Simulation of Fuzzy Controller based Isolated Zeta Converter fed BLDC motor drive

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***Abstract* - This paper deals with a brushless dc (BLDC) motor drive fed by an isolated zeta converter with fuzzy controller for power factor correction (PFC) which is suitable for low power applications. The diode bridge rectifier at the supply side is an uncontrolled rectifier causes distortion of supply current and poor power factor. The isolated zeta converter is the power factor corrector used here. It controls the dc link voltage of Voltage Source Inverter (VSI) using a single voltage sensor. Here Fuzzy Logic Controller (FLC) is used instead of PI controller to achieve desired performance in BLDC motor control system due to variation in system parameters and change in load. The proposed system helps to reduce the size and cost of the drive system. The performance of the drive is observed by simulating the system in MATLAB/Simulink.**

***IndexTerms* - Brusless dc (BLDC) motor, Discontinuous Conduction Mode (DCM), Fuzzy Logic Controller (FLC), High Frequency Transformer (HFT), Power Factor Correction (PFC), Voltage Source Inverter (VSI).**

I. INTRODUCTION

Brushless dc (BLDC) finds many applications in various fields such as automotive, industrial and household products etc. Brushless dc (BLDC) motors are suitable for these applications due to the advantages such that small size, better speed control, noiseless operation, low maintenance requirements, reliability, control simplicity, better efficiency etc. For achieving electronic commutation, it requires a three phase voltage source inverter (VSI). The rotor positions for electronic commutation are sensed by Hall effect position sensors. So the disadvantages due to sparking at the brushes are eliminated. [6]

A single phase AC supply is used to feed the motor through a diode bridge rectifier (DBR) followed by a filter and the converter via a voltage source inverter. Due to this uncontrolled rectifier, the supply current becomes highly distorted. Many power quality problems may cause due to this. Harmonics are also caused due to non-linearity such as adjustable speed drives, transformer saturation etc. In this case the total harmonic distortion (THD) will be very high. [2]

This harmonic current at AC mains causes power quality problems and degraded power factor. This problem can be corrected using passive power factor correctors or active power factor correctors. In passive PFC capacitors and inductors are used to improve power factor. But it requires large value of inductors and capacitors which are bulky and costly. Active power factor correctors are suitable for solving the power quality issues in non-linear loads. AC-DC converters developed with high frequency transformer isolation in buck, boost and buck-boost categories are efficient active power factor correctors. The buck and boost converters consists of forward, push-pull, half bridge and full bridge configuration. The Buck-boost configuration consists of Flyback, Cuk, SEPIC and Zeta type of converters. These converters are operating at high switching frequency to reduce size of the transformer and filter components. [1]

Different configuration requires different number of sensors. These converters can operate either in Continuous Conduction Mode (CCM) and Discontinuous Conduction Mode (DCM). The voltage follower approach is followed in DCM and in CCM average current mode control is followed. Converters operating in CCM require more sensors for sensing supply voltage, current and dc link voltage. For this mode of operation cost will also be high due to number of sensors. But a converter operating in DCM requires only one voltage sensor for dc link voltage control. The current loop can be avoided in the voltage follower approach. The speed can be controlled by this dc link voltage. But the discontinuous mode of operation is limited to low power applications due to the high stress on the converter switch. Continuous conduction mode is suitable for high power applications. [4]

IEC 61000 3-2 standard specifies the limits of harmonic component injected into the supply system. Using the proposed method a better power factor specified by IEC 61000 3-2 standard is attained.

II. FUZZY CONTROLLER BASED ISOLATED ZETA CONVERTER FED BLDC MOTOR DRIVE

Figure.1 shows the proposed fuzzy controller based isolated zeta converter fed BLDC motor drive. Isolated zeta converter is fed by a single phase AC source followed by an uncontrolled bridge rectifier and filter. The power factor corrector used here is the isolated zeta converter operating in discontinuous conduction mode. It is a buck-boost converter with transformer isolation. The transformer used here is a high frequency transformer with a switching frequency of 20 kHz. The voltage follower approach is followed in discontinuous conduction mode. So a single voltage sensor to measure the dc link voltage is needed. Here the speed of the BLDC motor is controlled by varying this dc link voltage. The dc link voltage V_{dc} and the reference voltage V_{dc}^{*} are compared and its output voltage is the error voltage V_e. The error voltage and its derivative V_{ce} is given to the fuzzy logic controller (FLC). The output voltage V_{cc},, is compared with a saw tooth signal and generate PWM pulses to trigger the converter switch.

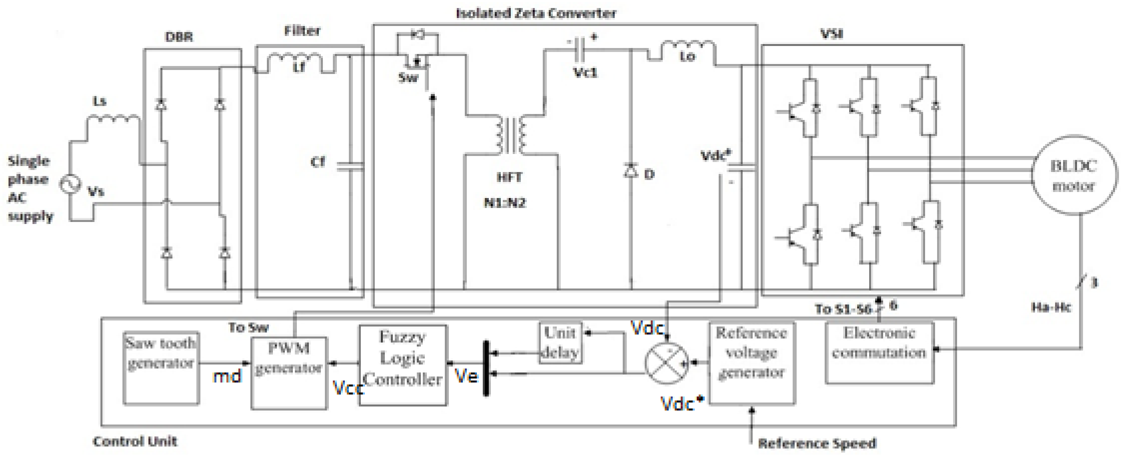

Fig 1. The proposed fuzzy controller based isolated zeta converter fed BLDC motor drive

III. DESIGN OF CONVERTER

The working of power factor correction converter is classified as 3 modes that is when the switch of the converter is turned ON, OFF and the discontinuous conduction mode (DCM). [2]

The turn ON operation of the converter is shown in fig 2. The magnetization inductance of the high frequency transformer is increased when the switch (Sw) of the converter turned ON. This time the energy to the dc link capacitor (C_d) and output inductor (L_o) is provided by the capacitor C_1.

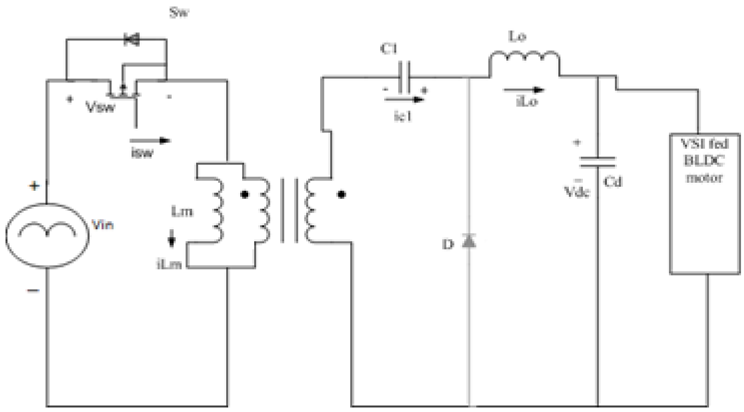

Fig 2. Converter Operation when the switch is ON

Figure 3 shows the mode of operation when the switch is turned OFF. The magnetization inductance will decrease when the converter switch (Sw) is turned OFF. The voltage of capacitor C_1 will rise when the energy of the transformer passed to it. The dc link voltage will also increases in this mode.

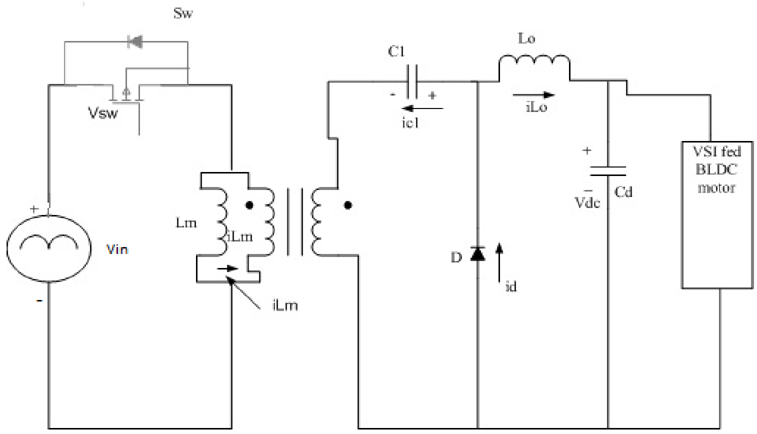

Fig 3. Converter Operation when the switch is OFF

The discontinuous mode of operation is shown in fig 4. In the discontinuous conduction mode, the output inductor current increases due to energy supplied by the capacitor C_1 and the dc link capacitor C_d. And the energy of transformed is fully discharged in this mode.

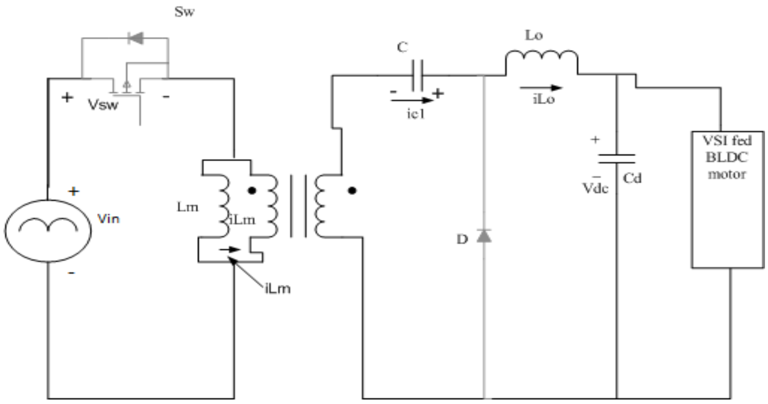

Fig 4. Converter Operation in Discontinuous Conduction Mode

The input voltage to the converter is

$$V_s(t) = V_m \sin(\omega_L t) \qquad (1)$$

The dc link voltage V_{dc} ie, the output voltage of the converter is

$$V_{dc} = \frac{N_2}{N_1}\frac{D}{1-D}V_{in} \qquad (2)$$

Where D is the duty ratio and N_2/N_1 is the turns ratio of the transformer. The instantaneous value of duty ratio D(t) is

$$D(t) = \frac{V_{dc}(t)}{\frac{N_2}{N_1}V_{in}(t)+V_{dc}} \qquad (3)$$

P_{in} is the instantaneous power at any dc link voltage and is given as

$$P_{in} = \frac{P_{max}}{V_{dcmax}}V_{dc} \qquad (4)$$

L_{mc} is the critical value of magnetizing inductance of the high frequency transformer [1]

$$L_{mc} = \frac{R_L(1-D(t))^2}{2D(t)f_s\left(\frac{N_2}{N_1}\right)^2} \qquad (5)$$

Here R_L is the load resistance and f_s is the switching frequency. In discontinuous conduction mode the value of magnetization inductance L_m is taken lower than the critical value. The output inductor L_O is taken as [1]

$$L_O = \frac{V_{dc}(1-D(t))^2}{\Delta i_{LO}\, f_s} \qquad (6)$$

C_1 is the intermediate capacitor at the secondary of high frequency transformer is given as [1]

$$C_1 = \frac{V_{dc}D(t)}{\Delta V_C(t) f_s R_L} \qquad (7)$$

The dc link capacitor is given as [1]

$$C_d = \frac{I_{dc}}{2\omega \Delta V_{dc}} \qquad (8)$$

The harmonics in the supply system is eliminated by the low pass filter. C_f and L_f are the filter components used. [5]

$$C_f = \frac{I_{peak}}{V_m\omega_L}\tan\theta \qquad (9)$$

$$L_f = \frac{1}{4\pi C_f f_c^2} \qquad (10)$$

IV. FUZZY LOGIC CONTROLLER

Fuzzy logic gives solution to the certain problems which are difficult to explain using the conventional techniques. Fuzzy logic approach is similar to a human brain as it can interpret imprecise and incomplete information. So in fuzzification it converts crisp input values into linguistic values. The fuzzy logic can be applicable to control the system with uncertain parameters.

Fuzzy Rules

Table 1 Fuzzy Rules

e \ ce	**NB**	**NM**	**NS**	**ZE**	**PS**	**PM**	**PB**
NB	NVB	NVB	NVB	NB	NM	NS	ZE
NM	NVB	NVB	NB	NM	NS	ZE	PS
NS	NVB	NB	NM	NS	ZE	PS	PM
ZE	NB	NM	NS	ZE	PS	PM	PB
PS	NM	NS	ZE	PS	PM	PB	PVB
PM	NS	ZE	PS	PM	PB	PVB	PVB
PB	ZE	PS	PM	PB	PVB	PVB	PVB

The output of the dc link voltage V_{dc} and the reference voltage V_{dc}^* is compared and the output voltage V_e ie the error voltage and the change of error V_{ce} is given to a fuzzy logic controller. The inputs are classified into 7 membership functions such as NB-Negative Big, NM-Negative Medium, NS-Negative Small, ZE-Zero, PS-Positive Small, PM-Positive Medium, PB-Positive Big etc. Here there are 7*7, 49 If-then rules are formed as there are 7 groups in each input. The output is the voltage from the fuzzy controller. The output voltage V_o is divided into 9 membership functions such as NVB-Negative Very Big, NB, NM, NS, ZE, PS, PM, PB, PVB-Positive Very Big etc. These rules are shown in the table 1.

Fuzzy Inference System

Fuzzy Inference System is a computing based on the concepts of fuzzy set theory, if-then rules and fuzzy reasoning. The block diagram which represents the fuzzy inference system is shown in fig 5. The input values are fuzzified and they can relate by AND or OR operators. The fuzzy If-then rules states that if there is an ANTECEDENT then the CONCLUSION. As the fuzzy system is used as a controller the output values are defuzzified to get the crisp values.

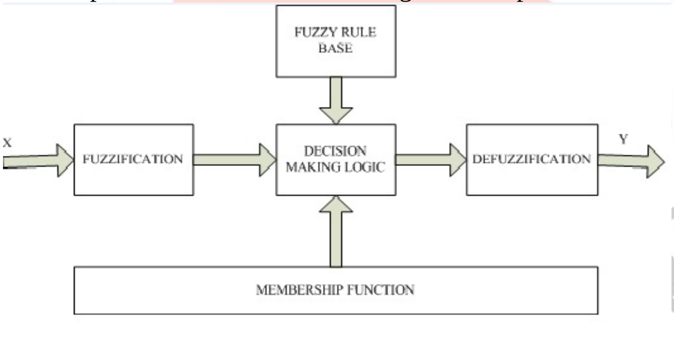

Fig 5. Block diagram of Fuzzy Inference System (FIS)

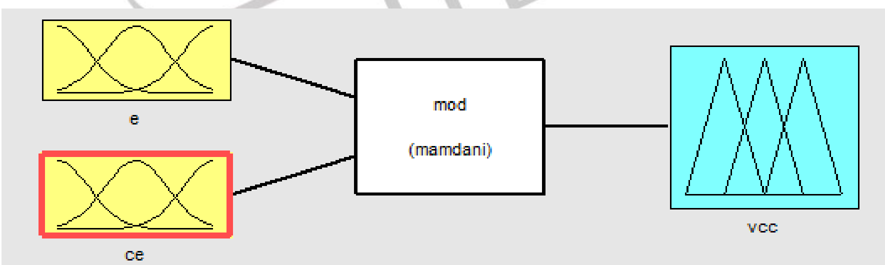

Fig 6. FIS generated in MATLAB/Simulink

Fuzzy Membership Functions

Fuzzy membership function maps the fuzzy set elements to the real number values within the interval 0 to 1. There are different types of membership functions such as triangular, trapezoidal, guassidal, generalized bell function etc. Here triangular membership function is used for two inputs and the output. The y-axis represents the membership grade from 0 to 1 and x-axis values are varies according to the range we chosen. The input and output membership function is shown in fig 7 and 8.

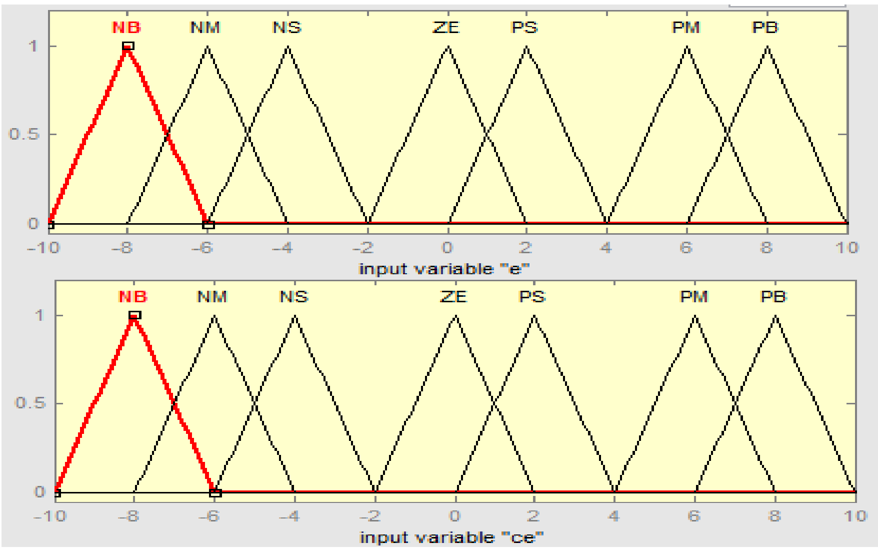

Fig 7. Inputs error (e) and change in error (ce)

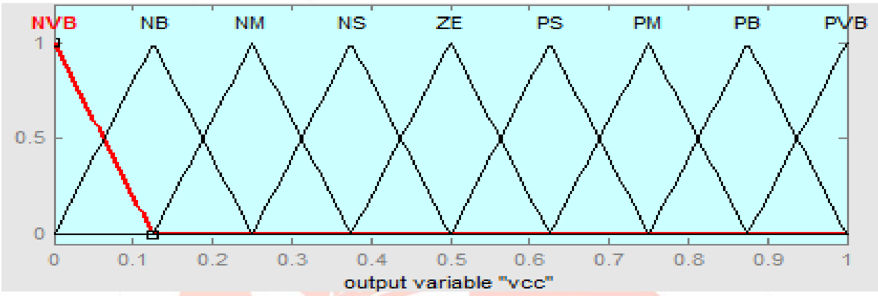

Fig 8. Output V_{cc}

V. SIMULATION RESULTS

The simulation was performed in MATLAB/Simulink. The overall simulation diagram of the system using Fuzzy controller is shown in the fig 9.

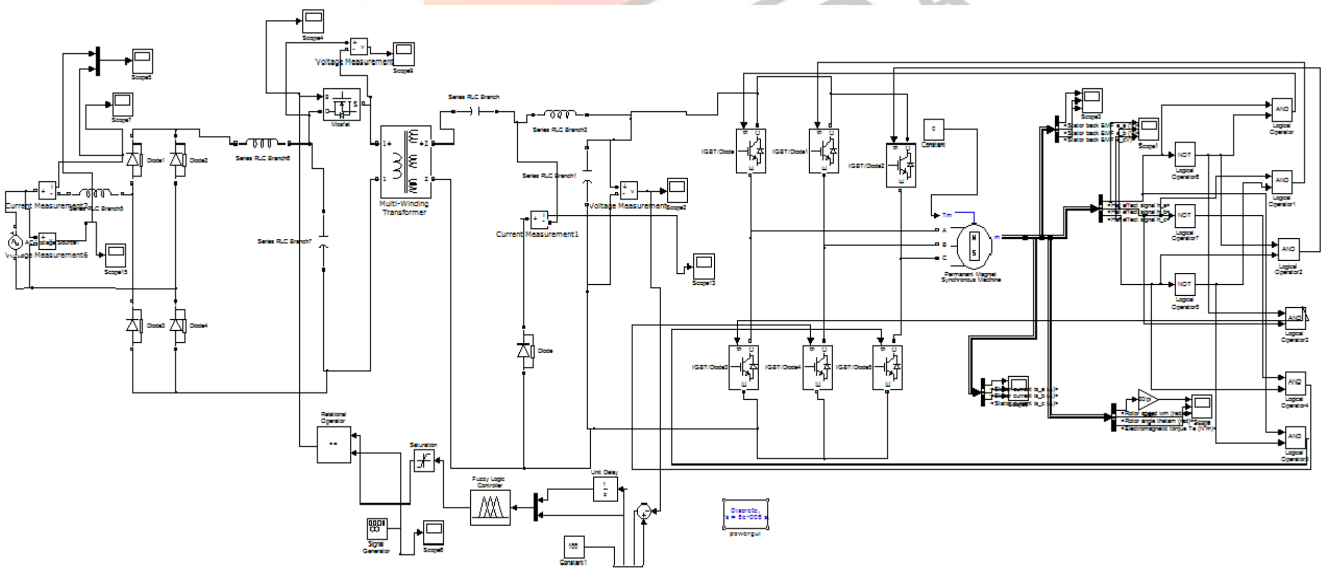

Fig 9. MATLAB/Simulink model of proposed fuzzy controller based isolated zeta converter fed BLDC motor drive

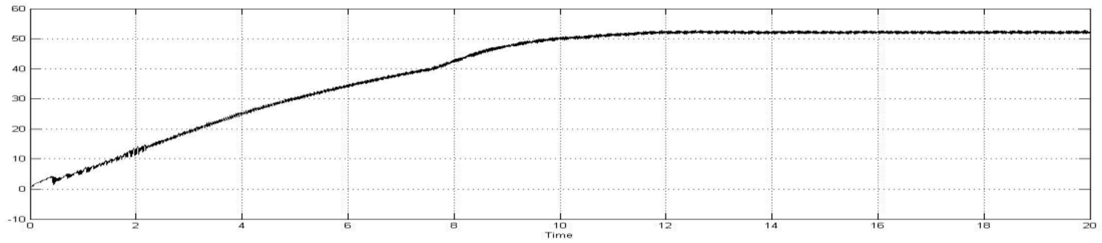

Fig 10. 50 V dc link voltage

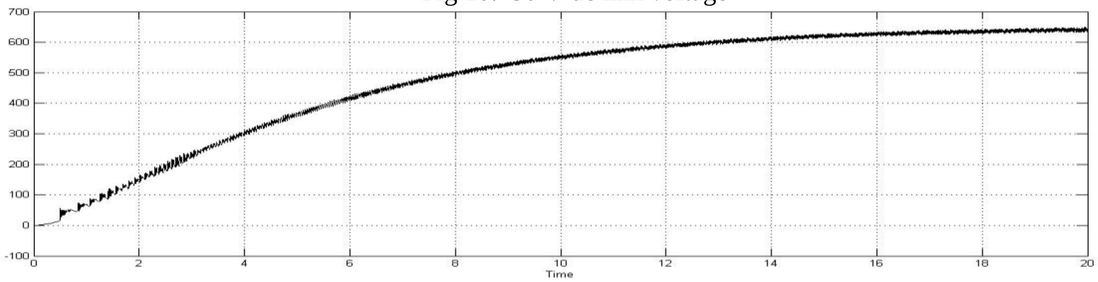

Fig 11. Speed of BLDC motor at 50V dc link voltage

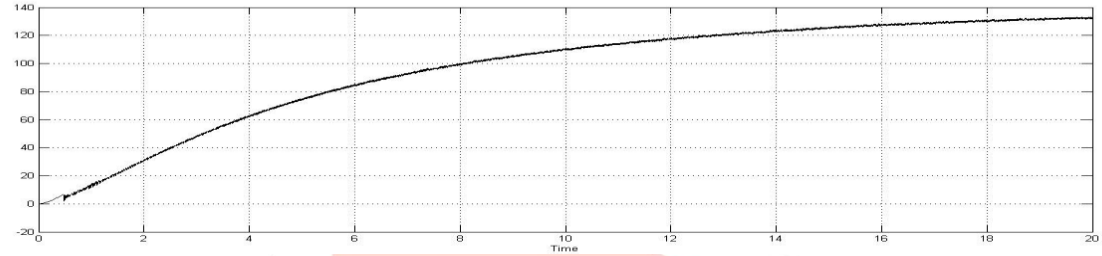

Fig 12. 130 V dc link voltage

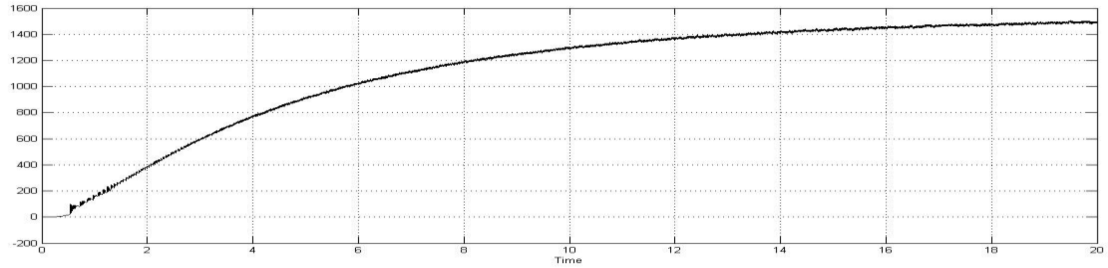

Fig 13. Speed of BLDC motor at 130V dc link voltage

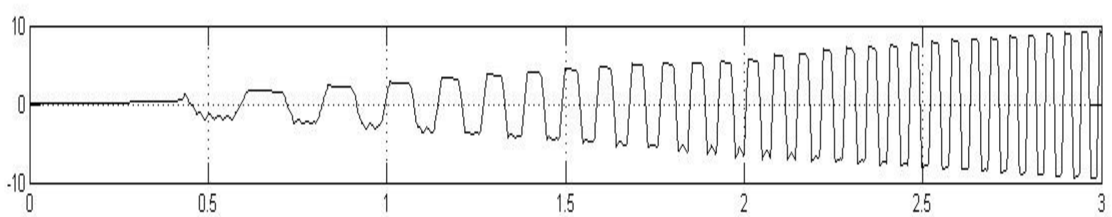

Fig 14. Back emf of BLDC motor drive

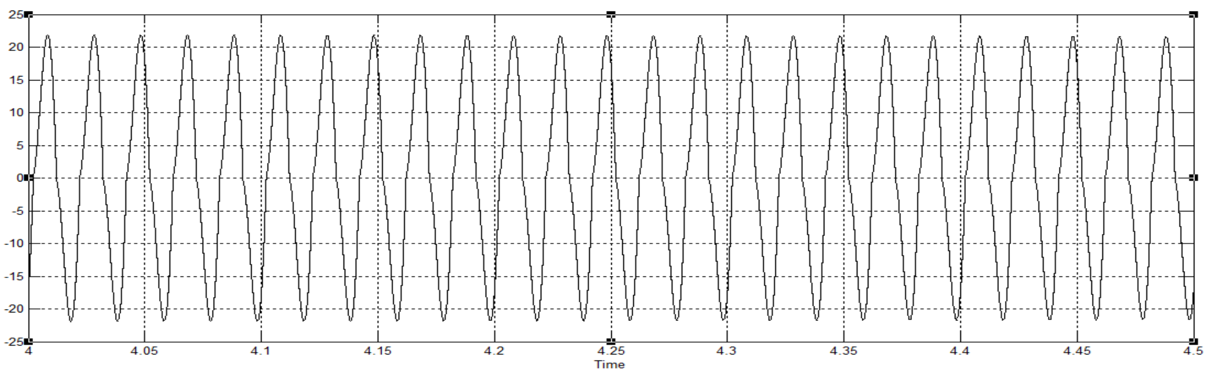

Fig 15. Supply current

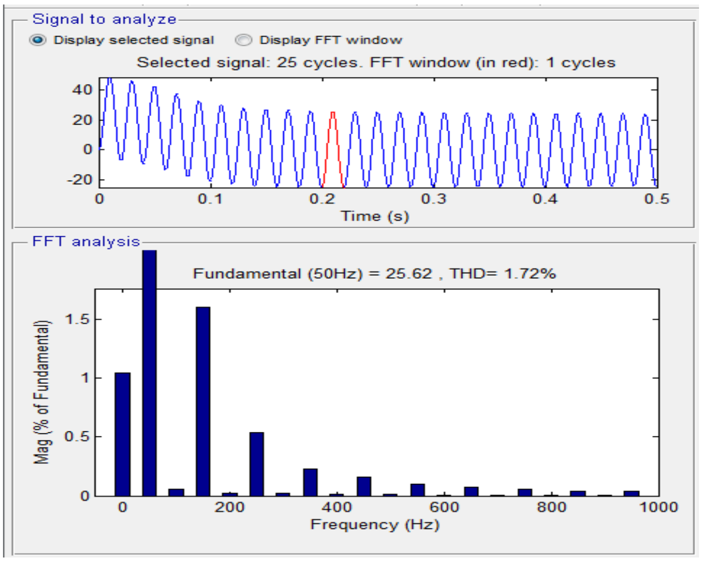

Fig 16. Input current THD

The simulation results in fig 10 to fig 13 shows two different dc link voltages and the variation in speed. The speed is controlled by the variation in dc link voltage of the converter. The back emf waveform of the BLDC motor and the supply current waveforms are shown in fig 14 and 15 respectively. The input current THD is shown in fig 16. This is calculated by performing FFT analysis of supply current in MATLAB/Simulink. The THD value is 1.72% and the power factor is approximately 0.99.

VI. CONCLUSION

The speed control of the motor drive is achieved by varying the dc link voltage of the converter. A simple voltage follower approach is using for voltage control in discontinuous conduction mode. In this converter a High Frequency Transformer (HFT) provides isolation for safety. Switch of the converter is operating at high switching frequency for effective control and to reduce the size of components. This configuration is simple as the number of sensors required is less compared to other converters. So the overall cost is less. Fuzzy logic control is used to avoid complex mathematical calculations. The simulation results show the reduced THD (better power factor) and speed control of the system.

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