ISSN (Print) : 2320 – 3765
ISSN (Online): 2278 – 8875

International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering

(An ISO 3297: 2007 Certified Organization)

Vol. 4, Issue 5, May 2015

Hardware Implementation of Fuzzy Controller Based PFC Cuk Converter Fed BLDC Motor Drive

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ABSTRACT: The use of permanent-magnet brushless dc motor (BLDC) in low-power appliances is increasing because of its features of high efficiency, wide speed range, and low maintenance. This project deals with a power factor correction (PFC) based Cuk converter fed brushless DC motor (BLDC) drive as a cost effective solution for low power applications. The speed of the BLDC motor is controlled by varying the Dc bus voltage of voltage source inverter(VSI) which uses a low frequency switching of VSI (electronic commutation of BLDC motor) for low switching losses. A diode bridge rectifier (DBR) followed by a Cuk converter working in discontinuous conduction mode(DCM)is used for control DC link voltage with unity power factor at AC mains. The fuzzy based controller system is used for general purpose industrial applications. Performance of the PFC Cuk converter is evaluated in four different operation condition of discontinuous and continuous conduction mode (CCM) and a comparison is made to select a best suited mode of operation. Keywords: Converter, BLDC Motor, Fuzzy Controller, Matlab.

1. INTRODUCTION

BRUSHLESS DC (BLDC) motors are recommended for many low and medium power drives applications because of their high efficiency, high flux density per unit volume, low maintenance requirement, low EMI problems, high ruggedness and a wide range of speed control.[1] Due to these advantages, they find applications in numerous areas such as household application, transportation (hybrid vehicle), aerospace, heating, ventilation and air conditioning (HVAC), motion control and robotics, renewable energy application etc. The BLDC motor is a three phase synchronous motor consisting of a stator having a three phase concentrated windings and a rotor having permanent magnets. It doesn't have mechanical brushes and commutator assembly, hence wear and tear of the brushes and sparking issues as in case of conventional DC machines are eliminated in BLDC motor and thus has low EMI problems.[2-4] This motor is also referred as electronically commutated motor (ECM) since an electronic commutation based on the Hall-Effect rotor position signals is used rather than a mechanical commutation. There is a requirement of an improved power quality as per the international power quality (PQ) standard IEC 61000-3- 2which recommends a high power factor (PF) and low total harmonic distortion (THD) of AC mains current for Class-A applications (<600W, <16A) which includes many household equipments. [5]The conventional scheme of a BLDC motor fed by a diode bridge rectifier (DBR) and a high value of DC link capacitor draws a non-sinusoidal current, from AC mains which is rich in harmonics such that the THD of supply current is as high as 65%, which results in power factor as low as 0.8.[6] These types of power quality indices can't comply with the international PQ standards such as IEC 61000-3-2. Hence, single-phase power factor correction (PFC) converters are used to attain a unity power factor at AC mains. These converters have gained attention due to single stage requirement for DC link voltage control with unity power factor at AC mains. It also has low component count as compared to multistage converter and therefore offers reduced losses. Conventional schemes of PFC converters fed BLDC motor drive utilize an approach of constant DC link voltage of the VSI and controlling the speed by controlling the duty ratio of high frequency pulse width modulation (PWM) signals. The losses of VSI in such type of configuration are considerable since switching losses depend on the square of switching frequency (Psw_loss α fS2). Ozturk have proposed a boost PFC converter based direct torque controlled

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(DTC) BLDC motor drive. They have the disadvantages of using a complex control which requires large amount of sensors and higher end digital signal processor (DSP) for attaining a DTC operation with PFC at AC mains. Hence, this scheme is not suited for low cost applications. Ho have proposed an active power factor correction (APFC) scheme which uses a PWM switching of VSI and hence has high switching losses. Wu have proposed a cascaded buck-boost converter fed BLDC motor drive, which utilizes two switches for PFC operation. This offers high switching losses in the front end converter due to doubles witch and reduces the efficiency of overall system. [7-10]

Selection of operating mode of front end converter is a trade-off between the allowed stresses on PFC switch and cost of the overall system. Continuous conduction mode (CCM) and discontinuous conduction mode (DCM) are the two different modes of operation in which a front end converter is designed to operate. A voltage follower approach is one of the control techniques which is used for a PFC converter operating in DCM. This voltage follower technique requires a single voltage sensor for controlling the DC link voltage with a unity power factor. Therefore, voltage follower control has an advantage over a current multiplier control of requiring a single voltage sensor.[11] This makes the control of voltage follower a simple way to achieve PFC and DC link voltage control, but at the cost of high stress on PFC converter switch. On the other hand, the current multiplier approach offers low stresses on the PFC

switch, but requires three sensors for PFC and DC link voltage control. [12]

II. BLOCK DIAGRAM & EXPLANATION

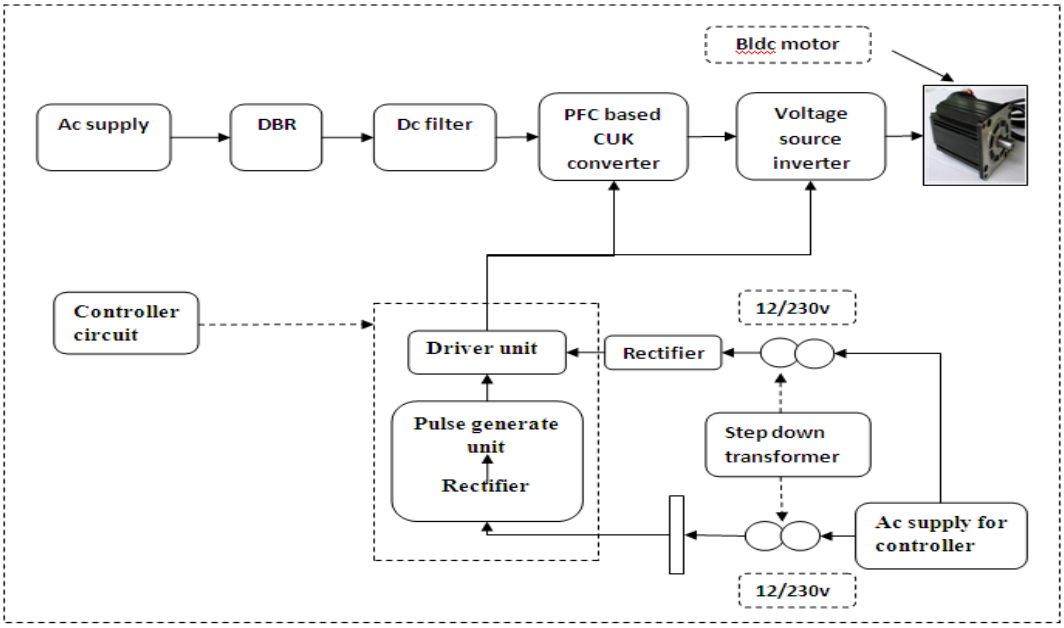

Figure 1 Block diagram

The proposed system consists of a AC supply, Diode bridge rectifier, Dc filter , Cuk converter and a Voltage source inverter.[13-15] The controller unit and a pulse generation unit is used to give a pulses during commutation. The block diagram of proposed system is shown in fig .1 .The AC supply is given as input to the diode bridge rectifier, where it is converted into dc output and given to DC filter. Where the filter is used to remove the unwanted or undesirable frequencies from a signal of a rectifier output .Then the cuk converter unit is operated as continuous or discontinuous conduction mode. Voltage source inverter is commutated and the speed of the motor is controlled as per variation of voltages.[16-18]

III. CIRCUIT CONFIGURATION

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3.1 SYSTEM CONFIGURATION

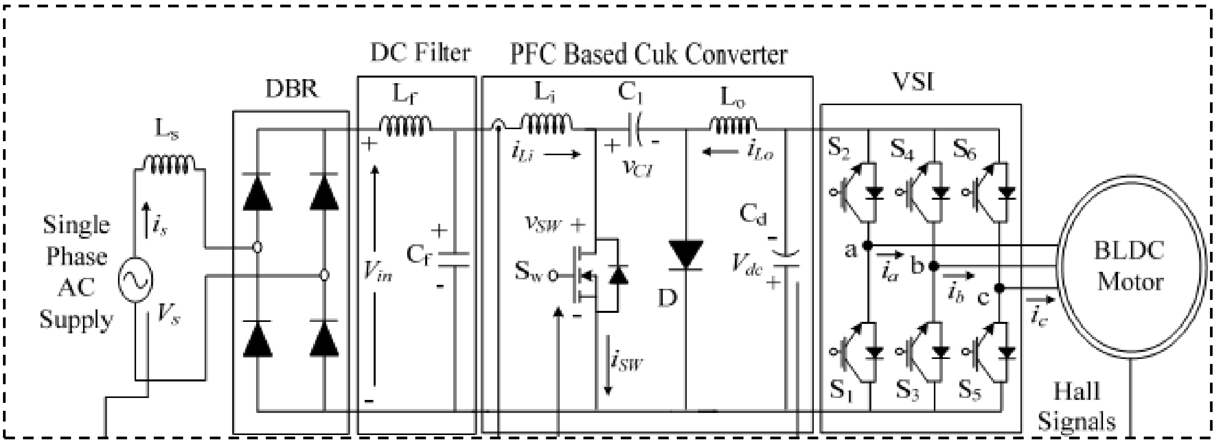

Fig 2 BLDC motor drive fed by a PFC Cuk converter

Fig.2- shows the PFC Cuk converter based VSI fed BLDC motor drive using a current multiplier and a voltage follower approach respectively. [19]A high frequency metal oxide semiconductor field effect transistor (MOSFET) is used in Cuk converter for PFC and voltage control, whereas insulated gate bipolar transistor's (IGBT) are used in the VSI for its low frequency operation.[20] BLDC motor is commutated electronically to operate the IGBT's of VSI in fundamental frequency switching mode to reduce its switching losses. The PFC Cuk converter operating in CCM using a current multiplier approach is shown in Fig4.1; i.e. the current flowing in the input and output inductors (Li and Lo), and the voltage across the intermediate capacitor (C1) remain continuous in a switching period. The current flowing in either of the input or output inductor (Li and Lo) or the voltage across the intermediate capacitor (C1) become discontinuous in a switching period for a PFC Cuk converter operating in DCM. A Cuk converter is designed to operate in all three discontinuous conduction modes and a continuous conduction mode of operation and its performance is evaluated for a wide voltage control with unity power factor at AC mains.[21]

3.2 OPERATION OF CUK CONVERTER IN DIFFERENT MODES

The operation of Cuk converter is studied in four different modes of CCM and DCM. In CCM, the current in inductors (Li and Lo) and voltage across intermediate capacitor C1remain continuous in a switching period.[22-24] Moreover, the DCM operation is further classified into two broad categories of discontinuous inductor current mode (DICM) and discontinuous capacitor voltage mode (DCVM). In DICM, the current flowing in inductor Li or Lo becomes discontinuous in their respective modes of operation. While in DCVM operation, the voltage appearing across the intermediate capacitor C1 becomes discontinuous in a switching period. Different modes for operation of CCM and DCM are discussed as follows.[25]

CCM Operation

The operation of Cuk converter in CCM is described as follows. Figs.4. 2(a) and (b) show the operation of Cuk converter in two different intervals of a switching period and Fig.4.2(c) shows the associated waveforms in a complete switching period.[26-28]

Interval I: When switch Sw in turned on,inductor Li stores energy while capacitor C1 discharges and transfers its energy to DC link capacitor Cd as shown in Fig.4.2(a). [29]Input inductor current i_{Li} increases while the voltage across the intermediate capacitor VC1 decreases as shown in Fig4.2(c).[30]

Interval II: When switch Sw is turned off, then the energy stored in inductor Lo is transferred to DC link capacitor Cd, and inductor Li transfers its stored energy to the intermediate capacitor C1 as shown in Fig4.2(b). [31-33] The designed values of Li, Lo and C1 are large enough such that a finite amount of energy is always stored in these components in a switching period.[34-35]

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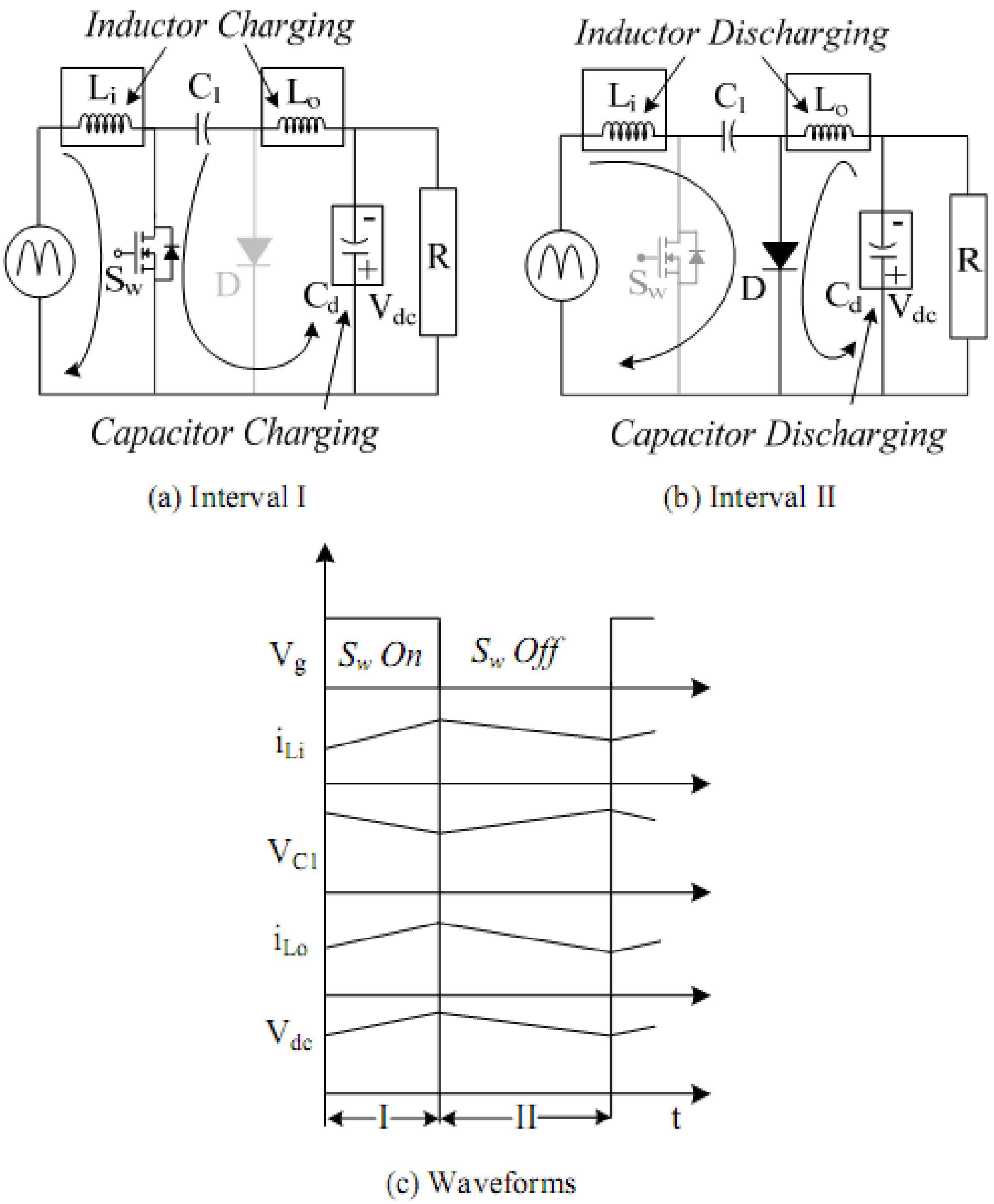

Fig.3. Operation of Cuk converter in CCM during different intervals of switching period(a)Sw On and (b)Sw Off (c) the associated waveforms.

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IV. HARDWARE IMPLEMENTATION

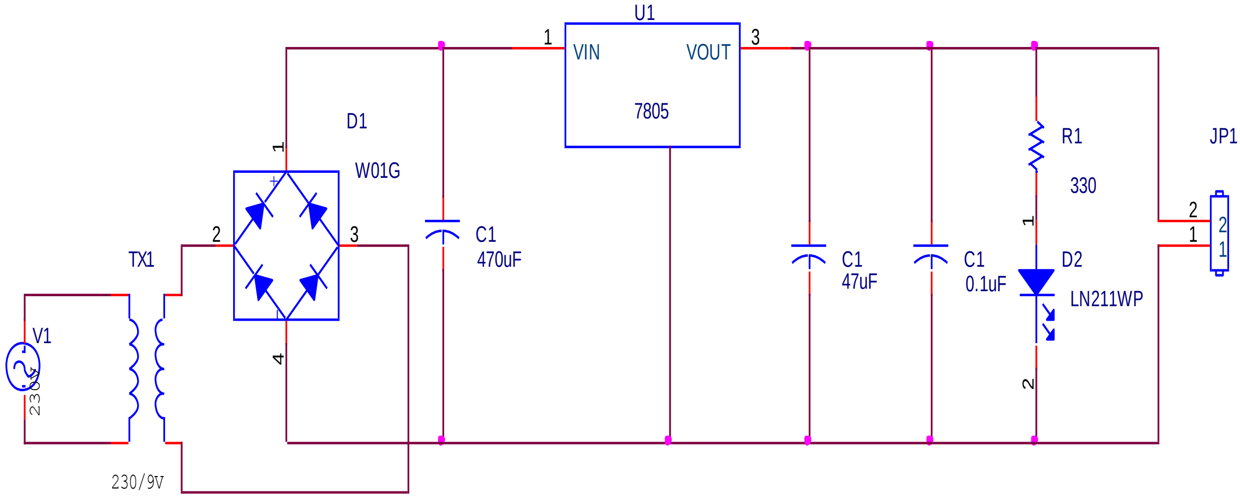

Fig. 4 Power circuit

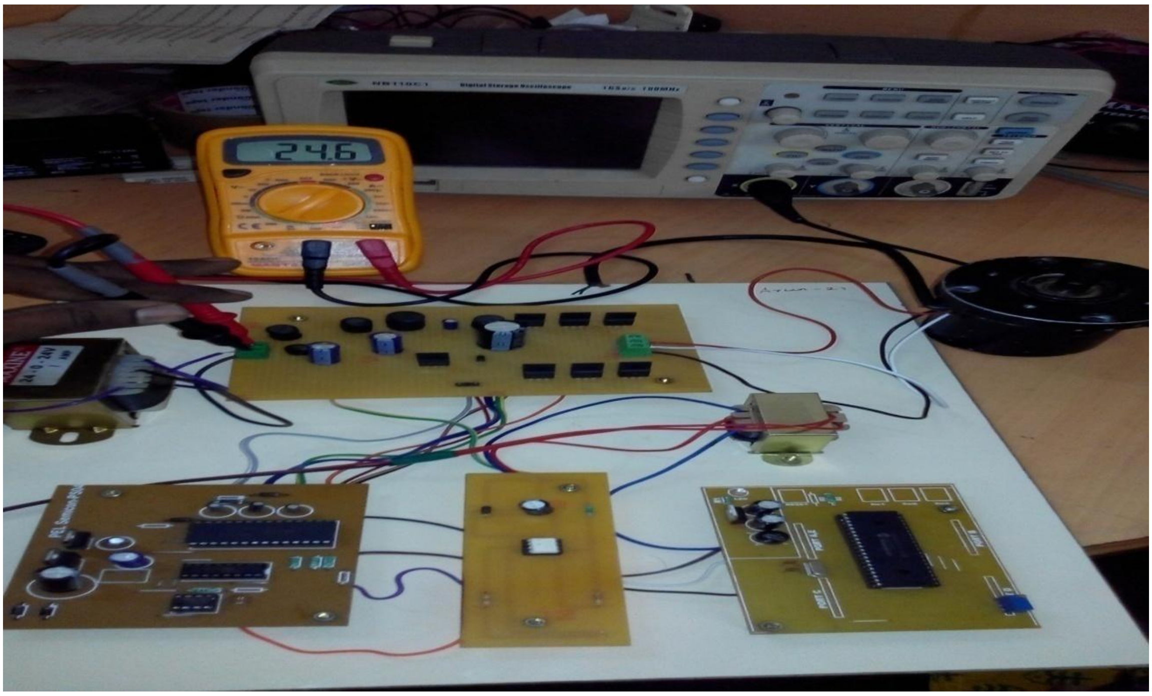

Fig.5 Hardware setup.

ISSN (Print) : 2320 – 3765
ISSN (Online): 2278 – 8875

International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering

(An ISO 3297: 2007 Certified Organization)

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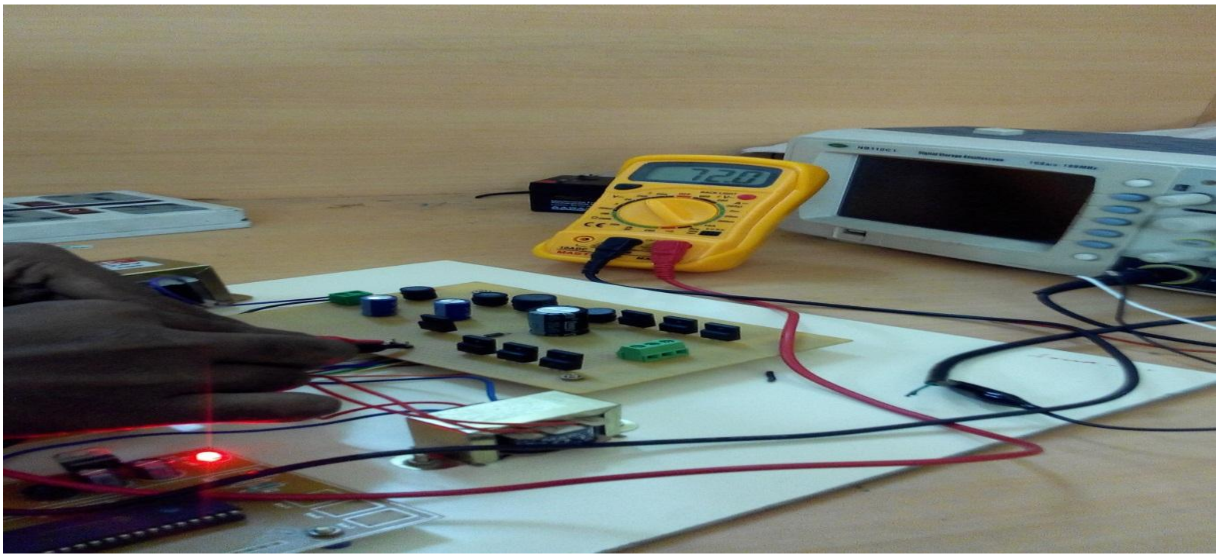

Fig 6 BLDC motor output.

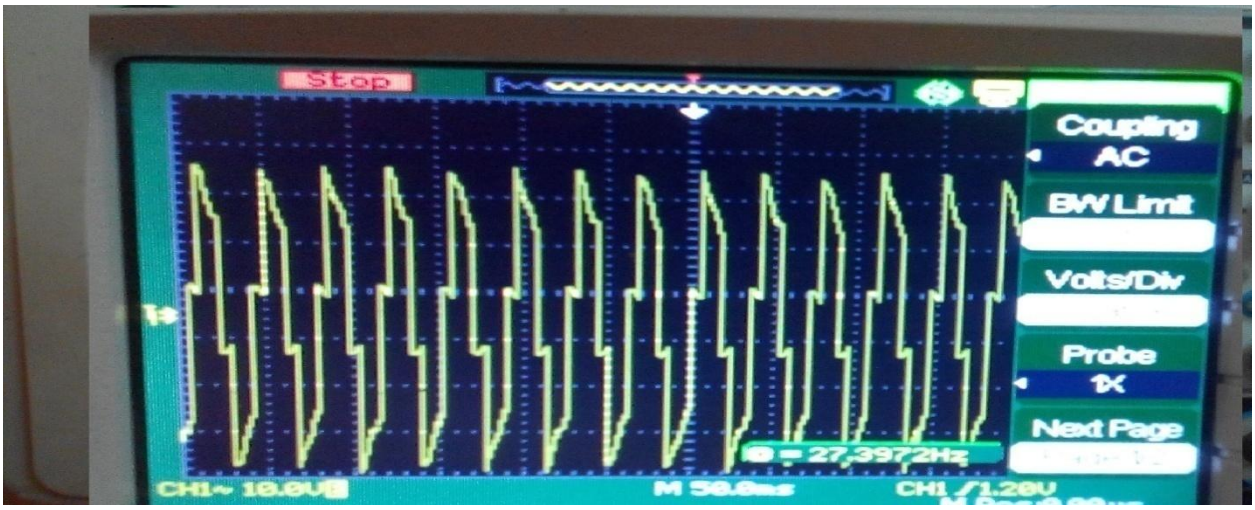

Fig 7 BLDC motor output voltage waveform.

V. CONCLUSION

A Cuk converter for VSI fed BLDC motor drive has been designed for achieving a unity power factor at AC mains for the development of low cost PFC motor for numerous low power equipments such fans, blowers, water pumps etc. The speed of the BLDC motor drive has been controlled by varying the DC link voltage of VSI; which allows the VSI to operate in fundamental frequency switching mode for reduced switching losses. Four different modes of Cuk converter operating in CCM and DCM have been explored for the development of BLDC motor drive with unity power factor at AC mains. A detailed comparison of all modes of operation has been presented on the basis of feasibility in design and the cost constraint in the development of such drive for low power applications. Finally, a best suited mode of Cuk converter with output inductor current operating in DICM has been selected for experimental verifications. The proposed drive system has shown satisfactory results in all aspects and is a recommended solution for low power BLDC motor drives.

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