Canonical Switching Cell Converter Based BLDC Motor Drive with Power Factor Correction

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Abstract:  
This paper deals with a BLDC motor drive which is used to replace the conventional diode bridge rectifier BLDC motor drive for speed control, to overcome the disadvantages of the conventional diode bridge drives a canonical switching cell converter BLDC drive is used where a CSC converter is inserted between the diode bridge and the VSI inverter which helps in improving the power quality at the input mains as well as controls speed by varying the dc link voltage of the CSC converter. The CSC BLDC motor drive improves the power factor and THD of the input supply side current and also aids in a low cost speed control by varying the DC link voltage of the converter.

Index Terms: Canonical switching cell converter (CSC) Brushless dc motor (BLDC),Total Harmonic Distortion (THD).

I. INTRODUCTION

The application of Brushless DC motors are widely increasing in large number of spheres to extract its advantages in speed control, they are widely replacing induction machines as well as DC machines in industrial applications too. But the main disadvantage of conventional BLDC motor drive using diode bridge at its input side for feeding the VSI inverter are the large amount of harmonics induced in the input supply current which increases the total harmonic distortion as well decreases the power factor.

The conventional diode bridge rectifier BLDC drive also has other disadvantages of speed control as it uses high frequency switching of the VSI inverter for speed control which increases the losses and further reduces the efficiency of the drive; further for speed control the number of sensors required are more and hence the cost of the drive increases.[1] Hence to overcome these disadvantages of the conventional diode bridge drives a canonical switching cell converter BLDC drive is used where a CSC converter is inserted between the diode bridge and the VSI inverter which helps in improving the power quality at the input mains as well as controls speed by varying the dc link voltage of the CSC converter.

A BLDC motor is similar in operation to a DC motor but the mechanical commutators and brushes are replaced by electronic commutation circuits which overcomes the disadvantages of sparking and regular replacement of brushes as in DC machines. The BLDC motor consists of stator windings which acts as electromagnets and the rotor consists of permanent magnets. The required torque is produced by switching the appropriate stator windings based on the current position of the rotor which causes interaction of the two fluxes. Hall effect sensors are used for rotor position sensing and based on electronic circuitry the corresponding switches of the VSI inverter are switched which further switches the required stator windings[2]. Conventional Brushless DC motor drives use a diode bridge rectifier at the input side hence the current drawn by the diode bridge rectifier will be rich in harmonics and will cause decrease in the power factor at the supply side and also an increase in THD.

Thus power factor correction converters are used in between the diode bridge rectifier and the VSI inverter to correct the distortion power factor due to diode bridge rectifier in BLDC motor drives. Various topologies of power factor correction converters are available and the most suitable converter is chosen according to cost and application. Canonical switching cell converter is one type of power factor correction converter used in BLDC drives and the main advantages of CSC converters as opposed to other topologies is that the CSC converter uses the least number of components as compared to other converters without compromising in quality [2].

II. CSC CONVERTER BLDC DRIVE

Fig.1 shows the conventional diode bridge rectifier based BLDC motor drive, which has many disadvantages like high THD and low power factor at the input, hence a cost effective model of canonical switching cell converter is proposed. The Canonical switching cell converter helps in both power factor correction at the input side as well as speed control.

The speed of the motor is controlled by varying the dc link voltage of the CSC converter. The speed of the motor directly depends on the dc link voltage which acts as the input of the VSI inverter, thus varying the dc link voltage the speed is varied. This is a cost effective technique as the number of sensors required in this technique is one voltage sensor as opposed to two current sensors in PWM technique where pulse width modulation of VSI inverter switches is used to control speed of the motor [1].

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III. CSC CONVERTER OPERATION

The dc link voltage can be varied by changing the reference value of the PI voltage controller hence speed control is achieved by varying the dc link voltage of the converter rather than using high frequency switching of VSI inverter. The dc link voltage is sensed using a voltage sensor and is compared with a reference voltage which is a function of reference speed, the error signal thus obtained is given to a PI controller which produces the required signal for gate pulse of the CSC converter switch. Thus losses are minimised and efficiency is improved along with reduction in cost. There are three states of operation of the CSC converter [1]. During the first stage of operation the switch is in on mode and it conducts, inductor stores energy and the intermediate capacitor discharges its stored energy to the output capacitor. The voltage across the output capacitor increases. During the second stage the switch is in off mode, when the switch is turned off the intermediate capacitor starts charging from the supply and the voltage across it starts increasing, the inductor discharges its stored energy to the output capacitor Fig 4 shows the intermediate capacitor voltage which is continuous. In the last stage the output capacitor discharges to the load which is a BLDC motor and in this state the inductor current remains zero and the switch remains in the off state. The dc link capacitor discharges to the load and the voltage across it decreases. This state is also called the discontinuous state as the inductor current is not continuous.

IV. CSC BLDC DRIVE SCHEMATIC

Fig 3, shows the canonical switching cell converter based BLDC motor drive which is used to overcome the disadvantages of conventional diode bridge BLDC motor drive, a canonical switching cell converter is used between the diode bridge and the VSI inverter in order to improve the power factor of the input side as well as to control the speed of the motor. The converter works in discontinuous state of operation which aids in using only one voltage sensor for speed control and the power factor at input supply mains is also in accordance with IEC standards [2]. The proposed drive decreases the cost of the drive by reducing the number of sensors required, it also improves the power quality at the input mains and provides a better technique than high frequency PWM switching of VSI inverter which causes large amount of switching losses.

V. MATLAB/SIMULINK SIMULATION

Fig 5, shows stator current of BLDC motor. For control part a PI controller is used to control the speed of the motor, it acts as a voltage controller. The reference voltage which depends on speed is compared with the dc link voltage and the error signal is used to produce duty cycle for the switch of the CSC converter. Changing the DC link voltage will change the speed of the BLDC motor [1].
Performance of CSC converter based BLDC drive is validated by a simulation model of BLDC motor drive modelled in MATLAB/SIMULINK. A PI controller is used to vary the speed as opposed to sinusoidal PWM in conventional BLDC motor drives. Electronic commutation is used for position sensing of rotor. Hall effect sensors senses the rotor position and based on the current position of the rotor corresponding switches of the VSI inverter are switched. Simulation results of proposed BLDC motor drive are discussed and are shown below. BLDC motor drive is simulated at rated load of 1.5 Nm with supply voltage as 220 V and rated dc link voltage of 200 V which corresponds to a rated speed of 2000 rpm for the BLDC motor. Fig 6 shows the MATLAB model of the CSC based motor drive. The performance of the proposed BLDC drive at rated supply voltage, rated load on BLDC, and dc-bus voltage of 200 V (2000 rpm) is obtained. A unity power factor is achieved at the ac mains and supply current is in phase with ac mains voltage and is sinusoidal in nature. The DC link voltage is obtained at the desired reference value, whereas the frequency of stator current decides the speed of BLDC motor. As the CSC converter is designed to operate in DCM state, a discontinuous current in inductor and continuous voltage across intermediate capacitor are achieved. Fig.2 shows discontinuous inductor current and and fig. 4 shows the continuous intermediate capacitor voltage. Fig. 8 (a) shows dc link voltage waveform and fig. 8 (b) shows the speed of the motor at the rated dc link voltage. A peak voltage stress of 510V and peak current stress of 22A is obtained at the PFC switch, which is quite acceptable for a PFC converter operating in DICM, the switch used in CSC converter is MOSFET and the switching frequency is 20 kHz. The inductor operates in discontinuous state and the current through the inductor reaches zero value in the DCM state. The dc link capacitor of the CSC converter supplies a constant DC voltage to the BLDC motor which acts as the load.

VI. SIMULATION RESULTS AND DISCUSSIONS

The performance of the system is analysed in MATLAB/ SIMULINK using the parameters given in Table 1, the rated value of dc link voltage is applied at 200 V, the rated load torque is 1.5 Nm. For analysis the dc link voltage is kept constant at 200 V analysis the dc link voltage is changed from 200 to 160 V, hence the speed of the motor also changes from 2000 rpm to 1600 rpm. The number of pole pairs of BLDC motor is four and a three phase BLDC machine is used.

<table>
<thead>
<tr>
<th>Table.1. Motor Parameters Values</th>
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<tbody>
<tr>
<td>Input Voltage</td>
</tr>
<tr>
<td>Stator phase resistance</td>
</tr>
<tr>
<td>Stator phase inductance</td>
</tr>
<tr>
<td>Voltage constant</td>
</tr>
<tr>
<td>Torque constant</td>
</tr>
<tr>
<td>Pole pairs</td>
</tr>
<tr>
<td>Load Torque</td>
</tr>
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</table>

VII. STEADY STATE OF CSC FED BLDC MOTOR DRIVE.

The steady state input current waveform and THD of the input supply current waveform of diode bridge fed drive are shown in Fig. 7, thus it can be concluded that the power quality at input mains in a diode bridge rectifier fed BLDC drive is poor and THD is close to 56%. Fig. 8 shows the steady state responses of the drive. BLDC motor is loaded at the rated load torque of 1.5 N-m, supply voltage of 220 V. A sinusoidal current is drawn at AC mains with the DC link voltage of 200 V and it is in-phase with the supply voltage gives the near unity power factor. Fig 7 shows the distorted current wave in a diode bridge rectifier fed BLDC drive, the THD is as high as 56%, which is un acceptable according to IEC standards.

Figure.7. (a). Input current waveform of diode bridge BLDC drive (b) Fourier analysis of input current

Fig 8 (a) shows the steady state analysis of CSC converter fed BLDC motor drive, the DC link voltage is set at the 200 V which the rated value and the speed at that DC link voltage is 2000 rpm shown in fig 8 (b).

Figure.8. Steady state performances (a) DC link voltage (b) speed of BLDC motor

VIII. LOAD TORQUE CHANGE ANALYSIS

Fig 9. shows the load torque variation of the drive, here the torque is reduced from 1.5 Nm to 1.2 Nm since the DC link...
voltage is held at a constant value due to controller action, the speed of the BLDC motor decreases as shown.

Figure.9. Steady state performances of proposed BLDCM drive system during load change

IX. POWER QUALITY ANALYSIS OF THE DRIVE

Performance of CSC converter based BLDC drive for power quality improvement is shown in Fig 10, the voltage and current waveform are shown, the current waveform is sinusoidal in shape and the THD obtain is less than 4% which is in accordance to the IEC standards, thus a CSC converter aids in improving the power quality of the converter. The analysis for change in dc link voltage and power factor, THD are shown in Table 2, thus for an increase in dc link voltage the power factor and THD increases and the power quality at input mains is improved. Further power quality can be improved by eliminating the diode bridge rectifier from input side.

Figure.10. Steady state performances of proposed BLDCM drive

Table.2. Power factor and THD variation

<table>
<thead>
<tr>
<th>DC LINK VOLTAGE</th>
<th>SPEED (rpm)</th>
<th>THD (%)</th>
<th>DISTORTION POWER FACTOR</th>
</tr>
</thead>
<tbody>
<tr>
<td>200 V</td>
<td>2000</td>
<td>4.165</td>
<td>0.9968</td>
</tr>
<tr>
<td>175 V</td>
<td>1750</td>
<td>4.441</td>
<td>0.9955</td>
</tr>
<tr>
<td>150 V</td>
<td>1500</td>
<td>4.571</td>
<td>0.9952</td>
</tr>
<tr>
<td>120 V</td>
<td>1200</td>
<td>5.062</td>
<td>0.9908</td>
</tr>
<tr>
<td>80 V</td>
<td>800</td>
<td>6.443</td>
<td>0.9825</td>
</tr>
</tbody>
</table>

Figure.11. Variation of THD with dc link voltage

X. CONCLUSIONS

A conventional diode bridge rectifier based BLDC motor drive draws harmonic induced current from the supply hence power factor of the system will be low and THD of the current waveform will be very high. The speed control in diode bridge BLDC drive is done using high frequency PWM switching at the VSI inverter which leads to high switching losses and decrease in efficiency. To overcome the disadvantages from the conventional BLDC motor drive a CSC converter is inserted between the diode bridge rectifier and the BLDC motor to improve the power factor at the input mains and also decreases the THD at the input side of the current waveform. The CSC based BLDC motor drive is also a cost effective technique as compared to the conventional diode bridge drive as the number of sensors required for speed control operation is reduced hence decreasing the cost of the overall drive. Further conduction losses can be reduced.

XI. REFERENCES


[5]. Limits for Harmonic Current Emissions (Equipment input current < 16 A Per Phase), International Standard IEC 61000-3-2