Implementation of Bridgeless Boost Converter Fed PMBLDC Motor Drive Using PIC

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***Abstract*-In this work a bridgeless PFC boost rectifier is proposed to reduce harmonic current of a BLDC motor. The aim of the work is to improve the input power factor of PMBLDC drive. Conventional bridged PFC topology is replaced by bridgeless PFC topology. Conventional VSI fed BLDC motor suffers from the high conduction loss in the input rectifier-bridge. Higher efficiency can be achieved by using the bridgeless boost topology. Performance comparison between the VSI fed BLDC motors with filters and the bridgeless boost rectifier fed BLDC motor are presented. The simulation results with bridgeless boost converter show that there is an improvement in power factor. The hardware is fabricated and tested. Simulation and experimental results of these systems are presented and the performance measures are compared. Experimental measurements agree acceptably with simulation results, and validate the proposed methods.**

Keywords-Boost rectifier; low conduction losses; Power factor correction (PFC); PMBLDC motor

I. INTRODUCTION

A PMBLDC motor is a kind of three-phase synchronous motor with permanent magnets (PMs) on the rotor and trapezoidal back EMF waveform, which operates on electronic commutation accomplished by solid state switches. It is powered through a three-phase voltage source inverter (VSI) which is fed from single-phase AC supply using a diode bridge rectifier (DBR) followed by a smoothening DC link capacitor. This arrangement suffers from power quality (PQ) disturbances such as poor power factor (PF), increased total harmonic distortion (THD) of current at input AC mains. It is mainly due to uncontrolled charging of the DC link capacitor which results in a pulsed current waveform having a peak value higher than the amplitude of the fundamental input current at AC mains. Moreover, the PQ standards for low power equipments such as IEC 61000-3-2 [1] , emphasize on low harmonic contents and near unity power factor current to be drawn from AC mains by these motors. Therefore, use of a power factor correction (PFC) topology amongst various available topologies is almost inevitable for a PMBLDCM drive.

Permanent magnet synchronous motor (PMSM) with sinusoidal back-EMF and Permanent Magnet Brushless DC motor (PMBLDCM) with trapezoidal back EMF are widely used in industrial and household products for its reliability, high efficiency, high power density, low maintenance requirement, lower weight and low cost. PMBLDC motor is suitable for high speed and low power applications due to high efficiency and wide speed control. They are used in industries such as Automotive, Aerospace, Consumer, Medical, Industrial Automation Equipment and Instrumentation. In the field of inverter appliance, the application of AC/DC/AC converter is more and more popular. Front stage is AC/DC converter, a kind of non-linear converter, made up of uncontrolled rectifier bridge and electrolytic capacitors. There are serious contaminations from harmonic currents at the mains side, making the products not pass IEC61000-3-2 and IEC61000-3-12 [1] successfully. In order to mitigate the harmonic current pollution, most of the household inverters are equipped with power factor correction converter as front AC/DC converter, and the input power factor approaches one. But the conventional active PFC has to employ uncontrolled rectifier and costly boost inductor, and these power components result in power loss, low efficiency and high cost. Nevertheless, the bridgeless PFC (BLPFC) is characteristic of small number of power switches, making room for low power loss [2]. Additionally, the conventional active PFC works as a complete PFC, and the power switches are in on and off state in a whole mains period, enduring high voltage and current stresses, producing a lot of switching loss and conduction loss and limiting the efficiency.

II. VOLTAGE SOURCE FED BLDC MOTOR WITH T FILTER

The poor quality of voltage and current of a conventional inverter fed BLDC motor is due to the presence of harmonics and hence there is significant level of energy losses. The inverters with a large number of steps can generate high quality voltage waveforms [3]. A voltage source inverter can run the BLDC motor by applying three phase square wave voltages to the stator winding of the motor .A variable frequency square wave voltage can be applied to the motor by controlling the switching frequency of the power semiconductor switches. The square wave voltage will induce low frequency harmonic torque pulsation in the machine. Also variable voltage control with variable frequency operation is not possible with square wave inverters. The total harmonic distortion of the classical inverter is very high. In this paper the total harmonic distortion is analyzed between VSI (with and without filters) fed BLDC using Simulation results. Power electronic devices such as power rectifiers, thyristor converters and static VAR compensators contribute a considerable amount of harmonics. Even updated pulse-width modulation (PWM) techniques used

to control modern static converters such as machine drives, power factor compensators do not produce perfect waveforms, which strongly depend on the semiconductors switching frequency. Voltage or current converters, as they generate discrete output waveforms, force the use of machines with special isolation, and in some applications large inductances connected in series with the respective load.

Also, it is well known that distorted voltages and current waveforms produce harmonic contamination, additional power losses, and high frequency noise that can affect not only the power load but also the associated controllers [3] .All these unwanted operating characteristics associated with PWM converters could be overcome with improved bridgeless PFC boost converters.

III. PFC USING BOOST CONVERTERS

The traditional boost converter PFC is designed to provide higher output DC voltage. This causes high switching stresses to power switches and hence results in lower conversion efficiency [4]. So this converter cannot be used in high power applications. In this paper an improved bridgeless PFC boost rectifier is proposed to save energy, to suppress harmonic current and to improve drive performance of a BLDC motor. Conventional bridged PFC topology is replaced by bridgeless PFC topology [5]. Even though the bridgeless boost rectifiers reduce the conduction loss by reducing the number of switches they exhibit a significant degradation of performance at low line voltage [6]-[7]. Performance comparison between the conventional VSI (with and without filters) fed BLDC motor and the bridgeless boost rectifier fed BLDC motor is also presented here using simulation results.

It is possible to improve the input power factor by using a T-filter on the AC side. The AC line current can also be smoothened by using filters in the line just before the power electronic converter system. Two inductors present in the T filter basically increase source side inductance. They reduce higher order harmonics in the current. They also reduce output voltage ripple and current stresses on the rectifier diodes. The capacitor suppresses the high frequency harmonics and transients from being coupled to and from the source.

IV. PRINCIPLE OF THE BRIDGELESS TOPOLOGY

The basic topology of the bridgeless PFC boost rectifier [8] is shown in Fig. 1. Compared to the conventional PFC boost rectifier, shown in Fig. 2, one diode is eliminated from the line-current path [9], so that the line current simultaneously flows through only two semiconductors resulting in reduced conduction losses [10]. There are a number of available DC-DC converter topologies [11-13]. Among all these topologies half bridge topology [11-18] is selected for power factor correction due to its features like high-voltage conversion ratio, low conduction losses in switches [10] [11] and low input current ripple. The PFC half bridge boost converter is preferred over other PFC converters for medium and high power applications since this converter results in low EMI (electromagnetic interference) when operated in continuous conduction mode [14] [15].However, the bridgeless PFC boost rectifier in Fig. 1 has significantly larger common-mode noise than the conventional PFC boost rectifier [19].

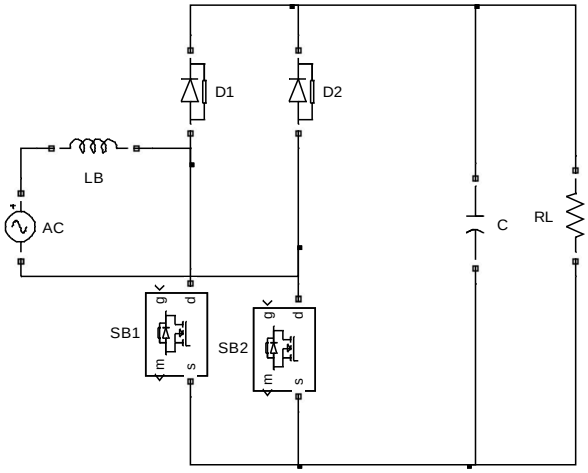

Fig. 1 Bridgeless Boost Converter

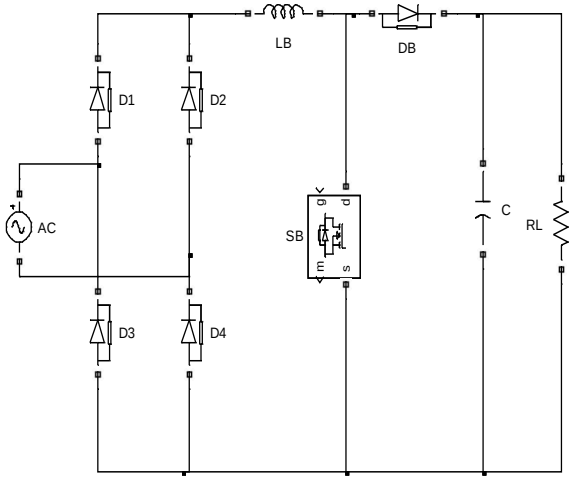

Fig. 2 Conventional PFC boost rectifier

Based on the analysis above, the bridgeless PFC circuit can simplify the circuit topology and improve the efficiency as well. The bridgeless PFC topology removes the input rectifier conduction losses and is able to achieve higher efficiency.

TABLE I –DIFFERENCES BETWEEN CONVENTIONAL AND BRIDGELESS PFC

	Slow diode	Fast diode	IGBT	Conduction Path On/(Off)
Conventional PFC	4	1	1	2 slow diode, 1IGBT/ (2 slow diode, 1 fast diode)
Bridgeless PFC	0	2	2	1 body diode, 1 IGBT/ (1 IGBT body diode, 1diode)

The difference between the bridgeless PFC and conventional PFC is summarized in Table 1. Comparing the conduction path of these two circuits, at every moment, bridgeless PFC inductor current only goes through two semiconductor devices, but inductor current goes through three semiconductor devices for the conventional PFC circuit. As

shown in Table 1, the bridgeless PFC uses one IGBT body diode to replace the two slow diodes of the conventional PFC. Since both the circuits operate as a boost DC/DC converters, the switching loss should be the same. Thus the efficiency improvement relies on the conduction loss difference between the two slow diodes and the body diode of the IGBT. Besides, comparing with the conventional PFC, the bridgeless PFC not only reduces conduction loss, but also reduces the total components count and thereby increases the efficiency of the drive. The above literature does not deal with implementation of PF correction converter fed PMBLDC motor. An attempt is made in the present work to implement PFC converter fed PMBLDC drive.

V. SIMULATION RESULTS OF VSI FED BLDC MOTOR WITH AND WITHOUT FILTER

Simulation results of VSI fed BLDC motor with and without filter are compared with that of bridgeless boost converter fed BLDC motor.

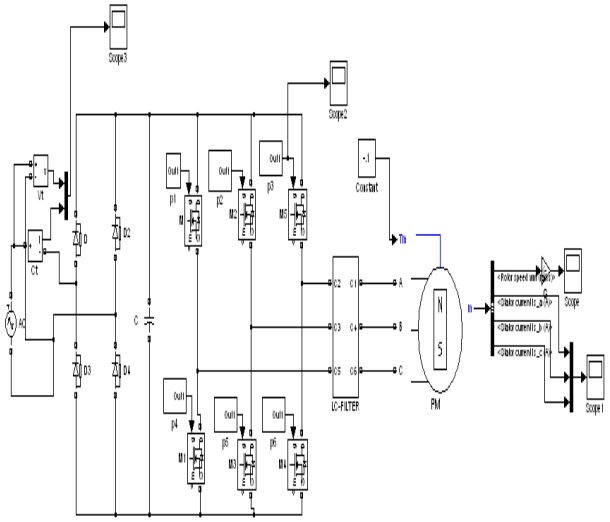

Fig. 3 (a) VSI fed BLDC motor

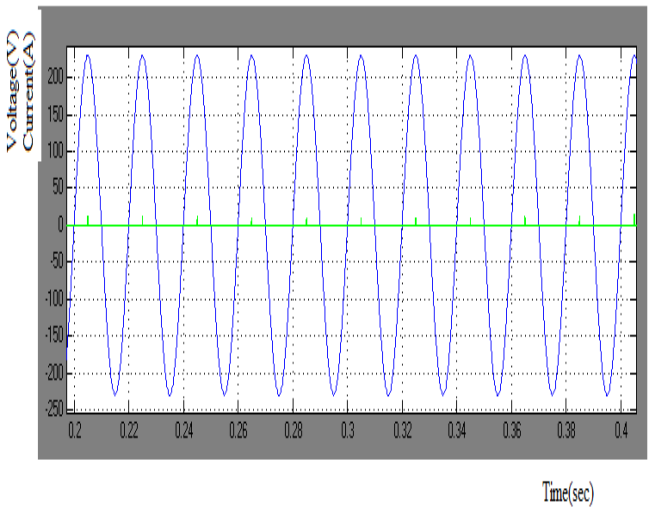

Fig. 3 (b) Input voltage and current waveform

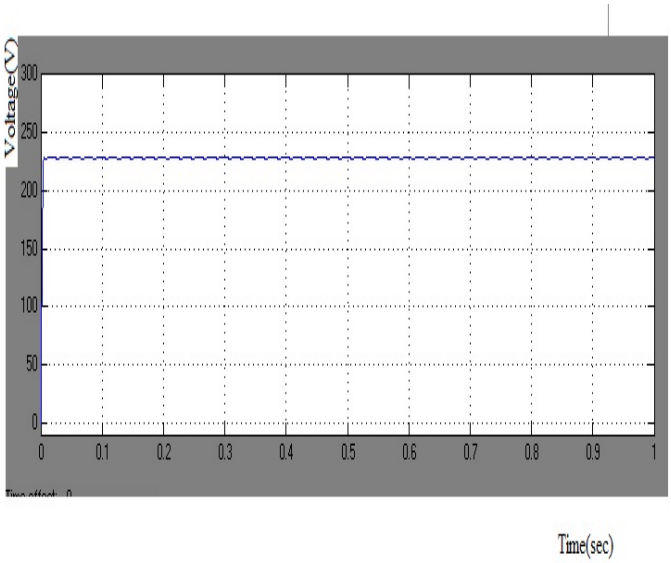

Fig. 3 (c) Rectifier output (volt)

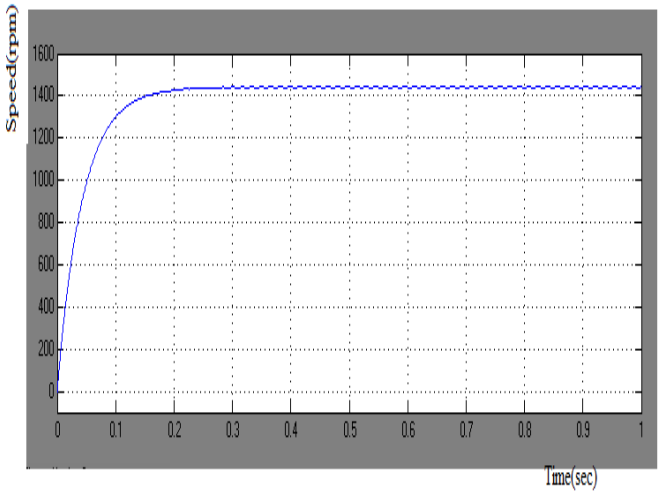

Fig. 3 (d) Rotor speed (rpm)

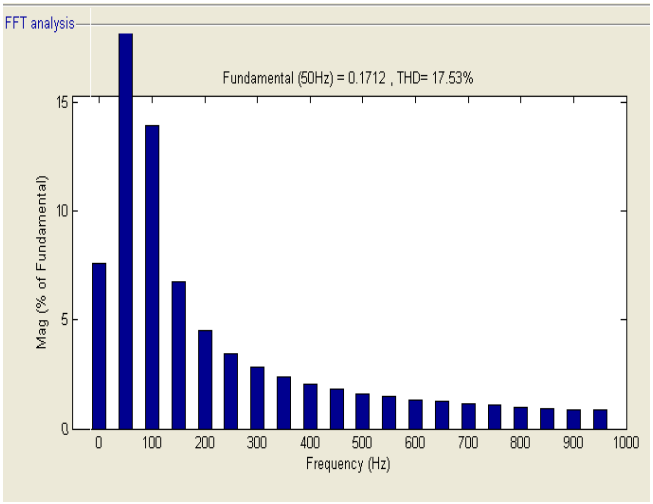

Fig. 3 (e) FFT Analysis

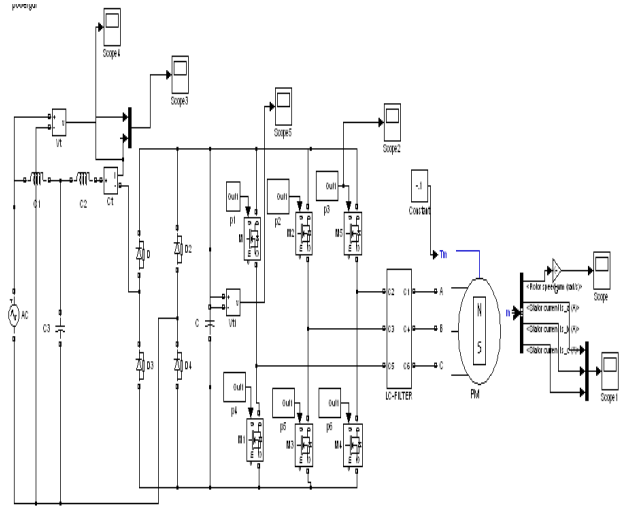

Fig. 4 (a) VSI with input T-filter fed BLDC motor

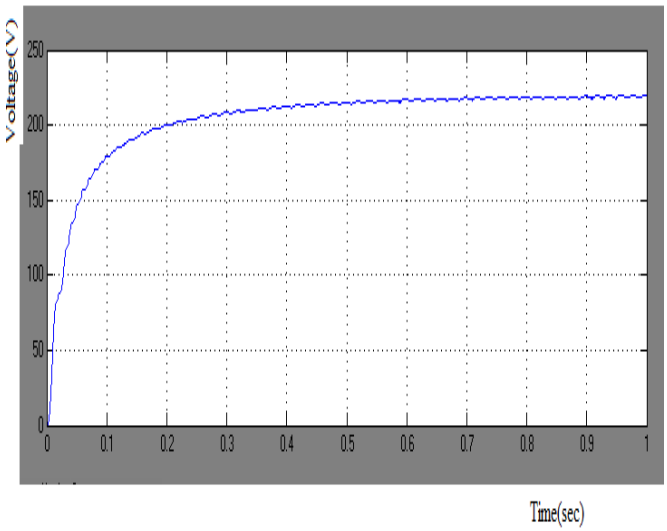

Fig. 4 (d) Rectifier output voltage

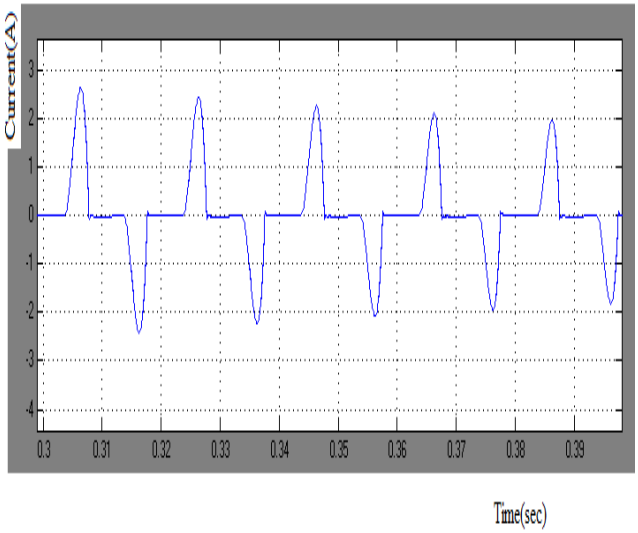

Fig. 4 (b) Input current waveform

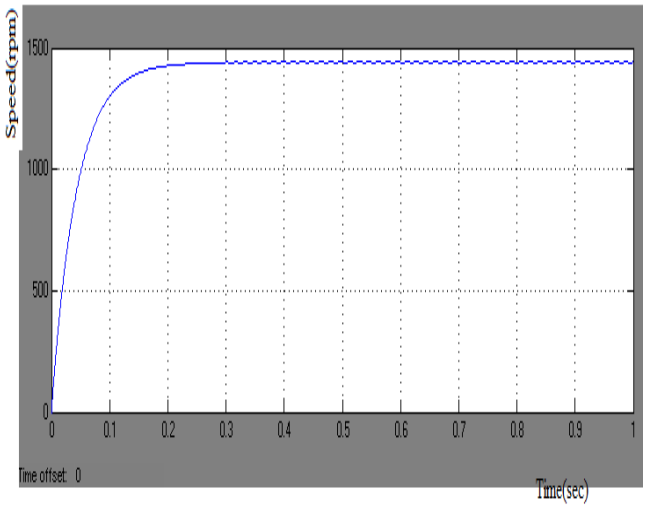

Fig. 4 (e) Rotor speed

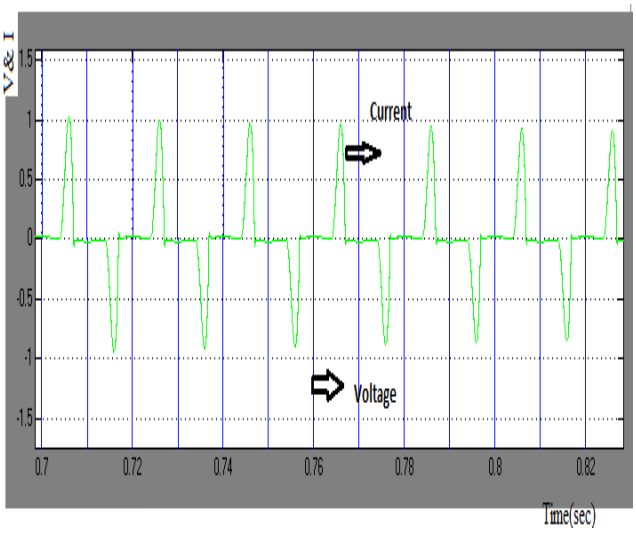

Fig. 4 (c) Input current and voltage waveform

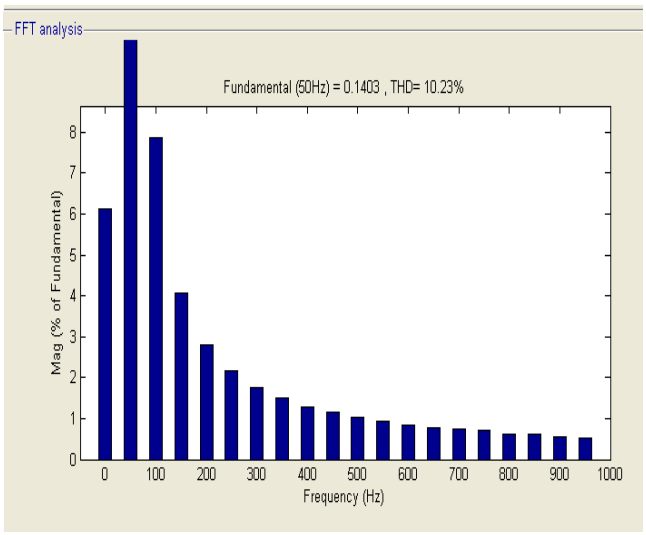

Fig. 4 (f) FFT Analysis

VSI fed BLDC motor with capacitor filter is shown in Fig. 3 (a). Input voltage and current waveforms are shown in Fig. 3 (b).It can be seen that the current is displaced by 88°. Hence the power factor is very less with capacitor filter system. Output of the rectifier is shown in Fig. 3 (c). The variation of speed is shown in Fig. 3 (d).The speed increases and settles at 1400 rpm.FFT analysis is done for the output voltage of the motor and the THD is found to be 17.1% as shown in Fig. 3 (e).

The phase angle can be further reduced by using T-filter. The T-filter is designed such that XL is greater than Xc.

VSI with input T-filter fed BLDC motor system is shown in Fig. 4 (a). Input current waveform is shown in Fig. 4 (b). Input voltage and current waveforms are shown in Fig. 4 (c). It can be seen that the current is displaced by 66°. Hence the power factor is found to have further improved with T filter. Output of the rectifier is shown in Fig. 4 (d). Variation of speed is shown in Fig. 4 (e) .The speed increases and settles at 1400 rpm.FFT analysis is done for output voltage of the motor and the THD is found to be 11.38% as shown in Fig. 4 (f).

VI. SIMULATION RESULTS OF VSI FED BLDC MOTOR WITH PFC BRIDGELESS BOOST CONVERTER

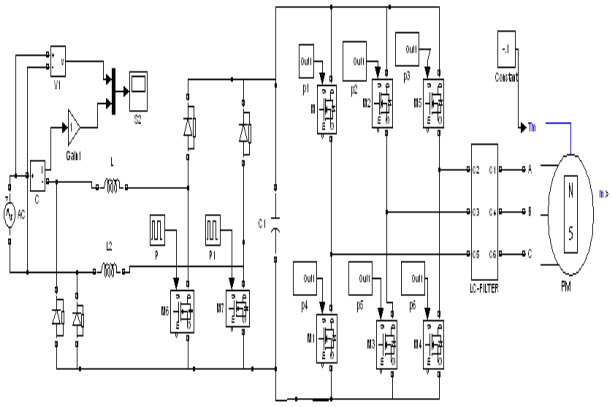

Fig. 5 (a) Bridgeless boost converter fed BLDC motor

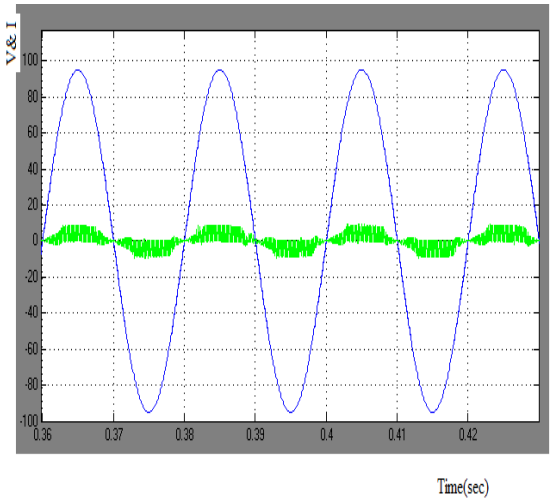

Fig. 5 (b) Input voltages and current waveform

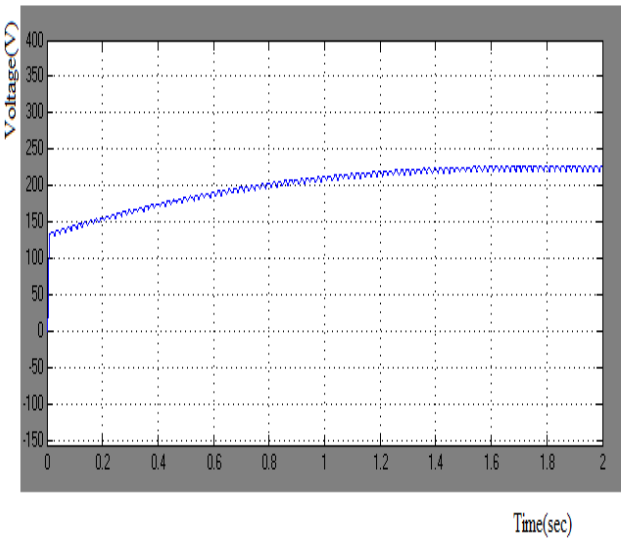

Fig. 5 (c) Boost converter output voltage

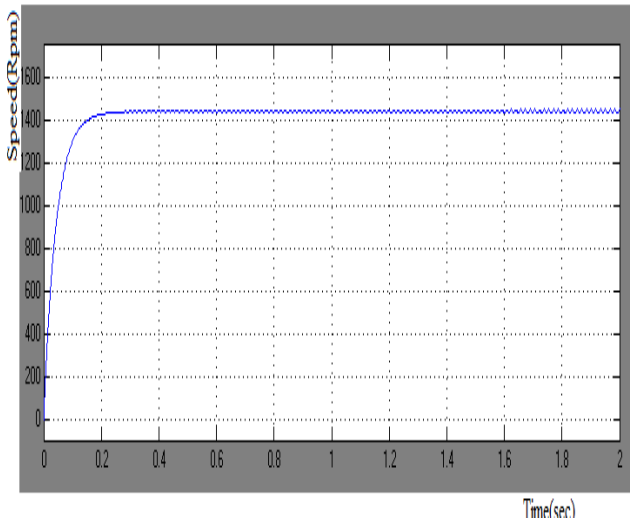

Fig. 5 (d) Rotor speed (rpm)

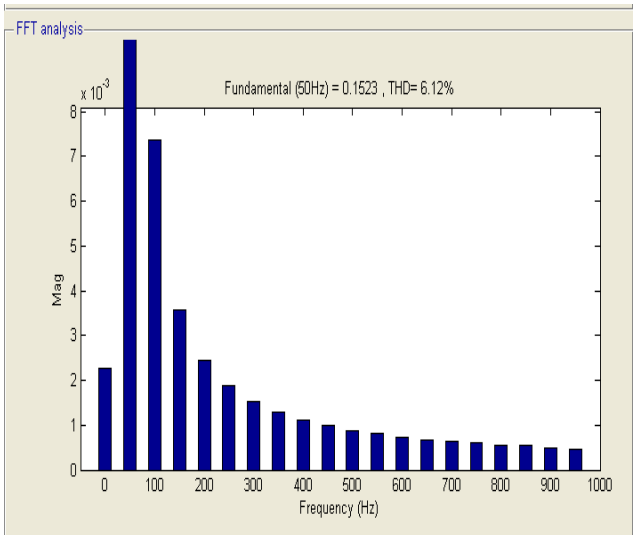

Fig. 5 (e) FFT Analysis

Bridgeless boost converter fed BLDC motor with capacitor filter is shown in Fig. 5 (a). Input voltage and current waveforms are shown in Fig. 5 (b). It can be seen that the current is almost in phase with the voltage. Hence the power factor is nearly unity. The output voltage is shown in Fig. 5 (c). Variation of speed is shown in Fig. 5 (d). The speed increases and settles at 1400 rpm. The FFT analysis is done for output voltage of the motor and the THD is found to be 6.70% as shown in Fig. 5 (e).

VII. EXPERIMENTAL RESULTS

After the simulation studies, VSI fed BLDC motor with input T-filter and a bridgeless boost converter fed BLDC motor with capacitor filter are fabricated and tested. The top view of the hardware is depicted in Figures 6 (a) .The hardware consists of power circuit, control circuit and PMBLDC motor. Driving pulses are shown in Fig. 6 (b). Input voltage and current waveforms are shown in Fig. 6 (c).

The components used in the hardware and their ratings are given below:

- Step down transformer-230/24 V, 1A
- T-filter- L=1.7mH, C=2200 micro farad
- Bridge rectifier-5A
- Rectifier capacitor-63V, 1000 micro farad
- MOSFET-IRF 840
- PIC controller- PIC 16F877
- Voltage regulator-5V output
- Crystal Oscillator-10Mhz
- Buffer IC-CD 4050
- Opto couplers-MCT 2E
- TTL with totem pole output-2npn (CK 100), 1 pnp (2N 222)
- PMBLDC motor-24v, 4000rpm, 2amps, 50w

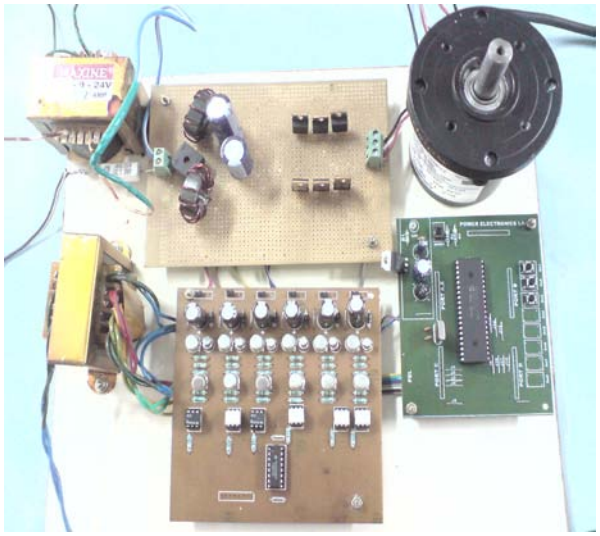

Fig. 6 (a) Hardware Implementation of T-filter system

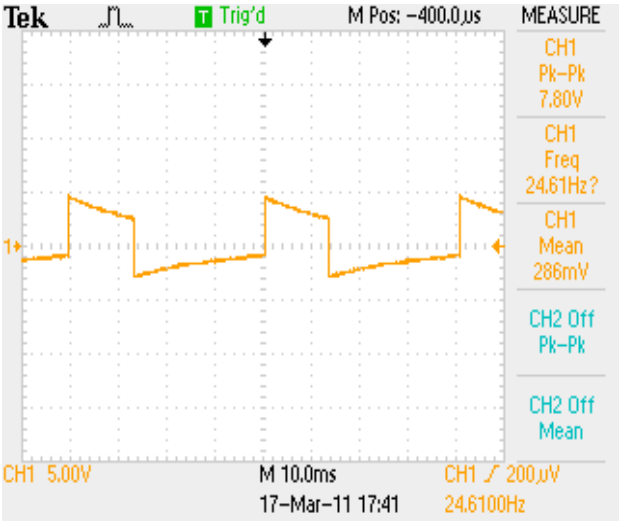

Fig. 6 (b) Driving pulses

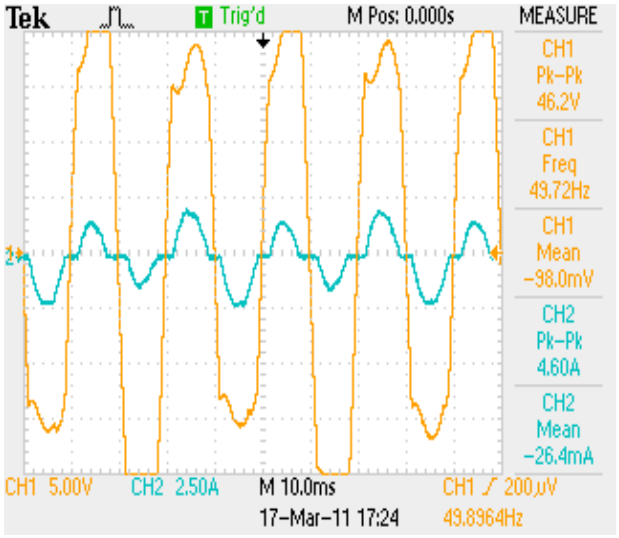

Fig. 6 (c) Input Voltage and Current waveforms

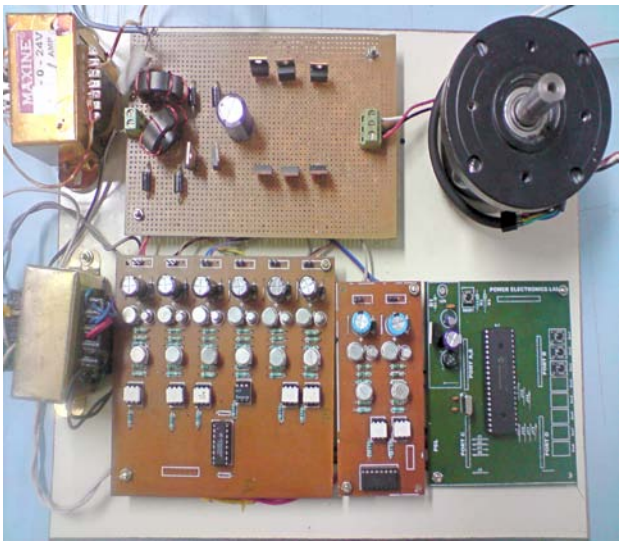

Fig. 7 (a) Hardware of Bridgeless boost converter fed BLDC motor

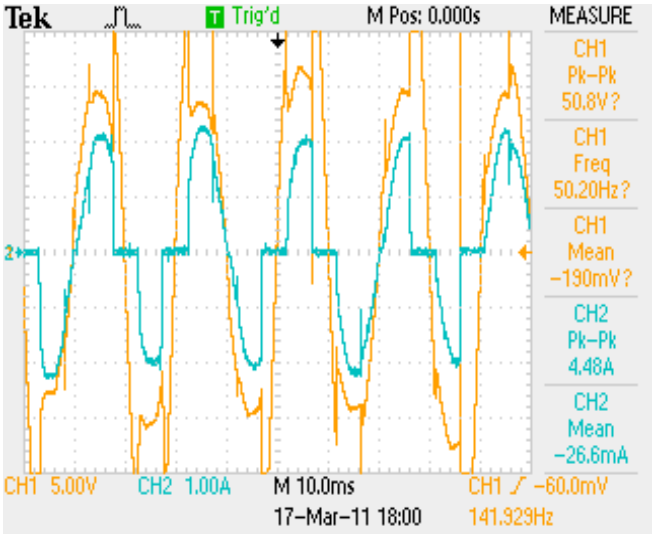

Fig. 7 (b) Input Voltage and Current waveforms

Hardware implementation of a bridgeless boost converter fed PMBLDC motor is shown in Fig 7(a).The hardware consists of driver board, power board and control board. The hardware details are as mentioned above.Input voltage and current waveforms are shown in Fig 7(b).It can be seen that voltage and current are in phase.

As seen from the experimental results the power factor is found to have improved when using a bridgeless boost converter than in a PMBLDC motor fed with a VSI with an input T-filter.

VIII. CONCLUSION

This paper presents simulation and experimental results of a VSI fed PMBLDC motor with input T-Filter and bridgeless PFC boost rectifier. With bridgeless boost converter it is possible to save energy, suppress harmonic current and improve drive performance. The bridgeless boost converter fed BLDC drive is modeled and simulated using Simulink blocks. It is found that THD can be reduced to 6.7% by using bridgeless PFC boost converter. The hardware is fabricated and tested. The experimental results are in line with the simulation results. The contribution of this work is the proposal of PFC bridgeless boost converter for the control of PMBLDC motor.

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