ABSTRACT
This paper presents a PFC (Power Factor Correction) based BL(Bridgeless)-Single Switch SEPIC) converter fed BLDC (Brush less DC) motor drive. The proposed topologies are designed to achieve near unity power factor in a simple and effective manner. The proposed speed control scheme has the concept of DC link voltage control proportional to the desired speed of the BLDC motor. The speed is regulated by a PI controller. The proposed converter combines the PFC and DC link voltage control in single stage and uses a single controller. This is designed for continuous conduction mode (CCM) of operation. The bridgeless single switch SEPIC converter topology is designed for obtaining the low conduction losses and requirement of low size of heat sink for the switches. The proposed system is designed and its performance is simulated to operate over a wide range of speed control with near unity power factor at AC mains. The proposed PFC converter provides less than 5% total harmonic distortion (THD) in current at AC mains. 

Keywords
Continuous Conduction Mode (CCM), Single Ended Primary Inductance Converter (SEPIC), Power Factor Correction(PFC),Brushless DC Motor (BLDC)

1. INTRODUCTION
Permanent Magnet Brushless DC (PMBLDC) motors are becoming more popular in low and medium power applications due to the features such as better speed versus torque characteristics, high dynamic response, high efficiency, noiseless operation, higher Torque to weight ratio. They also have speed ranges and long operating life. Recent developments in power electronics, microelectronics and modern control technologies have greatly influenced the wide-spread use of permanent magnet motors [1-2]. The major classifications of Permanent Magnet motors are permanent magnet synchronous motor (PMSM) and Permanent magnet Brushless DC motors (PMBLDCM). While PMSM has sinusoidal back-EMF waveform, the BLDC motor has trapezoidal back-EMF waveform. It has distributed windings on stator and permanent magnets on rotor. Comparing with conventional DC motors, BLDC motors do not have brushes for commutation. Instead, they are electronically commutated. For that we use Hall sensors which sense the rotor position and achieve the required commutation state. Due to this many problems such as sparking, wear and tear of brushes, noise problems, electromagnetic interference can be eliminated.

International Power Quality (PQ) standards like IEC-61000-3-2 [9]. emphasize on low harmonic content in supply current and near unity power factor has to be maintained by low power equipments. The BLDC motor fed by a diode bridge rectifier (DBR) with a high value of DC-link capacitor results in highly distorted supply current and a poor power factor. Hence use of a PFC converter has become inevitable for a PMBLDCM drive.

A DC-DC converter is used as a PFC converter, connected between the VSI and the DBR fed from a single phase AC supply to provide controlled voltage at DC link while improving the power factor (PF) at AC mains through high frequency switching [8]. There are many DC-DC converter topologies available such as buck, boost, buck-boost, Cuk, SEPIC and Zeta converters, amongst which the SEPIC converter topology is selected in this work due to its simplest construction and minimum component requirement. A Single Switch BL SEPIC PFC converter is explored in this paper for feeding a BLDC motor as a low cost solution for low power applications. This converter is designed for CCM operation to result in reduced sensor requirement with the desired speed control. The Single Switch BL SEPIC PFC circuit allows the current to flow through a minimum number of switching devices compared to the conventional PFC circuit. Accordingly, the converter conduction losses can significantly be reduced, and high efficiency can be obtained, as well as cost savings.
This paper presents detailed modelling and design of the Single Switch BL SEPIC PFC based PMBLDCM drive for its operation in CCM with voltage follower control. The simulated performance of the drive is also presented.

2. PROPOSED PFC SINGLE SWITCH BL-SEPIC CONVERTER-FED BLDC MOTOR DRIVE

Fig. 1 shows the proposed PFC based Single switch BL-SEPIC converter fed BLDC motor drive. A single-phase supply followed by filter and a Single switch BL-SEPIC converter used to feed a VSI driving a BLDC motor. The proposed Single switch BL-SEPIC converter is designed to operate in CCM. The speed of the BLDC motor is controlled by adjusting the DC link voltage of VSI using a single voltage sensor. This allows VSI to operate at fundamental frequency switching (i.e. electronic commutation of BLDC motor) and hence has low switching losses in it; which are considerably high in PWM based VSI feeding a BLDC motor. A voltage follower approach is used for the control of operating Single switch BL-SEPIC converter in (CCM) in which a single voltage sensor is required for the sensing of DC-link voltage $V_{dc}$. The proposed scheme is designed and its performance is simulated for achieving an improved power quality at AC mains for a wide range of speed control.

3. OPERATION OF SINGLE SWITCH BRIDGELESS SEPIC PFC CONVERTER

The bridgeless rectifier shown in Fig. 2 is constructed by connecting two DC-DC converters. Referring to Fig. 3(a) during the positive half-line cycle, the first DC-DC SEPIC circuit $L_1-S_1-C_1-L_0-D_0$ is active through diode $D_n$, which connects the input ac source to the output ground. During the negative half-line cycle, the second DC-DC SEPIC circuit, $L_2-S_2-C_2-L_0-D_0$, is active through diode $D_p$, which connects the input ac source to the output ground. Thus, due to the symmetry of the circuit, it is sufficient to analyze the circuit during the positive half-period of the input voltage. The rectifier is operated when the switch $S_1$ is turned on then diode $D_n$ is forward biased by the sum inductor currents $i_{L_1}$ and $i_{L_2}$. As a result, diode $D_p$ is reversed biased by the input voltage. The output diode is reversed biased by the reverse voltage ($V_{ac}+V_o$). Thus, the
loss due to the turn-on switching losses and the and the reverse recovery of the output diode are considerably reduced. A common DC-link capacitor \( C_d \) is used for both the positive and negative half cycle of operation.

3.1 Switch ON Stage
Figure 3(a) shows the on-time diagram for switch S1, for which switch S1 is on, and diode D1 is off. The input side . inductor \( L_1 \) is charged from the input voltage in this stage, the charged \( C_1 \) transfers energy into the output side inductor \( L_o \), and \( L_o \) is charging in this stage. In addition, the load current comes from the charged output capacitor \( C_0 \).

3.2 Switch OFF stage
Figure 3 (b) shows the off-state diagram for switch S1, in which switch S1 is off and the diode D1 is on. Inductor \( L_1 \) charges the capacitor \( C_1 \) and provides the load current. The Inductor \( L_2 \) is connected to the load: it charges the output capacitor \( C_0 \) and provides the load current.

4. DESIGN OF PFC SINGLE SWITCH BL-SEPIC CONVERTER
The dc link voltage of the PFC converter is given as

\[
V_{dc} = V_{in} \frac{D}{1-D}
\]

where \( V_{in} \) is the average input voltage of the converter for a given ac input \( V_i \).

\[
V_{in} = 2\sqrt{2} \frac{V_s}{\pi}
\]

The duty ratio \( D = \frac{V_{in}}{V_{dc}} \)
Based on the above equations the values shown in the TABLE 1 are calculated.

5. SPEED CONTROL SCHEME OF BLDC MOTOR DRIVE

In Figure.1, the speed control scheme is based on the control of the dc link voltage reference as an equivalent to the reference speed. However, the rotor position signals acquired by Hall-effect sensors are used by an electronic commutator to generate switching sequence for the VSI feeding the PMBLDC motor, and therefore, rotor position is required only at the commutation points. A single voltage control loop is used for the PFC Single switch BL-SEPIC converter operating in CCM. The proposed PFC converter is operated at a high switching frequency for fast and effective control with additional advantage of a small size filter. The control loop begins with the processing of voltage error (\(V_e\)), obtained after the comparison of sensed dc link voltage (\(V_{dc}\)) and a voltage \(V_{dc}^{*}\) equivalent to the reference speed, through a proportional–integral (PI) controller to give the modulating control signal (\(V_{cc}\)). This signal is compared with a high frequency saw tooth signal (\(m_{s}\)) to generate switching signal to S1.

6. EVALUATION OF PERFORMANCE OF PFC SEPIC CONVERTER FED BLDC DRIVE

A MATLAB/Simulink environment is used to evaluate the performance of proposed PFC BL-Luo converter fed BLDC motor drive for wide range of speed control and supply voltage variation using a standard model of BLDC motor [6]. Performances indices such as supply voltage (\(V_s\)), supply current (\(i_s\)), DC link voltage (\(V_{dc}\)), speed ((0)), electromagnetic torque (\(T_e\)), stator current (\(i_a\)), are analyzed for determining the performance of proposed BLDC motor drive. Power quality indices such as PF (Power Factor), THD (Total Harmonic Distortion) of supply current are analyzed for demonstrating the improved power quality at AC mains.

| TABLE I
SIMULATION DETAILS OF SINGLE SWITCH BL-SEPIC CONVERTER |
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<tr>
<td>Input inductors, (L_1 = L_2)</td>
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<td>Intermediate capacitors, (C_1 = C_2)</td>
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<td>Output inductor, (L_0)</td>
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<td>Output filter, (C_o)</td>
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The proposed PFC SEPIC converter based PMBLDC drive is fed from a 230 V AC mains and started at a rated torque (5.4Nm) and the reference speed is set at 1500 rpm. Simulink model of the proposed model of the closed loop controlled PMBLDC motor with PFC SEPIC converter, and a PI controller is shown in Figure 5. The input voltage and current waveforms are shown in Figure 10. The electromagnetic torque, stator current, rotor speed, back emf waveforms are shown in Figures 6 to 9 respectively.
Figure 7: Stator current

Figure 8: Rotor speed

Figure 9: Back emf
CONCLUSION
A PFC Single Switch BL-SEPIC Converter fed BLDC motor drive is simulated in MATLAB/Simulink environment and implemented. The speed control of the motor is achieved by using the concept of reference speed as an equivalent dc link voltage. The Single Switch BL-SEPIC Converter has ensured near unity power factor in a wide range of speed and the input ac voltage. The proposed converter has been designed to operate in CCM. The electronic commutation ensures a low frequency operation of VSI for reduced switching loss. The conduction losses in the proposed converter has also been reduced. The number of components conducting in a half cycle has been reduced which increases the system efficiency. The proposed drive is a cost effective solution for low and medium power applications.

REFERENCES

