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Application of Fuzzy Logic Controller for CSC Converter with BLDC Motor Drive

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Abstract:
This project presents a performance of the canonical switching cell (CSC) device fed brushless DC (BLDC) motor drive for power quality (PQ) improvement. The employment of CSC not solely controlled the DC link voltage however additionally create the inverter to control at low frequency in order that switching losses are reduced. Furthermore the utilization of front end CSC improves the power factor at AC mains. A design methodology is introduced that blends the classical fuzzy logic controllers in associate degree intelligent means and so a new intelligent controller has been achieved. Moreover, associate degree intelligent switching pattern is evoked on the mixing mechanism that produces a choice upon the priority of the two controller parts; particularly, the classical PI and also the fuzzy constituents. The simulations done on varied processes using the new fuzzy controller provides 'better' system responses in terms of transient and steady-state performances in comparison to the pure classical PI or the pure fuzzy controller applications. The performance graph has been plotted for the total harmonic distortion (THD) and also the power factor (PF). A front end Canonical switching cell device operating in Discontinuous inductor Current Mode (DICM) is planned for power factor correction operation at AC mains. fuzzy logic is introduced so as to suppress the chattering and enhancing the hardiness of the PFC control system. The performance has been evaluated with the help of Mat lab-Simulink.

***Keywords*—** Diode Bridge Rectifier (DBR); Canonical switching cell (CSC) converter; discontinuous inductor current mode (DICM); Power factor correction (PFC); fuzzy logic control.

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 maintainedconstant 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.

At present, conventional PI-type controllers are most widely used in control of industrial stoker-"redboilers due to their simple control structure ease of design and inexpensive cost. However, these PI controllers cannot yield a good control performance due to high nonlinearity and uncertainty of the boilersystems. Furthermore, when there exists a strong load change or a large disturbance, the PI-type controllermight be out of control so that a manual control must be operational.It was first reported about 20 years ago that a fuzzy logic controller is very suitable for a controlled objectwith nonlinearity and even with unknown structure. One of the widely used design

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methods for fuzzycontrollers is to membership functions of linguistic variables and to formulate fuzzy rules by controlengineers. Since solid fuels-coal causes a large time lag, it is laborious to manually fuzzyrules and membership functions during system operation. Another approach for design of the fuzzycontroller is to adapt rule base or/and membership functions by self-organizing algorithms or neuralnetwork according to previous responses until a desired control performance is achieved.However, this adaptive strategy might not be used for combustion control of a stoker-"red boiler due to itsconvergent problem.

The intent of this study is to design a new fuzzy controller so that a further improved system response performance in both the transient and steady states have been achieved as compared to the system response obtained when either the classical PI or the fuzzy controller has been implemented. Here, the classical PI and fuzzy controller have been combined by a blending mechanism that depends on a certain function of actuating error. An intelligent switching scheme is induced on the blending mechanism that makes a decision upon the priority of the two controller parts. Simulations are performed on MATLAB®/Simulink toolbox to illustrate the efficiency of the proposed method.

Figure 1 shows the conventional system with PFC-boost converter. A front end power factor correction (PFC) is used after the diode bridge rectifier.

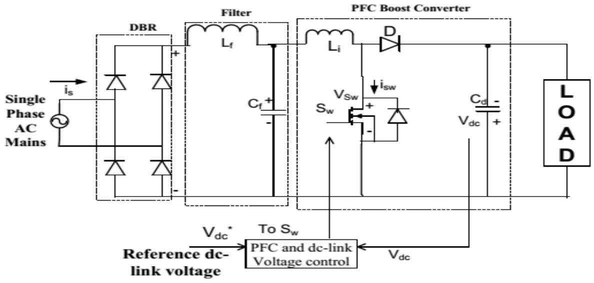

Fig.1 Conventional System with PFC-Boost Converter

II. Proposed Fuzzy Based Canonical Switching Cell Converter

A front-end power factor correction (PFC) converteris 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 PFCconverter's switch.

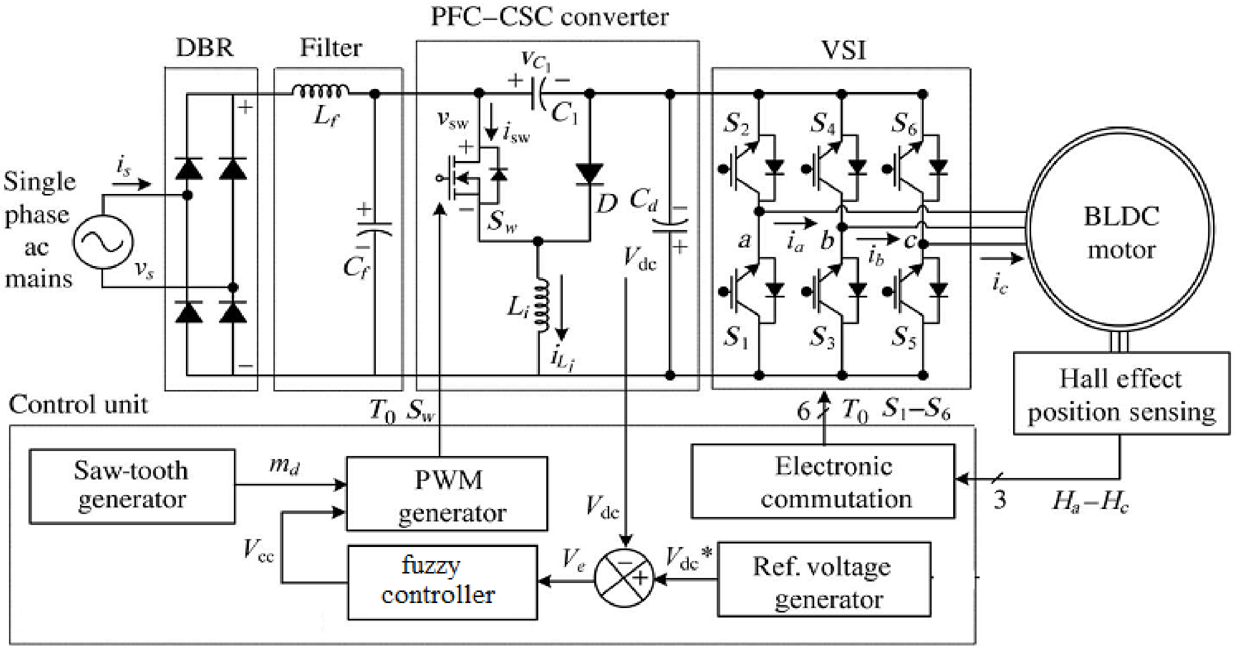

Fig. 2 Proposed Fuzzy Based Canonical Switching Cell Converter.

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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 S_w 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 inductorcurrent i_{Li} 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.

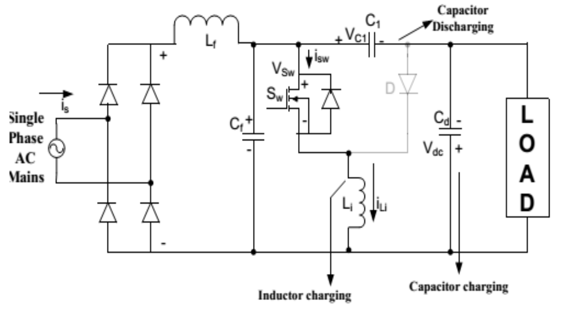

Fig. 3 Mode I

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 i_{Li}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.

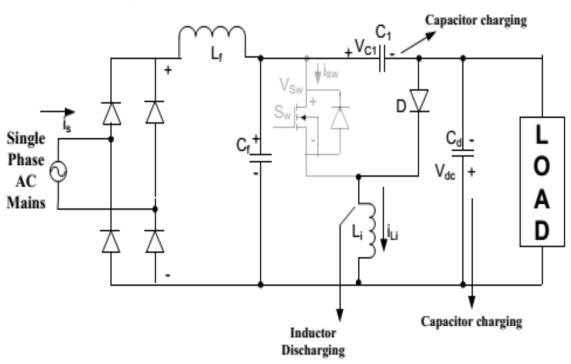

Fig. 4 Mode II

Mode III: This is the discontinuous conduction mode of operation as inductor Li is completely discharged and current i_{Li} becomes zero. Figure 5 shows the operation of Mode III operation of CSC converter. The voltage across the intermediate capacitor C_1 to increase, while dc-link capacitor supplies the required energy to the load, hence V_{dc} starts decreasing.

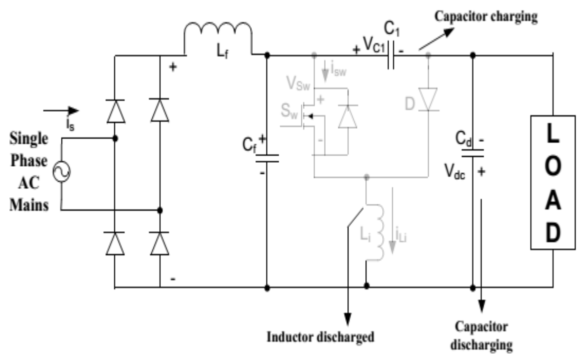

Fig. 5 Mode III

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

$$V_{dc}^* = k_b \omega^* \qquad (1)$$

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

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

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

The output of voltage controller is compared with a highfrequency saw-tooth signal (m_d) to generate PWM pulses aswhere $S_w$represents the switching signals given to the switch

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

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). A line current i_{ab} is drawn from the dc link capacitor in which magnitude depends on the applied dc-link voltage (V_{dc}), back-EMF's (e_{an} and e_{bn}), resistances (R_a and R_b), 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 rotorPosition 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, PID and fuzzy logic 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 PI and fuzzy logic control is built up by a group of rules based on the human knowledge of system behaviour.

In this paperHFLC is introduced to improve therobustness 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 HFLC 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 dclink 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.

V.FUZZY LOGIC CONTROL

L. A. Zadeh presented the first paper on fuzzy set theory in 1965. Since then, 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 power system. A simple fuzzy logic control is built up by a group of rules based on the human knowledge of system behavior. Mat lab/Simulink simulation model is built to study the dynamic behavior of converter. 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 compensator.

The basic scheme of a fuzzy logic controller is shown in Fig 6 and consists of four principal components such as: a fuzzification 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 .

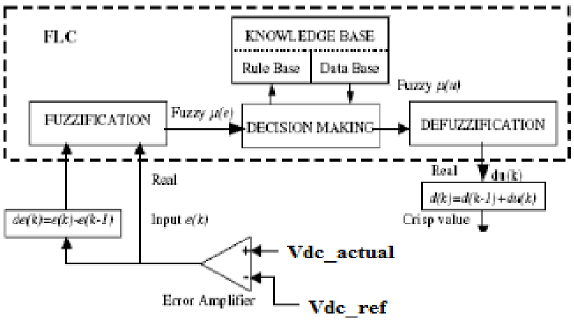

Fig.6.Block diagram of the Fuzzy Logic Controller (FLC)for proposed converter.

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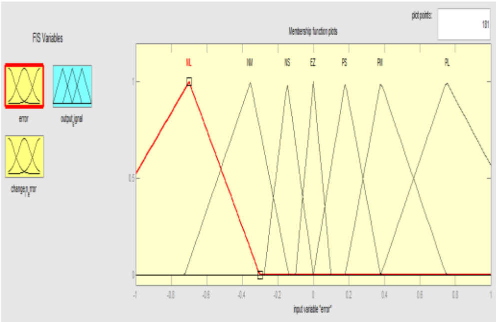

Fig.7. Membership functions for error.

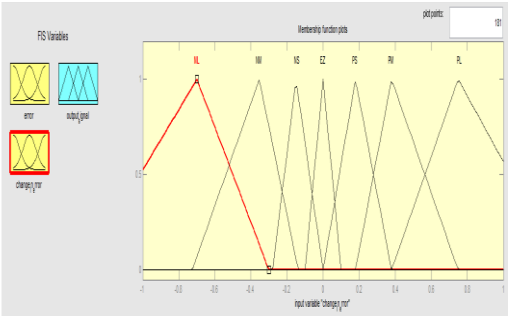

Fig.8. Membership functions for change in error.

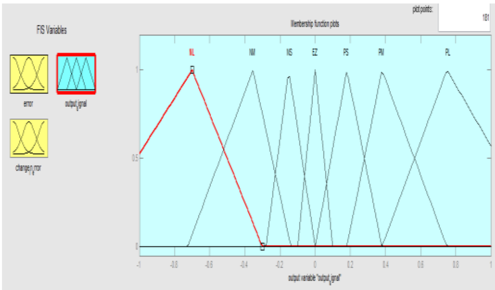

Fig.9. Membership functions for Output.

Table II
Table rules for error and change of error.

Error / Change error	NL	NM	NS	EZ	PS	PM	PL
NL	NL	NL	NL	NL	NM	NS	NL
NM	NL	NL	NL	NM	NS	EZ	NM
NS	NL	NL	NM	NS	EZ	PS	NS
EZ	NL	NM	NS	EZ	PS	PM	EZ
PS	NM	NS	EZ	PS	PM	PL	PS
PM	NS	EZ	PS	PM	PL	PL	PM
PL	EZ	PS	PM	PL	PL	PL	PL

VII. SIMULATION OF PROPOSED SYSTEM

Here Matlab/simulation results are presented below cases (i) Proposed converter with BLDC drive using PI controller and (ii) Proposed converter with BLDC drive using fuzzy controller

Case (i): Proposed converter with BLDC drive using PI controller

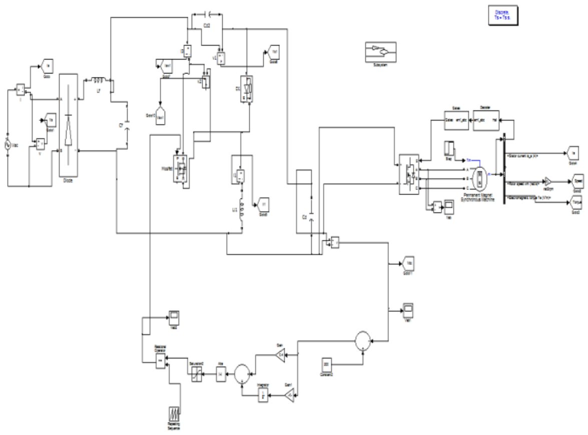

Fig.10.Simulink circuit for proposed BLDC drive system with PI controller

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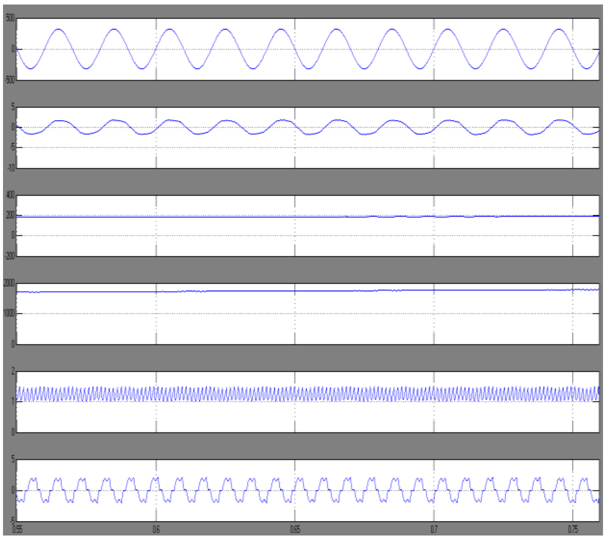

Fig.11.Simulation result for source voltage, source current, dc link voltage, speed of motor, torque of motor and stator current.

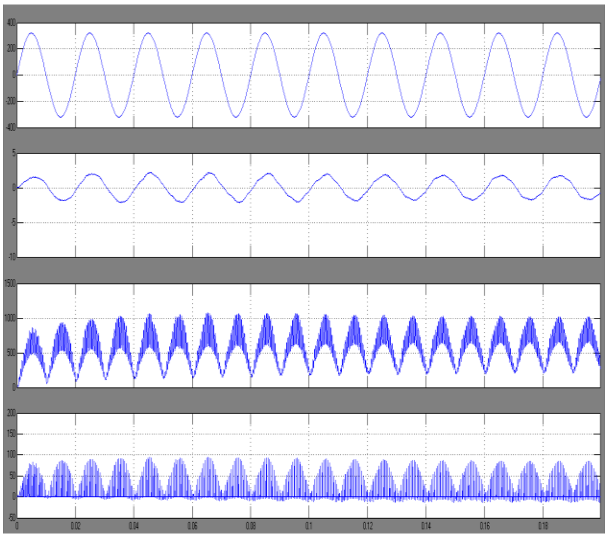

Fig.12.Simulation result for source voltage, current, capacitor voltage and inductor current.

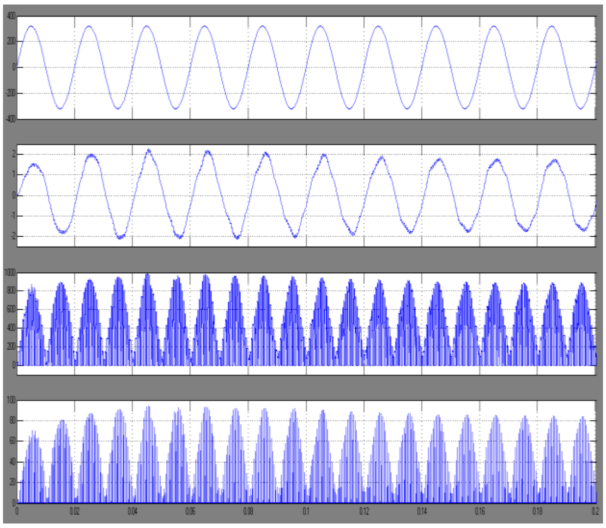

Fig.13.Source voltage, current, voltage stress and current stress of PFC converter.

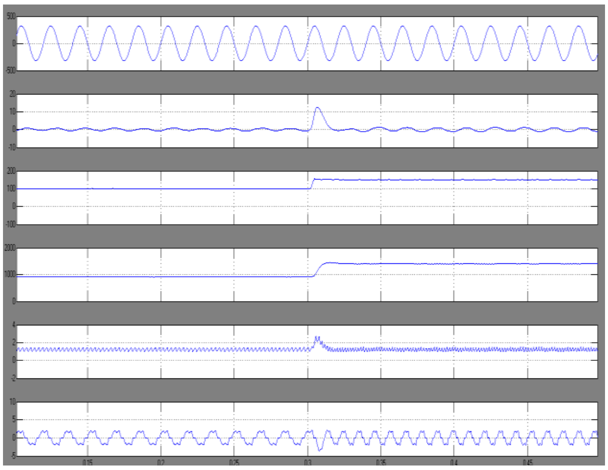

Fig.14.Simulation result for source voltage, current, dc link voltage, speed , torque and stator current of BLDC motor drive when dc link voltage changes from 100 to 150v

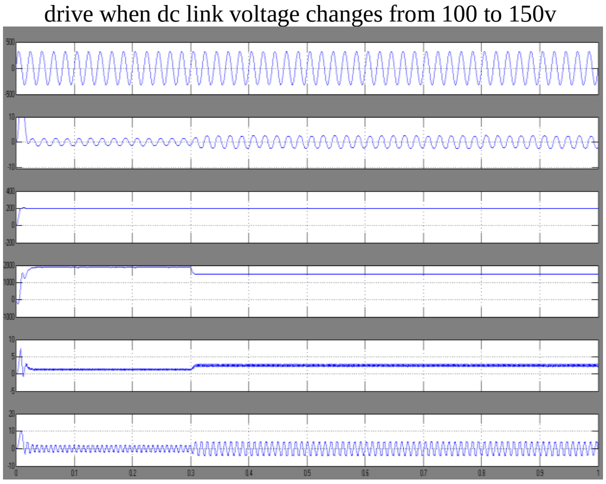

Fig.15. Simulation result for source voltage, current, dc link voltage, speed , torque and stator current of BLDC motor drive during load changing condition.

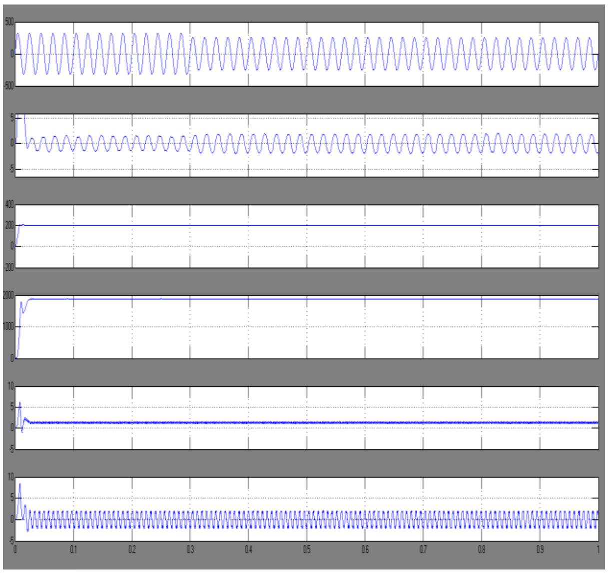

Fig.16. Simulation result for source voltage, current, dc link voltage, speed , torque and stator current of BLDC motor drive during variation supply voltage.

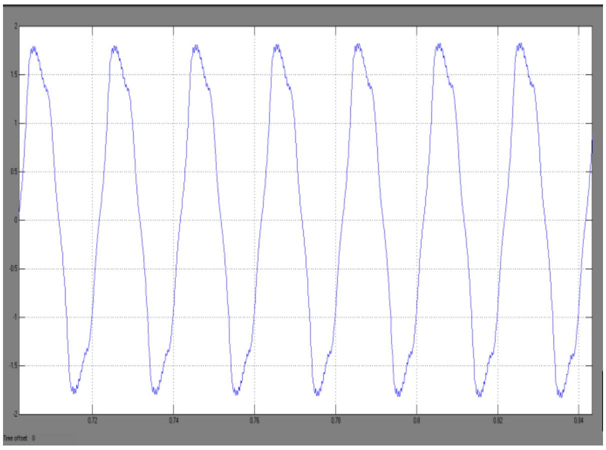

Fig 17 Source current using PI controller

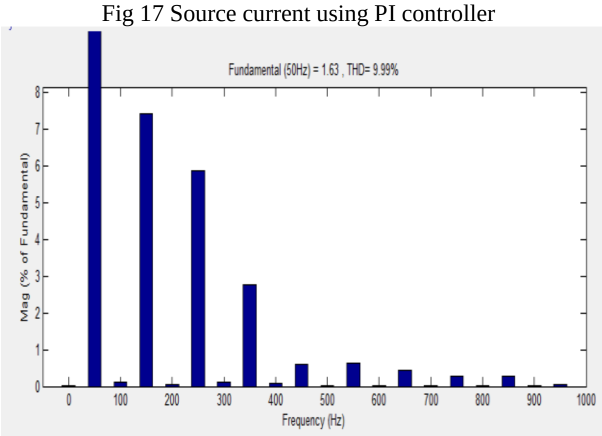

Fig.18.THD for source current by using PI controller.

Case (i): Proposed converter with BLDC drive using fuzzy controller

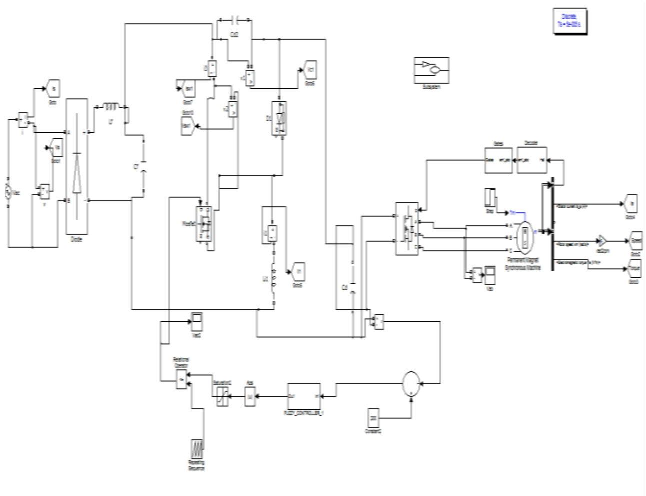

Fig 19. Matlab/simulation circuit of Proposed converter with BLDC drive using fuzzy logic controller.

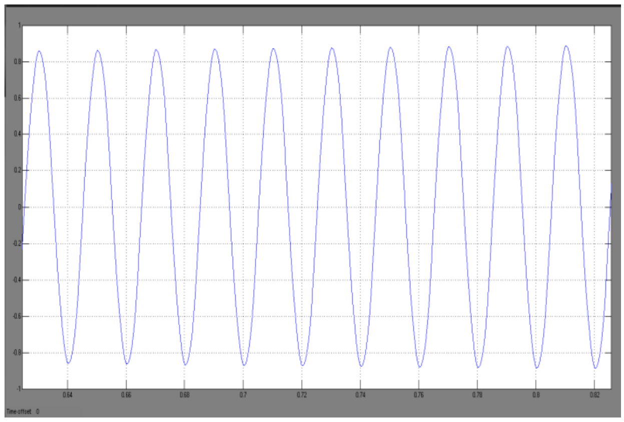

Fig 20 Source current with fuzzy controller

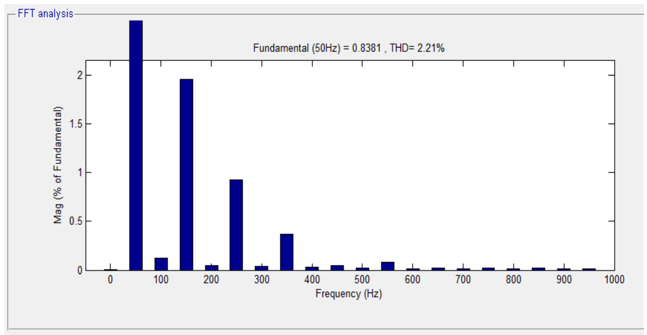

Fig.21. THD for source current by using fuzzy controller.

VIII. CONCLUSION

A PFC-based CSC Converter using Fuzzy Logic Controller has been proposed for targeting low-powerhouse 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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