Simulation And Analysis Of DTC-SPWM Fed PMSM Drive With Diode Clamped Inverter
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ABSTRACT: This paper presents a power factor corrected (PFC) bridgeless (BL) diode clamped converter-fed brushless direct current (PMSM) motor drive as a cost-effective solution for low-power applications. An approach of speed control of the PMSM motor by controlling the dc link voltage of the voltage source inverter (VSI) is used with a single voltage sensor. This facilitates the operation of VSI at fundamental frequency switching by using the electronic commutation of the PMSM motor which offers reduced switching losses. A BL configuration of the diode clamped converter is proposed which offers the elimination of the diode bridge rectifier, thus reducing the conduction losses associated with it. A PFC BL diode clamped converter is designed to operate in discontinuous inductor current mode (DICM) to provide an inherent PFC at ac mains. The performance of the proposed drive is evaluated over a wide range of speed control and varying supply voltages (universal ac mains at 90–265 V) with improved power quality at ac mains. The obtained power quality indices are within the acceptable limits of international power quality standards such as the IEC 61000-3-2. The performance of the proposed drive is simulated in MATLAB/Simulink environment.

Keywords: Bridgeless (BL) diode clamped converter, brushless direct current (BLDC) motor, discontinuous inductor current mode (DICM), power factor corrected (PFC), power quality.

I INTRODUCTION

Efficiency and cost are the major concerns in the development of low-power motor drives targeting household applications such as fans, water pumps, blowers, mixers, etc. The use of the brushless direct current (PMSM) motor in these applications is becoming very common due to features of high efficiency, high flux density per unit volume, low maintenance requirements, and low electromagnetic-interference problems. These BLDC motors are not limited to household applications, but these are suitable for other applications such as medical equipment, transportation, HVAC, motion control, and many industrial tools.

A PMSM motor has three phase windings on the stator and permanent magnets on the rotor. The PMSM motor is also known as an electronically commutated motor because an electronic commutation based on rotor position is used rather than a mechanical commutation which has disadvantages like sparking and wear and tear of brushes and commutator assembly.

The choice of mode of operation of a PFC converter is a critical issue because it directly affects the cost and rating of the components used in the PFC converter. The continuous conduction mode (CCM) and discontinuous conduction mode (DCM) are the two modes of operation in which a PFC converter is designed to operate. In CCM, the current in the inductor or the voltage across the intermediate capacitor remains continuous, but it requires the sensing of two voltages (dc link voltage and supply...
voltage) and input side current for PFC operation, which is not cost-effective. On the other hand, DCM requires a single voltage sensor for dc link voltage control, and inherent PFC is achieved at the ac mains, but at the cost of higher stresses on the PFC converter switch; hence, DCM is preferred for low-power applications.

II PROPOSED SYSTEM

Fig. 1. Proposed PMSM motor drive with front-end BL diode clamped converter.

Fig. 1 shows the proposed BL diode clamped converter-based VSI-fed BLDC motor drive. The parameters of the BL buck–boost converter are designed such that it operates in discontinuous inductor current mode (DICM) to achieve an inherent power factor correction at ac mains. The speed control of PMSM motor is achieved by the dc link voltage control of VSI using a BL buck–boost converter. This reduces the switching losses in VSI due to the low frequency operation of VSI for the electronic commutation of the PMSM motor. The performance of the proposed drive is evaluated for a wide range of speed control with improved power quality at ac mains. Moreover, the effect of supply voltage variation at universal ac mains is also studied to demonstrate the performance of the drive in practical supply conditions. Voltage and current stresses on the PFC converter switch are also evaluated for determining the switch rating and heat sink design. Finally, a hardware implementation of the proposed PMSM motor drive is carried out to demonstrate the feasibility of the proposed drive over a wide range of speed control with improved power quality at ac mains.

### III OPERATING PRINCIPLE OF PFC BL DIODE CLAMPED CONVERTER

The operation of the PFC BL diode clamped converter is classified into two parts which include the operation during the positive and negative half cycles of supply voltage and during the complete switching cycle.

#### A. Operation During Positive and Negative Half Cycles of Supply Voltage

In the proposed scheme of the BL diode clamped converter, switches Sw1 and Sw2 operate for the positive and negative half cycles of the supply voltage, respectively. During the positive half cycle of the supply voltage, switch Sw1, inductor Li1, and
diodes $D_1$ and $D_p$ are operated to transfer energy to dc link capacitor $C_d$. Similarly, for the negative half cycle of the supply voltage, switch $S_{w1}$, inductor $L_{i1}$, and diodes $D_2$ and $D_n$ conduct as shown in Fig. 2(a)–(c).

In the DICM operation of the BL buck–boost converter, the current in inductor $L_i$ becomes discontinuous for a certain duration in a switching period. The waveforms of different parameters during the positive and negative half cycles of supply voltage.

**B. Operation During Complete Switching Cycle**

Three modes of operation during a complete switching cycle are discussed for the positive half cycle of supply voltage as shown here in after.

Mode I: In this mode, switch $S_{w1}$ conducts to charge the inductor $L_{i1}$; hence, an inductor current $i_{L_{i1}}$ increases in this mode. Diode $D_p$ completes the input side circuitry, whereas the dc link capacitor $C_d$ is discharged by the VSI-fed PMSM motor as shown in Fig. 2(d).

Mode II: In this mode of operation, switch $S_{w1}$ is turned off, and the stored energy in inductor $L_{i1}$ is transferred to dc link capacitor $C_d$ until the inductor is completely discharged. The current in inductor $L_{i1}$ reduces and reaches zero as shown in Fig. 2(d).

Mode III: In this mode, inductor $L_{i1}$ enters discontinuous conduction, i.e., no energy is left in the inductor; hence, current $i_{L_{i1}}$ becomes zero for the rest of the switching period. None of the switch or diode is conducting in this mode, and dc link capacitor $C_d$ supplies energy to the load; hence, voltage $V_{dc}$ across dc link capacitor $C_d$ starts decreasing. The operation is repeated when switch $S_{w1}$ is turned on again after a complete switching cycle.

**TABLE II**

<table>
<thead>
<tr>
<th>$\theta$ ($^\circ$)</th>
<th>Hall Signals</th>
<th>Switching States</th>
</tr>
</thead>
<tbody>
<tr>
<td>NA</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>0-60</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>60-120</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>120-180</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>180-240</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>240-300</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>300-360</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>NA</td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>

$$V_{in} = \frac{2\sqrt{2}V_s}{\pi} = \frac{2\sqrt{2} \times 220}{\pi} \approx 198 \text{ V.}$$ (1)
The relation governing the voltage conversion ratio for a buck–boost converter is given as

\[ d = \frac{V_{dc}}{V_{dc} + V_{in}}. \]  

The value of inductance \( L_{ic1} \), to operate in critical conduction mode in the buck–boost converter, is given as

\[ L_{ic1} = \frac{R(1-d)^2}{2f_s} \]  

Fig. 3. Steady-state performance of the proposed PMSM motor drive at rated conditions.

Fig. 4. Dynamic performance of proposed PMSM motor drive during (a) starting, (b) speed control, and (c) supply voltage variation at rated conditions.

IV CONCLUSION

A PFC BL buck–boost converter-based VSI-fed PMSM motor drive has been proposed targeting low-power applications. A new method of speed control has been utilized by controlling the voltage at dc bus and operating the VSI at fundamental frequency for the electronic commutation of the PMSM motor for reducing the switching losses in VSI. The front-end BL buck–boost converter has been operated in DICM for achieving an inherent power factor correction at ac mains. A satisfactory performance has been achieved for speed control and supply voltage variation with power quality indices within the acceptable
limits of IEC 61000-3-2. Moreover, voltage and current stresses on the PFC switch have been evaluated for determining the practical application of the proposed scheme. Finally, an experimental prototype of the proposed drive has been developed to validate the performance of the proposed PMSM motor drive under speed control with improved power quality at ac mains. The proposed scheme has shown satisfactory performance, and it is a recommended solution applicable to low-power PMSM motor drives.

V REFERENCES


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