POWER FACTOR CORRECTION USING SENSORLESS BLDC MOTOR FOR WIDE SPEED OPERATION WITH BRIDGELESS CONVERTER TOPOLOGY

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Abstract—This project presents a power factor correction (PFC)-based bridgeless canonical switching cell (BL-CSC) converter-fed brushless dc (BLDC) motor drive. The proposed BL-CSC converter operating in a discontinuous inductor current mode is used to achieve a unity power factor at the ac mains using a single voltage sensor. The speed of the BLDC motor is controlled by varying the dc bus voltage of the voltage source inverter (VSI) feeding the BLDC motor via a PFC converter. Therefore, the BLDC motor is electronically commutated such that the VSI operates in fundamental frequency switching for reduced switching losses. Moreover, the bridgeless configuration of the CSC converter offers low conduction losses due to partial elimination of diode bridge rectifier at the front end. The fuzzy logic controller achieves closed loop operation. The proposed configuration shows a considerable increase in efficiency as compared with the conventional scheme.

Keywords- BLDC Motor, PI Controller, BL-CSC converter, VSI

I. INTRODUCTION

In a PMBLDCM, the dc field winding of the rotor is replaced by a permanent magnet to produce the air-gap magnetic flux. Having the magnets on the rotor, electrical losses due to field winding of the machine get reduced and the lack of the field losses improves the thermal characteristics of the PM machines and its efficiency. Absence of mechanical components like brushes and slip rings makes the motor lighter, high power to weight ratio for which a higher efficiency and reliability is achieved.

Disadvantages of PM machines are, at high temperature, demagnetization of the magnet, manufacturing difficulties and high cost of PM material.

PM electric machines are classified into 2 types: PMDC machines and PMAC machines. PMDC machines are like the DC commutator machines; with the field winding being replaced by the permanent magnets. In PMAC the field is generated by the permanent magnets placed on the rotor and the slip rings, the brushes and the commutator does not exist. That is why PMAC is simpler to use instead of PMDC.

PMAC is divided into two type depending on the nature of the back electromotive force (EMF): Trapezoidal type and Sinusoidal type. Sinusoidal type PMAC machine can be further divided as Surface mounted PMSM and Interior PMSM.

The trapezoidal PMAC machines also called Brushless DC motors (BLDC) and build up trapezoidal back EMF waveforms with following characteristics:

- Rectangular distribution of magnet flux in the air gap
- Rectangular current waveform
- Concentrated stator windings

BLDC motor drives, systems in which a permanent magnet excited synchronous motor is fed with a variable frequency inverter controlled by a shaft position sensor. There appears a lack of commercial simulation packages for the design of controller for such BLDC motor drives. One main
reason has been that the high software development cost incurred is not justified. For their typical low cost fractional/integral kW application areas such as NC machine tools and robot drives, even it could imply the possibility of demagnetizing the rotor magnets during commissioning or tuning stages. Nevertheless, recursive prototyping of both the motor and inverter may be involved in novel drive configurations for advance and specialized applications, resulting in high developmental cost of the drive system. Improved magnet material with high (B.H), product also helps push the BLDC motors market to tens of kW application areas where commissioning errors become prohibitively costly. Modeling is therefore essential and may offer potential cost savings.

A brushless dc motor is a dc motor turned inside out, so that the field is on the rotor and the armature is on the stator. The brushless dc motor is actually a permanent magnet ac motor whose torque-current characteristics mimic the dc motor. Instead of commutating the armature current using brushes, electronic commutation is used. This eliminates the problems associated with the brush and the commutator arrangement, for example, sparking and wearing out of the commutator-brush arrangement, thereby, making a BLDC more rugged as compared to a dc motor. Having the armature on the stator makes it easy to conduct heat away from the windings, and if desired, having cooling arrangement for the armature windings is much easier as compared to a dc motor. In effect, a BLDC is a modified PMSM motor with the modification being that the back-emf is trapezoidal instead of being sinusoidal as in the case of PMSM. The “commutation region” of the back-emf of a BLDC motor should be as small as possible, while at the same time it should not be so narrow as to make it difficult to commutate a phase of that motor when driven by a Current Source Inverter. The flat constant portion of the back-emf should be 120° for a smooth torque production. The position of the rotor can be sensed by using an optical position sensors and its associated logic. Optical position sensors consist of phototransistors (sensitive to light), revolving shutters, and a light source. The output of an optical position sensor is usually a Logical signal.

![BLDC Motor Diagram](image)

**Fig 1 Cross section view of BLDC Motor**

A brushless dc motor is defined as a permanent synchronous machine with rotor position feedback. The brushless motors are generally controlled using a three phase power semiconductor bridge. The motor requires a rotor position sensor for starting and for providing proper commutation sequence to turn on the power devices in the inverter bridge. Based on the rotor position, the power devices are commutated sequentially every 60 degrees. Instead of commutating the armature current using brushes, electronic commutation is used for this reason it is an electronic motor. This eliminates the problems associated with the brush and the commutator arrangement, for example, sparking and wearing out of the commutator brush arrangement, thereby, making a BLDC more rugged as compared to a dc motor. The brush less dc motor consists of four main parts power converter, hall sensors, and control algorithm. The power converter transforms
power from the source to the BLDC which in turn converts electrical energy to mechanical energy. One of the salient features of the brushless dc motor is the rotor position sensors, based on the rotor position and command signals which may be a torque command, voltage command, speed command and so on the control algorithms determine the gate signal to each semiconductor in the power electronic converter.

Fig 2 Trapezoidal back emf of three phase BLDC motor

The structure of the control algorithms determines the type of the brushless dc motor of which there are two main classes voltage source based drives and current source based drives. Both voltage source and current source based drive used with permanent magnet synchronous machine with either sinusoidal or non-sinusoidal back emf waveforms. Machine with sinusoidal back emf may be controlled so as to achieve nearly constant torque. However, machine with a non-sinusoidal back emf offer reduces inverter sizes and reduces losses for the same power level.

Fig 3 Sinusoidal phase back emf of BLDC motor

PM motor drives have been an area of interest for the past thirty years. Different researcher have carried out modelling, analysis and simulation of PMBLDC drives. This content offers a brief review of some of the published work on the PMSM drive system. Extra-high energy magnets are used in PM motor to improve the performance characteristics of the rotor. In this method Sebastian, T. Slemon, G. R. and Rahman, M. A. [2] in 1986, presented equivalent electric circuit models for these motors and compared estimated parameters with measured parameters. Pillay and Krishnan, R. [3] in 1988, presented views on PM motor drives and classified them into two types. These are permanent magnet synchronous motor drives and brushless dc motor (BDCM) drives. The PMSM had a sinusoidal back emf and required sinusoidal stator currents which produced constant torque while the BDCM had a trapezoidal back emf, required rectangular stator currents for producing constant torque. To implement Power factor correction in the PMBLDCM drive
applications using BL CSC converter with speed control. Implement Fuzzy logic control based speed control of BLDC motor. To compare these control schemes performance relative to each other.

II. PROPOSED SYSTEM

In the last decade, bridgeless PFC converters have gained importance due to low conduction losses at the front end. This is achieved due to partial or complete elimination of the DBR, thereby reducing the conduction losses associated with it. Many configurations of bridgeless converter are reported in the literature, each having their peculiar characteristics. A bridgeless buck and a bridgeless boost, converters suffer from a limited voltage conversion ratio (< 1 for buck and > 1 for boost) and therefore cannot be used for a wide voltage control. To overcome this, a bridgeless buck–boost converter has been proposed in, but it has high switching losses corresponding to three switches. A two-switch bridgeless buck–boost PFC converter is proposed in which has low losses compared with [23]. Higher order PFC bridgeless Cuk, SEPIC, and Zeta converters have been widely used but have a high number of components. However, no attention has been paid to the canonical switching cell (CSC) converter, although it has excellent performance as a power factor preregulator, a small component count (compared with the non isolated Cuk converter), and good light load regulation. The conventional PFC based CSC converter. In this, a combination of a switch \( S_w \), a capacitor \( C_1 \) and a diode \( D \) is known as a ‘canonical switching cell,’ and this cell, combined with an inductor \( L_i \) and a dc link capacitor \( C_d \), is known as a CSC converter. With proper design and selection of parameters, this combination is used to achieve PFC operation when fed by a single phase supply via a DBR and a dc filter. This work aims at the development of a bridgeless configuration of a CSC converter, which offers partial elimination of DBR at the front end for reducing the conduction losses associated with it. Moreover, the application of this converter for feeding a BLDC motor drive is discussed to develop a low cost solution for low-power application.

In this project a power factor correction (PFC)-based bridgeless canonical switching cell (BL-CSC) converter-fed brushless dc (BLDC) motor drive. The proposed BL-CSC converter operating in a discontinuous inductor current mode is used to achieve a unity power factor at the ac mains using a single voltage sensor. The speed of the BLDC motor is controlled by varying the dc bus voltage of the voltage source inverter (VSI) feeding the BLDC motor via a PFC converter. Therefore, the BLDC motor is electronically commutated such that the VSI operates in fundamental frequency switching for reduced switching losses. Moreover, the bridgeless configuration of the CSC converter offers low conduction losses due to partial elimination of diode bridge rectifier at the front end. The proposed configuration shows a considerable increase in efficiency as compared with the conventional scheme. The fuzzy logic algorithm is implemented to achieve closed loop speed control algorithm. The performance of the proposed drive is validated through matlab simulation and experimental results obtained on a developed prototype. Improved power quality is achieved at the ac mains for a wide range of control speeds and supply voltages. The proposed BL-CSC converter is designed to operate in DICM such that current in inductors \( L_1 \) and \( L_2 \) becomes discontinuous for a switching period. Fig 3.3 shows different modes of operation during a complete switching period for positive and negative half-cycles of the supply voltage, respectively.

Mode I-A:

As shown in Fig 3.3 when switch \( S_1 \) is turned on, the input side inductor \( L_1 \) starts charging via diode \( D_p \) and current \( iL_1 \) increases, whereas the intermediate capacitor \( C_1 \) starts discharging via switch \( S_1 \) to charge the dc link capacitor \( C_d \). Therefore, the voltage across intermediate capacitor \( V_{C_1} \) decreases, whereas the dc link voltage \( V_{dc} \) increases.

Mode I-B:

When switch \( S_1 \) is turned off, the energy stored in inductor \( L_1 \) discharges to dc link capacitor \( C_d \) via diode \( D_1 \), as shown in Fig 3.3. The current \( iL_1 \) reduces, whereas the dc link voltage continues to increase in this mode of operation. Intermediate capacitor \( C_1 \) starts charging, and voltage \( V_{C_1} \) increases.
Mode I-C:

This mode is the DCM of operation as the current in input inductor $L_1$ becomes zero, as shown in Fig 3.3. The intermediate capacitor $C_1$ continues to hold energy and retains its charge, whereas the dc link capacitor $C_d$ supplies the required energy to the load. The similar behavior of the converter is realized for the other negative half-cycle of the supply voltage. An inductor $L_2$, an intermediate capacitor $C_2$, and diodes $D_n$ and $D_2$ conduct in a similar way. A voltage follower approach is used for the control of the BL-CSC converter operating in DICM. A single voltage sensor is required for controlling the dc link voltage for speed control of BLDC motor, and inherent PFC is achieved at the ac mains. Fig. 5 shows a complete block diagram for the control of dc link voltage. This control scheme consists of a ‘reference voltage generator,’ a ‘voltage error generator,’ a voltage controller, and a PWM generator.
Hall-effect position sensors are used to sense the rotor position to achieve electronic commutation of BLDC motor. A standard commutation technique is used for this trapezoidal back electromotive force (EMF) BLDC motor, where only two stator phases conduct at any given instant of time. With the help of rotor position information, the switches in the VSI are switched ON and OFF to ensure proper direction of flow of current in respective windings. Hall-effect position sensors (Ha, Hb, and Hc) are used for sensing the rotor position on a span of 60° for electronic commutation. A line current $i_{ab}$ is drawn from the dc link, whose magnitude depends on the applied dc link voltage $V_{dc}$, back EMFs ($e_{an}$ and $e_{bn}$), resistances ($R_a$ and $R_b$), and mutual and self-inductances ($M$ and $L_a$ and $L_b$) of the stator windings. The comparator compares the actual and reference speed of the BLDC motor and the error signal is fed to the fuzzy logic controller, the fuzzy logic output is added with the PWM pulses, so that the motor will run at constant speed.

### III. MATHEMATICAL MODELLING OF CONVERTER

Now, the instantaneous value of voltage appearing across any of the switch and inductor combination is given as

$$V_{in}(t) = |V_m \sin(\omega t)|$$  \hspace{1cm} (1)

The output voltage $V_{dc}$ of the CSC converter is given as

$$V_{dc} = D/(1 - D)V_{in}$$  \hspace{1cm} (2)

Where $D$ represents the duty ratio.

The instantaneous value of duty ratio $D(t)$ depends on the input voltage $V_{in}(t)$ and the required dc link voltage $V_{dc}$. The instantaneous duty ratio $D(t)$ is obtained by

$$D(t) = V_{dc}/V_{in}(t) + V_{dc} = V_{dc}|V_m \sin(\omega t)| + V_{dc}$$  \hspace{1cm} (3)

Since the speed of the BLDC motor is controlled by varying the dc link voltage of the VSI, therefore, the instantaneous power $P_i$ at any dc link voltage $V_{dc}$ is taken as a linear function of $V_{dc}$ as

$$P_i = (P_{max}/V_{dc\text{max}})/V_{dc}$$  \hspace{1cm} (4)

Where $V_{dc\text{max}}$ represents maximum dc link voltage, and $P_{max}$ is the rated power for the PFC converter.
IV. SIMULATION RESULTS

Fig 7. Proposed system Simulink

Fig 8. Input AC voltage waveform

The figure 8 shows the input AC voltage waveform which has 48V amplitude and 50Hz frequency.

Fig 9. Input AC current waveform

The figure 9 shows input AC current waveform, which has affected by the BLDC motor back emf also its having harmonics.
Fig 10. PWM pulse to the BL CSC converter switch 1
The figure 10. shows the PWM pulses which has produced by PWM generator and it is fed to the BL CSC converter switch 1.

Fig 11. PWM pulse to the BL CSC converter switch 2
The figure 11 shows the PWM pulses which has produced by PWM generator and it is fed to the BL CSC converter switch 2.

Fig 12. Output voltage of the BL CSC converter
The figure 12 shows the output voltage of the BLCSC converter, the maximum peak overshoot comes to settle at 0.015sec.
Fig 13. Voltage source inverter output voltage
The figure 13 shows the inverter output voltage with 24V amplitude it is given to the three phase BLDC motor.

Fig 14. BLDC motor Back emf waveform
The figure 14 shows the BLDC motor back emf waveform due its 120 degree pole arc rotor construction.

Fig 15. BLDC motor stator current waveform
The figure 15 shows the three phase BLDC motor stator current waveform, at starting the current is high like an Induction motor.

Fig 16. BLDC motor stator speed waveform using fuzzy logic controller
The figure 16 shows the Speed waveform of the BLDC motor using fuzzy logic based speed control, due to this control the motor attains constant speed without peak overshoot like a Pi controller.

![Speed waveform](image)

**Fig 17 Input AC voltage and current waveform**

The figure 17 shows the Input AC voltage and current waveform, which are in phase with each other, so that input power factor becomes unity.

**V. CONCLUSION**

A PFC-based BL-CSC converter-fed BLDC motor drive has been proposed with improved power quality at the ac mains. A bridgeless configuration of a CSC converter has been used for achieving reduced conduction losses in the PFC converter. The speed control of BLDC motor and PFC at ac mains has been achieved using a single voltage sensor. The switching losses in the VSI have been reduced by the use of fundamental frequency switching by electronically commutating the BLDC motor. Moreover, the speed of the BLDC motor has been controlled by controlling the dc link voltage of the VSI. The closed loop speed control was achieved by using Fuzzy logic controller. The proposed drive has shown an improved power quality at the ac mains for a wide range of speed control and supply voltages. The obtained power quality indices have been found within the acceptable limits of IEC 61000-3-2. A satisfactory performance of the proposed drive has been obtained, and it is a recommended solution for low-power applications.

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