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Hardware implementation of fuzzy controlled isolated Zeta converter fed BLDC motor drive

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General Note

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ABSTRACT

A fuzzy controller based isolated zeta converter fed BLDC motor drive is proposed here. The non-linear load like rectifier with capacitor, adjustable speed drives etc add current spike and distorts the supply current. Due to this injected harmonics the quality of power degrades. Active power factor correctors are suitable for the harmonics caused due to the non-linear loads. Isolated Zeta Converter is a power factor corrector which can reduce harmonics, speed control and also provides isolation. The overall cost of this system is less due to the reduced number of sensors. The high switching frequency of the converter helps to reduce the component size. Fuzzy Logic Controller is used as it is suitable for parameter variation and simple control. So this system is simple, cost effective, provides better power factor and speed control.

Keywords: Brushless dc (BLDC) motor, Fuzzy Logic Controller (FLC), High Frequency Transformer (HFT), Power Factor Correction (PFC), Discontinuous Conduction Mode (DCM), Voltage Source Inverter (VSI).

1. INTRODUCTION

Brushless DC motor is a permanent magnet motor which have simple control and better power quality than induction motors. Here the Brushless DC motor is fed by a diode bridge rectifier with filter. Due to this uncontrolled rectifier, the supply current is highly distorted which has high total harmonic distortion (THD). This leads to reduction of power factor at AC mains. Electronic commutation in BLDC is achieved by 3 phase Voltage Source Inverter (VSI). Switching frequency of Pulse Width Modulated (PWM) signal causes high switching losses in VSI.

Power factor correction (PFC) converters are used for improving the power quality. The power factor can be reduced due to highly inductive loads. Buck, Boost and Buck-Boost configuration with high frequency transformers are active power factor correctors. Isolated zeta converter comes under the Buck-Boost category. A combination of diode bridge rectifier and isolated zeta converter is proposed as power factor corrector. It controls the DC link voltage of VSI using single voltage sensor. This dc link voltage is fed to the voltage source inverter. The variation of this dc link voltage regulates the speed of the BLDC motor. This configuration can be used for industrial and household applications and isolation is required for safety issues.

Another challenge is to reduce the size and cost of drive system without affecting the performance. This converter adopting the voltage follower approach and it requires only one voltage sensor helps to reduce the cost of this system. The high operating frequency reduces the component size also. The operating frequency of the converter is 20 kHz. Conventional controllers fail to achieve desired performance in BLDC motor control system due to variation in system parameters and change in load. So as a modification artificial intelligent technique like fuzzy logic control can be implemented instead of conventional PI controller. The dynamic characteristics of brushless DC motor such as speed, torque, current and voltage can be observed and analyzed in MATLAB/Simulink. The hardware platform used is PIC 16F877A and ATMEL 2051. PIC 16F877A is used to trigger the converter MOSFET and ATMEL 2051 is used for the electronic commutation of the BLDC motor.

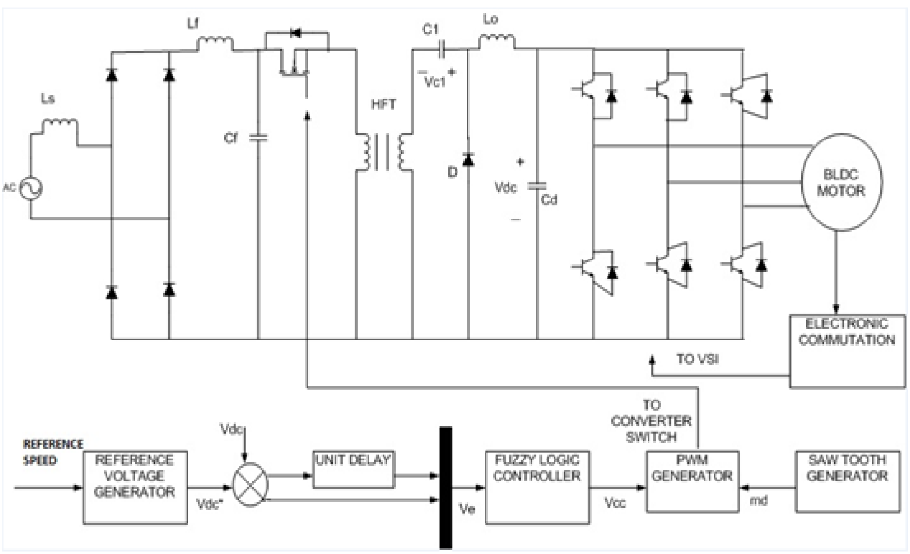

Figure 1 Circuit diagram of the proposed system

2. PROPOSED SYSTEM

The circuit of fuzzy controlled isolated zeta converter fed BLDC motor drive is shown in fig 1. A single phase AC supply is fed to the diode bridge rectifier with LC filter. This DC voltage is fed to the isolated zeta converter. It is a buck-boost converter with high frequency transformer isolation. The core of the transformer is ferrite. The output dc link voltage is fed to voltage source inverter and then to the BLDC motor. The speed of the motor is controlled by adjusting this voltage. The reference speed is multiplied by the motor constant is the set reference voltage V_{dc}^* shown in fig 1. This reference voltage is compared with the dc link voltage. The difference between these two voltages is the error voltage V_e. This error voltage is fed to the fuzzy controller to decrease the error. The output from the fuzzy controller compared with the saw tooth signal generates the PWM pulses to trigger the isolated zeta converter MOSFET. The discontinuous mode of operation is used here. While working in Continuous Conduction Mode, more number of sensors required. But the Discontinuous Conduction Mode (DCM) is suitable for low power applications.

The energy of the transformer is completely released in the discontinuous mode of operation. The energy is stored in the transformer while the converter switch is ON. In the discontinuous mode of operation the dc link voltage and the intermediate capacitor voltage at the secondary side of the converter will get reduced as these capacitors supply the energy to the load and the output inductor.

The input voltage to the isolated zeta converter is given as

$$V_{in}(t) = V_m \sin(\omega_L t) \qquad (1)$$

The dc link voltage V_{dc} ie, the input voltage to the inverter is given as

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

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The isolated zeta converter is a buck-boost converter with transformer isolation. So the dc link voltage equation is similar to the output equation of a flyback converter.

The instantaneous value of duty ratio D(t) is

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

The critical value of magnetizing inductance of the transformer is (B. Singh et al. 2011)

$$L_{cri} = \frac{R_L(1-D(t))^2}{2D(t)f_s\left(\frac{N_2}{N_1}\right)^2} \quad (4)$$

where f_s and R_L are the switching frequency and load resistance respectively.

The load resistance can be calculated by V_{dc}^2/P_{inst}, where P_{inst} is the instantaneous power which can be calculated by $(P_M/V_{dcM})\,V_{dc}$. P_M is the converter rated power and V_{dcM} is the maximum dc link voltage.

In discontinuous conduction mode of operation of the converter the value of magnetizing inductance is taken less than the critical value L_{cri} . The output inductance L_O is (B. Singh et al. 2011)

$$L_O = \frac{V_{dc}(1-D(t))^2}{\Delta i_{LO}\, f_s} \quad (5)$$

Where Δi_{LO} is the ripple percentage of the output inductor current.

The intermediate capacitor C_1 at the secondary part of the converter is (B. Singh et al. 2011)

$$C_1 = \frac{V_{dc}D(t)}{\Delta V_C(t) f_s R_L} \quad (6)$$

The dc link capacitance is calculated as (B. Singh et al. 2011)

$$C_d = \frac{I_{dc}}{2\omega\Delta V_{dc}} \quad (7)$$

The value of filter components, C_f and L_f are (V. Vlatkovic et al. 1996)

$$C_f = \frac{I_{peak}}{V_m\omega_L}\tan\theta \quad (8)$$

$$L_f = \frac{1}{4\pi C_f f_c^2} \quad (9)$$

3. FUZZY LOGIC CONTROLLER

Fuzzy logic gives solution to problems which have indirect or imprecise information. Fuzzy logic controller (FLC) is suitable to many engineering problems as it can avoid complex mathematical modeling. First the numerical values have to be converted to linguistic variables by the fuzzification process. Then fuzzy rules are formulated and finally defuzzified to get the crisp output values.

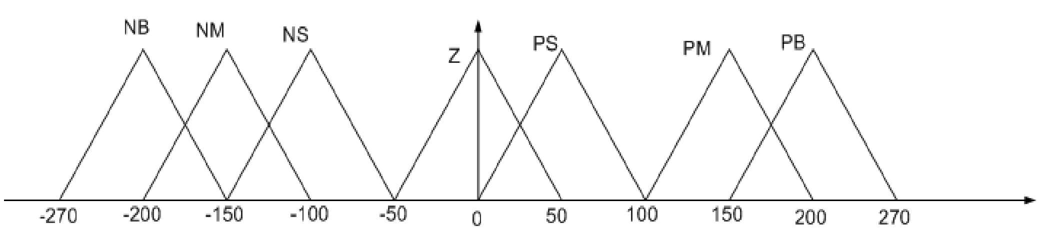

Figure 2 Input (error) fuzzy membership functions

Fuzzy Membership Functions

Fuzzy membership function maps the elements as real number values in the range 0 to 1. The mapping can be any shapes like triangular, guassidal, trapezoidal according to our need and convenience. Here triangular membership function is used for the two inputs and one output. The fuzzy membership function for inputs error and change of error is shown in fig 2. shown below. The two inputs are error and change of error. Here the error is the difference between the dc link voltage and the reference value. The change in error is the difference between the obtained error and the previous error. In fuzzy logic controller these range of values are set according to our convenience. The isolated zeta converter is a buck-boost converter and the output of the converter is the dc link voltage. Here the range can be set as -270V to +270V as the error is the difference between dc link voltage and reference value will be within this range. The output is the change in duty cycle of the pulse to the converter. The range of output values are set as -100 to +100.

Fuzzy Rules

Table 1 Fuzzy Rules

e \ ce	NB	NM	NS	Z	PS	PM	PB
NB	NVB	NVB	NVB	NB	NM	NS	Z
NM	NVB	NVB	NB	NM	NS	Z	PS
NS	NVB	NB	NM	NS	Z	PS	PM
Z	NB	NM	NS	Z	PS	PM	PB
PS	NM	NS	Z	PS	PM	PB	PVB
PM	NS	Z	PS	PM	PB	PVB	PVB
PB	Z	PS	PM	PB	PVB	PVB	PVB

The fuzzy rules are formulated according to the number of inputs. Here there are two inputs ie, the error voltage and rate of change of error. In fuzzy logic the numerical values are defined by the linguistic terms shown in table 1. These linguistic terms are also decided by us. Each term corresponds to a range of values. If the error and change of error are within a particular range the output range will be defined in the rules Each input consists of 7 membership functions, namely - NB-Negative Big, NM-Negative Medium, NS-Negative Small, Z-Zero, PS-Positive Small, PM-Positive Medium and PB-Positive Big. As illustrated in the table for 7x7 inputs there are 49 If-Then rules. If there is an ANTECEDENT then there is CONCLUSION. That means for different range of input values corresponding output is assigned in each rule. For output there are 9 membership functions. Along with the 7 functions NVB-Negative Very Big and PVB-Positive Very Big is added. According to the rules formulated, the output value is chose corresponding to each error value is shown in Table 1. If the error is negative big and change in error is negative big then the output is negative very big. Then the change in duty cycle will decrease. If both inputs are zero then output is zero, no change in duty cycle. If the input values are positive big then the output will be positive very big, then the duty cycle increase. Similar to these 3 rules the 49 rules are formulated for different combination of two inputs as stated in the table 1. The PWM pulse thus generated is used to trigger the isolated zeta converter switch. It regulates the output dc link voltage and correspondingly speed changes. The reference speed and measured speed are maintained throughout the operation.

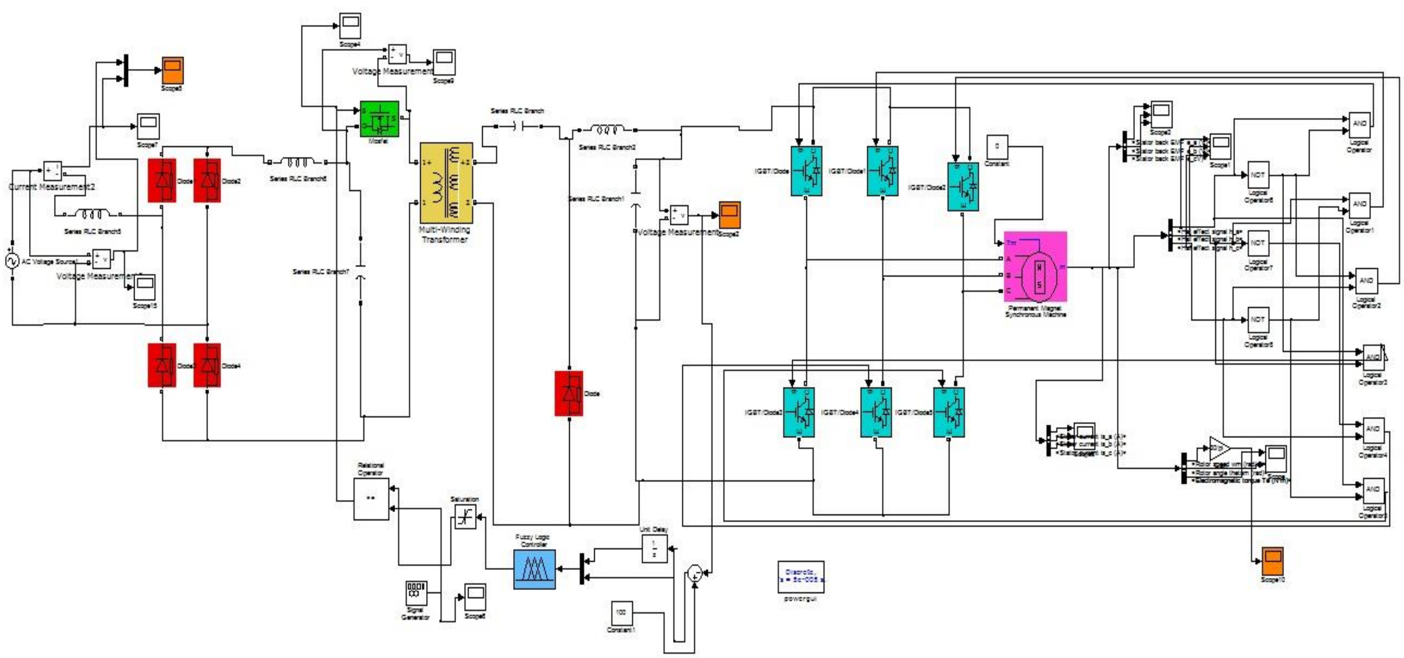

Figure 3 Simulation diagram of the proposed system

4. SIMULATION RESULTS

The simulation diagram of the fuzzy controlled isolated zeta converter is shown in fig 3. The simulation was done using MATLAB/Simulink tool. The supply given is single phase AC supply. It is fed to the isolated zeta converter through a diode bridge rectifier and filter. This dc voltage is fed to the inverter and then to the BLDC motor. The dc link voltage is controlled by a fuzzy logic controller.

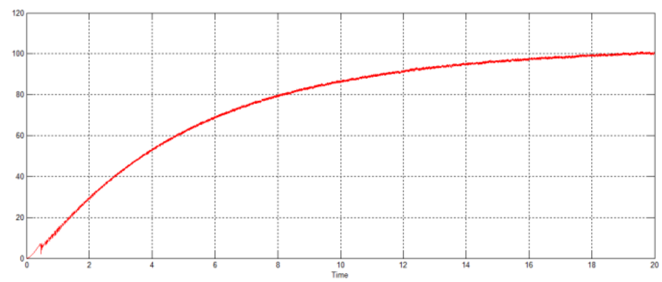

Figure 4 DC link voltage – 100 V

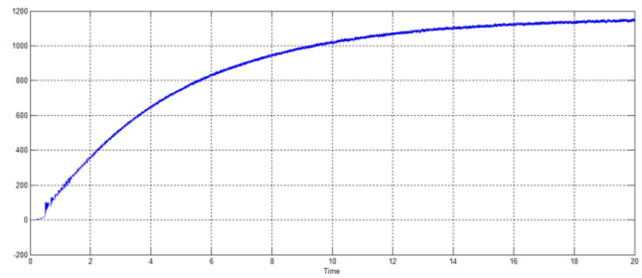

Figure 5 Speed corresponding to 100V- dc link voltage

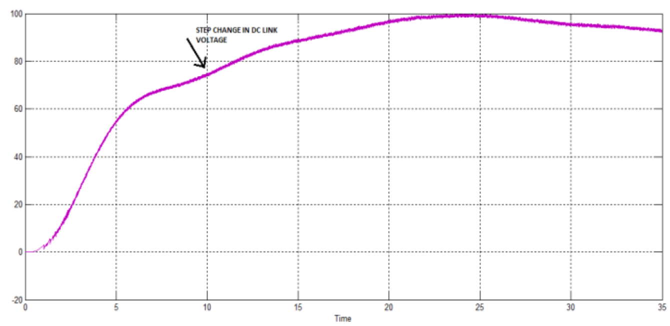

Figure 6 Step change in dc link voltage

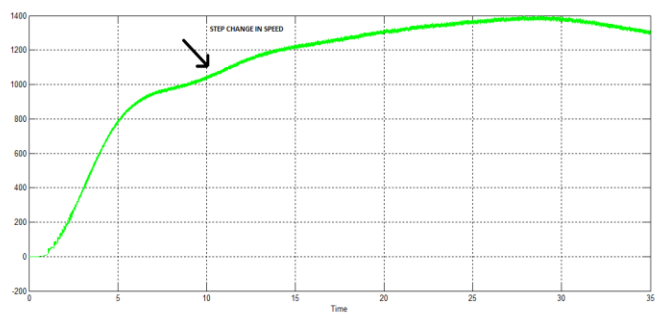

Figure7 Step change in speed

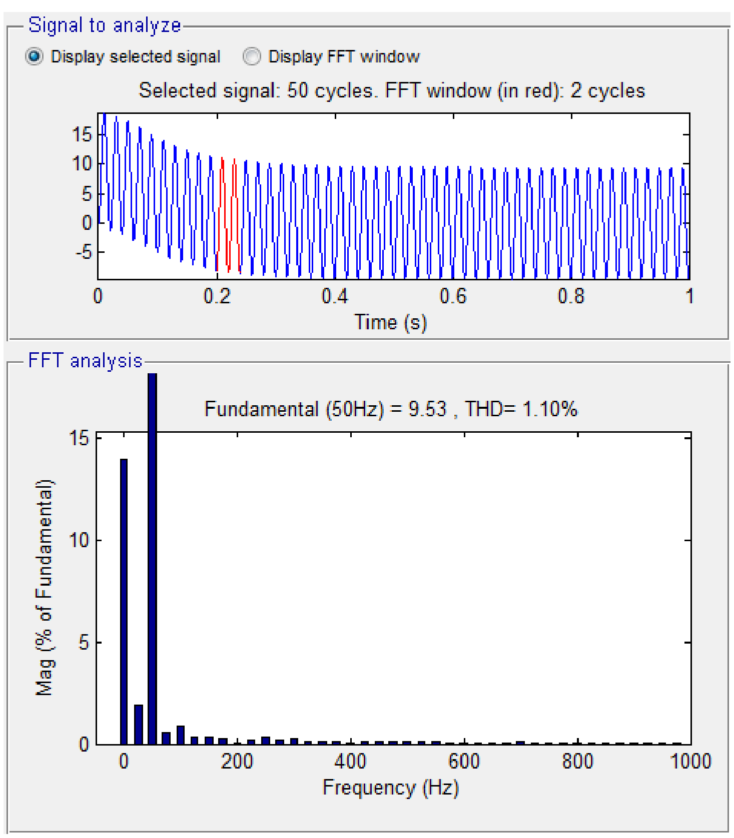

Figure 9 THD Measurement

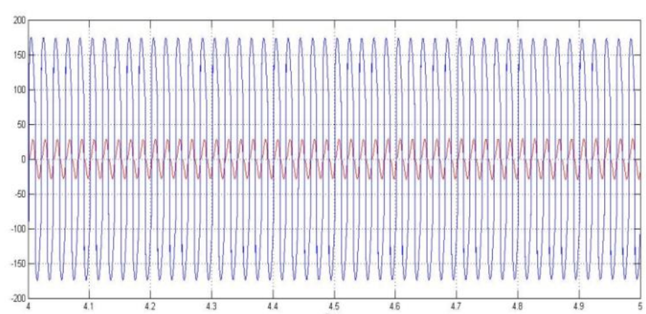

Figure 8 Supply voltage and current

The dc link voltage 100V is shown in fig 4. and the corresponding speed waveform is shown in fig 5. Using the proposed system it is observed that the total harmonic distortion is less. Here the dc link voltage and speed takes more time to settle to the reference value. The rising time is not reduced because it affects the power quality of the whole system. The ultimate aim of this paper is to reduce the Total Harmonic Distortion (THD) and to bring the power factor within the range of IEC 61000-3-2 standard. The THD measurement is done by the FFT analysis in MATLAB/Simulink and the THD obtained was 1.10% (fig 9). As the total harmonic distortion is very less the power factor will be high in the range of 0.99. So the supply voltage and current are inphase and there are no spikes in the supply

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current. The Total Harmonic Distortion less than 5% gives better power factor. Increased THD reduces the quality of supply by adding more spikes to the supply current. The supply voltage and current is shown in fig 8. The step change in dc link voltage is shown in fig 6. As the speed is controlled by the dc link voltage the speed also changed correspondingly. Fig 7 shows the change in speed. The step change is inserted in the control part of the converter at the step time shown in figure. The initial and final value set in the step signal gives the rising and falling of the waveforms. The dc link voltage can be varied to get a speed ranging from low value to high value.

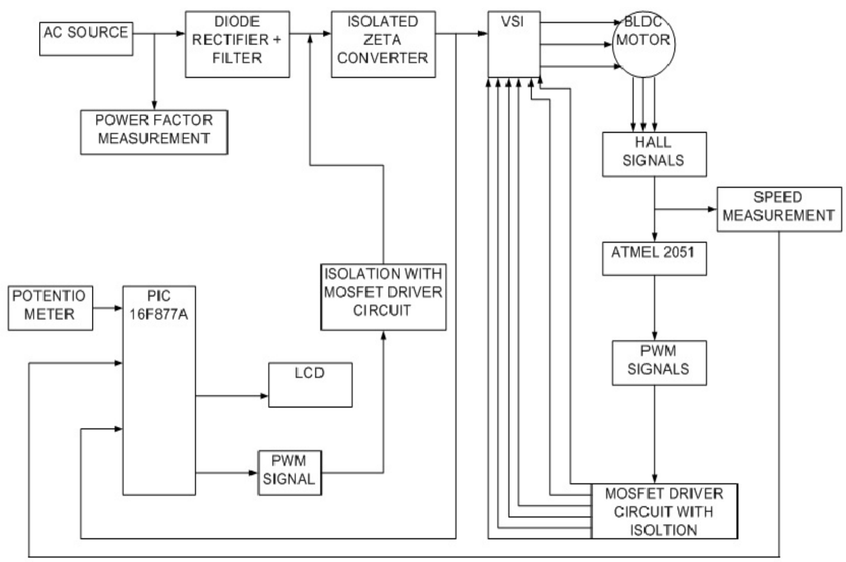

Figure10 Hardware block diagram of fuzzy controlled isolated zeta converter fed BLDC motor drive

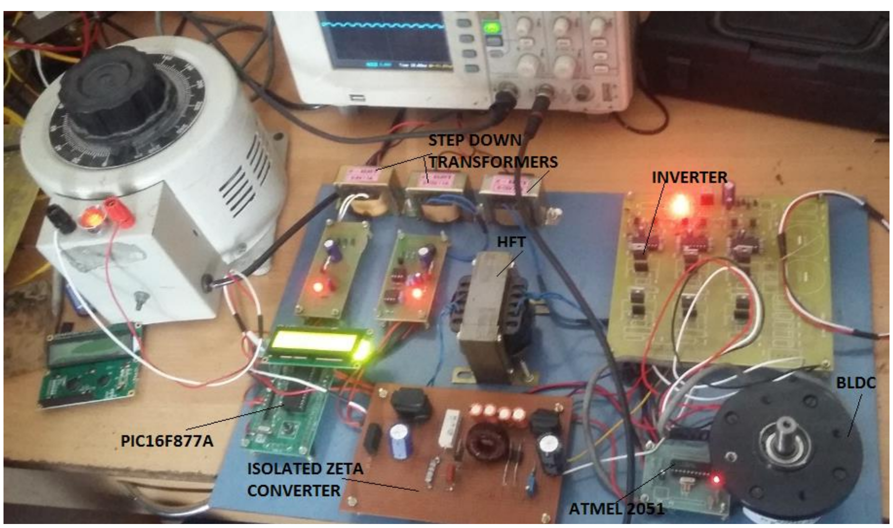

Figure 11 Experimental set up of the proposed system

5. HARDWARE BLOCK DIAGRAM

The hardware block diagram is shown in fig 10. There are separate power supplies for control circuit and power circuit. The main circuit consists of single phase AC supply fed to a diode bridge rectifier and filter followed by the isolated zeta converter. The converter is connected to voltage source inverter and then the BLDC motor drive. The hardware implemented is a prototype of the proposed system. The converter MOSFET is triggered by PIC 16F877A microcontroller.

The inverter switches used are MOSFETS instead of IGBT to reduce the cost. The PIC 16F877A has very few instruction (approximately 35) in the program. The length of the instruction is small and fixed and takes same amount of time for processing. The instruction being small, less time is taken to process another word, and hence CPU will be fast. It is a 40 pin IC in Dual Inline Package (DIP). There are 15 interrupts in this microcontroller. The input is the dc link voltage is given to the ADC port of microcontroller. There is an external clock of 4MHz frequency. It is provide by a crystal oscillator. Using fuzzy logic controller the width of the pulses is adjusted in the program. This PWM pulses is used to trigger the converter switch. The reference speed and measured speed is displayed in LCD connected to the microcontroller. There is a MOSFET driver circuit with optocoupler isolation. The MOSFET driver circuit used here are IR2110. An optocoupler or optoisolator can provide isolation and along with that it permits dc coupling, provides protection in case of overvoltage etc. The driver circuit is essential to control current or any components that used in the circuit. The reference speed is set by adjusting the potentiometer shown. The maximum speed that can set is 1500 rpm. The harmonic distortion is visible in the supply side current. So the power factor is measured at the supply side using the power quality analyzer. The electronic commutation of BLDC motor is done with VSI. The hall signal from motor is given to ATMEL 2051 microcontroller. The two switches of inverter are triggered by the program done in the microcontroller. Here also there is MOSFET driver circuit with optocoupler. The single phase AC supply is provided using an autotransformer. The input AC supply to the system is step down using transformer. The power supply to the converter and inverter is 12V and to the PIC microcontroller is 5V. This voltage is regulated using a voltage regulator. The voltage regulators used are 7812 and 7805. The output from the step down transformer passed to a diode bridge rectifier and to a capacitive filter.

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Figure 12(a) DC link voltage

Figure 12(b) Converter pulses

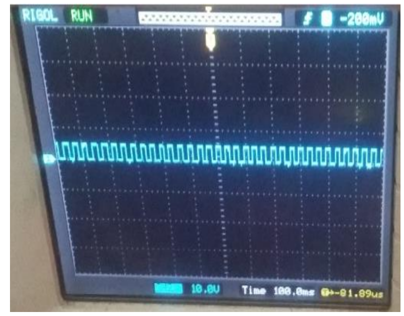

Figure 12(c) Pulses to the inverter switch

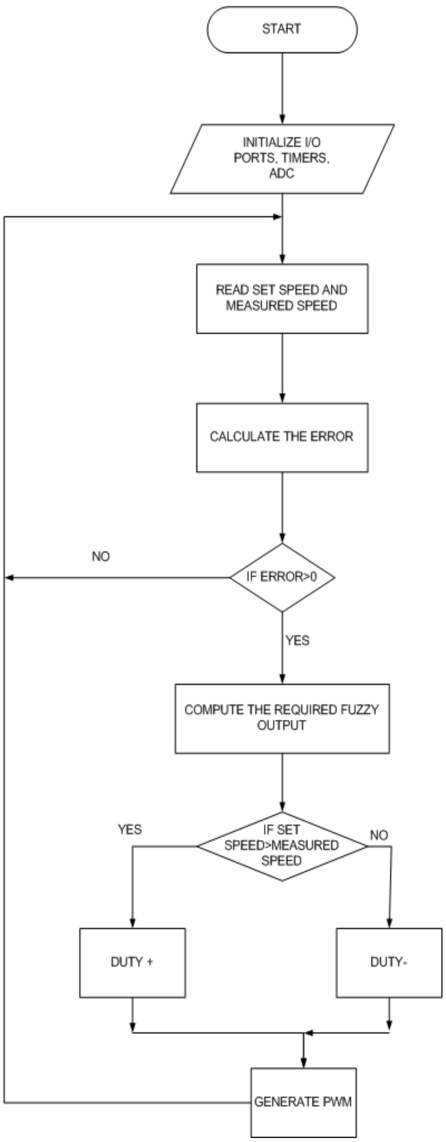

Figure 13 Flow chart of the system for the control of isolated zeta converter

6. EXPERIMENTAL RESULTS

The experimental set up is shown in fig 11. The reference speed and measured speed is displayed in LCD connected to the PIC microcontroller. The speed can also be measured using a tachometer. The output waveforms can be displayed in the CRO. The speed can be varied corresponding to the dc link voltage of the converter. The dc link voltage fed to the inverter (fig 12(a)), pulses to trigger the converter (fig 12(b)) and inverter pulses (fig. 12(c)) can be observed. The system flow chart is shown in fig 13. The control is done using PIC16F877A microcontroller. If the measured speed of the motor is not equal to the reference speed then the error is minimized by the fuzzy controller. The fuzzy values are set in the program according to the error value. The width of the PWM pulses to the converter will change to minimize the error. The input to the microcontroller is the dc link voltage and the output pulses are fed to the triggering switch of the converter.

7. CONCLUSION

The proposed BLDC motor fed by isolated zeta converter is suitable for low power applications. This configuration can be used for applications requiring isolation for safety. Here the speed of BLDC motor drive is controlled by varying the dc link voltage to the VSI (Voltage Source Inverter) feeding the BLDC motor. For controlling this dc link voltage, a power factor correction based isolated zeta converter is used. Power factor correction converters are widely used for improving the power quality at AC mains. The dc link voltage is controlled by comparing it with reference voltage and feeding it to fuzzy controller. The PWM pulse use to trigger the gate of the converter circuit is generated in the controller part. Fuzzy Controller is more suitable to parameter changes, sudden load variations and easy to formulate because no need of precise values and complex mathematical calculations. The proposed circuit provides better power factor within the limits of IEC 61000-3-2 standard. The circuit performance is checked using MATLAB/Simulink based simulation and observed the necessary results. The hardware platform is PIC 16F877A and ATMEL 2051. The speed is changing according to the variation in dc link voltage. The measured speed and reference speed set are observed as same.

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