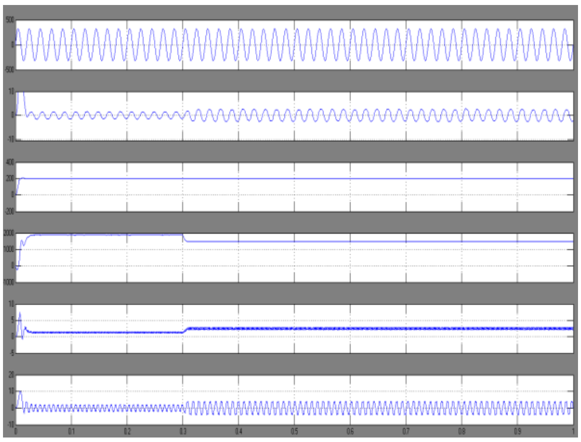

Fig.16. Simulation result for source voltage, current, dc link voltage, speed , torque and stator current of BLDC motor drive during load changing condition

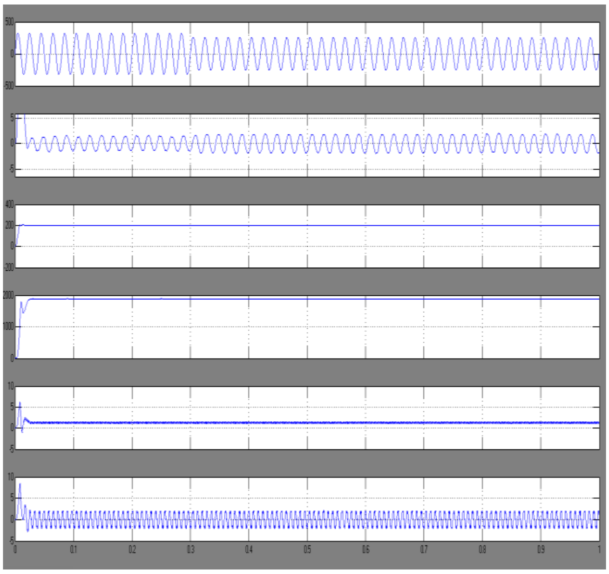

Fig.17. Simulation result for source voltage, current, dc link voltage, speed , torque and stator current of BLDC motor drive during variation supply voltage

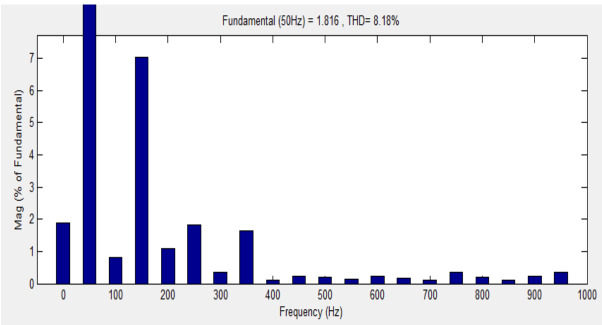

Fig.18.THD for source current by using conventional controller

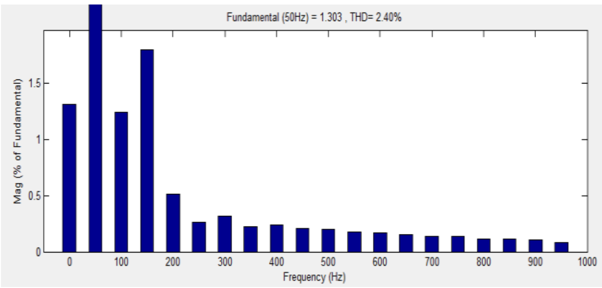

Fig.19.THD for source current by using conventional controller

VII. CONCLUSION

A PFC-based CSC Converter using Fuzzy Logic Controller has been proposed for targeting low-power house hold applications. A variable voltage of dc bus has been used for controlling the speed of load. A front-end CSC converter operating in DICM has been used for dual objectives of dc-link voltage control and achieving a unity power factor at AC mains. Using this PFC-converter configuration, the limits various international PQ standards such as IEC 61000-3-2 can be achieved.

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