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Performance Assessment of a Canonical Switching Cell (CSC) Converter-fed Sensor-less Brushless DC Motor

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ABSTRACT

This paper reports a Power Factor Correction (PFC) Canonical Switching Cell (CSC) converter for a sensor-less Brushless DC (BLDC) motor drive system. CSC converter achieves continuous current in input and output, at the expense of reduced number of passive components. The drive speed is adjusted using Voltage Mode control of the converter. Discontinuous Inductor Current Mode (DICM) operation is used in this converter. This helps in attaining enhanced power quality (PQ) at the ac supply mains and intrinsic (PFC). By Line Frequency Switching (LFS) of the Voltage Source Inverter (VSI) switches, losses in the switches of the VSI are reduced. BLDC motor is operated in Sensor-less mode which prevents the need for bulk and expensive Hall-Effect position sensors. Drive performance is assessed over a broad speed spectrum. Unity Power Factor (UPF) is attained with enhanced power quality indicators within suggested thresholds of IEC 61000-3-2.

Keywords: Brushless DC motor, Discontinuous Inductor Current Mode, Power Factor Correction, Canonical Switching Cell converter, Sensor-less control.

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INTRODUCTION

A basic Brushless DC motor drive system consists of a full-bridge diode rectifier, a DC-bus capacitor and a VSI fed BLDC motor [1],[2],[3],[4],[5],[9]. The VSI is switched using a high frequency PWM scheme. This scheme heaves a peaky current from the supply, which results in a low value of power factor (PF) and an exalted value of Total Harmonic Distortion (THD). These factors fail to lie within the tolerable range of IEC61000-3-2 standards [1],[2],[3],[4],[5],[9]. Hence, Power Factor Correction (PFC) converters are utilized to obtain an UPF operation at the supply side. PFC converters can be operated in two modes, namely, Continuous Conduction Mode (CCM) and Discontinuous Conduction Mode (DCM). CCM offers continuous inductor current, while, DCM offers discontinuous inductor current [6],[7],[8],[9]. The former offers decreased stress on the PFC converter switch with increased sensor count, whereas, the later requires just one voltage sensor for sensing the DC-link voltage. CCM is predominantly employed in high power applications. As the stress on the converter switch increases in DCM mode, it is limited to low-power applications [6],[7],[8],[9].

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Many converter configurations for PFC are available. A survey on various PFC converters for Brushless DC motor drives [9] illustrates the various possible configurations of DC-DC converters having inherent PFC property. It broadly classifies these converters as Isolated, Non-Isolated, Bridgeless Isolated, Bridgeless Non-isolated and Integrated & IHQRR configurations. This study investigates the inherent PFC capability of the basic configurations of Cuk, SEPIC, Zeta, Luo, Buck-Boost, CSC, Sheppard Taylor and Switched Capacitor Buck-Boost converters [6],[7],[8],[[9]. It also showed that these converters have enhanced power quality at the supply mains over a broad speed range. Earlier, boost configurations [4] were used as PFC converters. These converters were switched at high frequency, maintaining the DC-link voltage constant. This led to tremendous inverter switching losses and required larger sensing requirements. As, a possible solution to these problems, variable DC-link voltage method was adopted. This scheme employed line frequency gating pulses ere made based on this approach. Singh and Singh [10] proposed a Buck-Boost PFC converter having minimum components, but higher input and output current ripples. Bist and Singh [5] have designed a Cuk converter for PFC operation. Singh and Bist [11] proposed a BLDC motor driven by a Luo converter in DICM operation. Singh and Bist [12],[13] described a SEPIC and a Sheppard Taylor converter respectively, and their three operational modes for power factor correction. The latter converter, in addition to PFC, offers high light–load efficiency, excellent voltage regulation and no-detuning problems. Bist and Singh [1] reported BLDC motor driven by a CSC converter for PFC. This offers the advantages of reduced peripheral count and economy. The application of PFC Zeta converter was explored for variable speed drives in [8],[9]. Bridgeless configurations of Cuk[3], SEPIC[14], Zeta[15], Luo[16], Sheppard Taylor[17], CSC[3] have also been reported. These configurations exclude full bridge diode rectifier (FDBR) in the power circuit; offering reduced conduction losses, with increased number of passive components.

This paper reports a PFC Canonical Switching Cell (CSC) converter for a Sensor-less BLDC motor drive. Back-EMF Zero–Crossing detection scheme[18] is employed for sensor-less control of the BLDC motor.

Drive Configuration

Fig. 1 depicts the drive system schematic of a Sensor-less BLDC motor fed from a CSC converter. The converter runs in Discontinuous Inductor Current Mode (DICM) and provides an intrinsic UPF at the supply mains[1]. Voltage Mode control is employed for varying the dc-bus voltage and thereby, the motor speed. The inverter switches are controlled at very low frequency and thus their switching losses are considerably reduced. Sensor-less back-emf zero crossing detection technique [18] is utilized to generate the switching sequences for electronically commutating the drive.

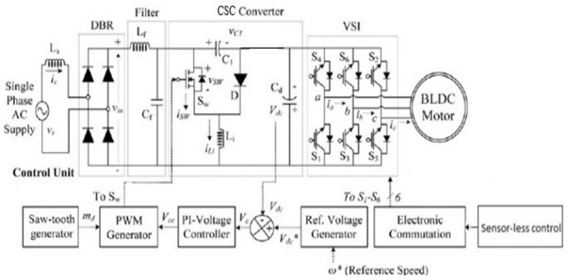

Figure 1: A CSC converter-fed Sensor-less brushless DC Motor Drive System

Operational Modes of Csc Converter

During the working of the PFC converter in DICM, the input inductor current turns out to be discontinuous in an entire switching cycle. Converter operation in this mode helps to attain UPF innately at the supply mains [1].

Mode I: When the switch is triggered on, the inductor, L_i is charged both from the supply mains and from the energy retained in the intermediate capacitor, C_1 . The capacitor, C_0 is charged by the discharging output inductor, L_0. Thus, intermediate capacitor voltage, V_{C1} starts reducing and DC-bus voltage, V_{dc} begins to increase as in Fig. 2(a)[1]. Intermediate capacitor, C_1 is amply large such that V_{C1} always remains continuous.

Mode II: By switching off the switch, the input inductor embarks to discharge through the diode, D. The inductor, L_0 and the capacitor, C_1 start charging from the supply as in Fig. 2(b). Hence, V_{C1} starts increasing and V_{dc} begins to decrease.

Mode III: In this stage, the input inductor, L_i is thoroughly discharged and enters DICM. Thus, V_{C1} continues to decrease; input inductor current, I_{Li} falls to zero; output inductor current, I_{L0} begins to increase, as in Fig. 2(c).

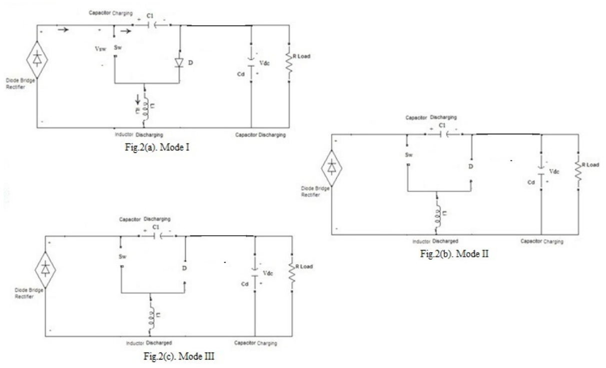

Figure 2: Operational Modes of a CSC converter

SIMULATION RESULTS & DISCUSSIONS

Simulation of the PFC CSC converter fed BLDC motor drive is performed using MATLAB/Simulink software package. Drive performance is assessed for different speeds, supply voltages and loadings on the motor. Analysis and evaluation of various motor variables like rotor speed (w_r), electromagnetic torque (T_e), stator current (I_a), back-emf (e_b) is done. The converter parameters like DC-bus voltage, inductor currents, and intermediate capacitor voltages are observed to demonstrate its performance. Power Factor (PF) & Total Harmonic Distortion (THD) of the source current are assessed. Peak voltage stress and peak current stress of the PFC switch is measured to decide the rating of the converter switches.

Steady-State & Dynamic Performance Characteristics of the drive

Fig.3 depicts the performance attributes of the drive at steady state, under rated conditions. Source current in phase-concurrence with the source voltage establishes the UPF operation. The discontinuous input inductor current in the converter confirms its DICM operation. The maximum voltage and current stresses of the PFC switch are found to be 600V and 20A respectively; comes under the acceptable range. THD of source current in the drive system is below 5%, which is within the tolerable limits of IEC 61000-3-2. To describe the dynamic behaviour of this drive system, four conditions are studied; namely, (i) Starting of the drive during step change in dc-bus voltage from 0V to 75V, with a limited inrush in stator current and ac mains current (ii) Dynamic behaviour during speed control with a step-change in dc-bus voltage from 100V to 150V (iii) Dynamic behaviour during a step-change in load from 0.4Nm to 0.8 Nm [1]. Drive performance during a source voltage fluctuation from 270V to 180V is analyzed.

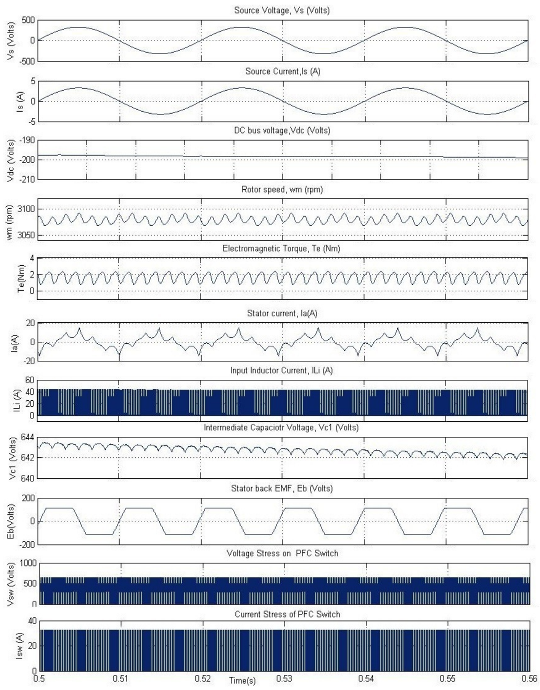

Figure 3: Steady-state characteristics of the drive under rated conditions

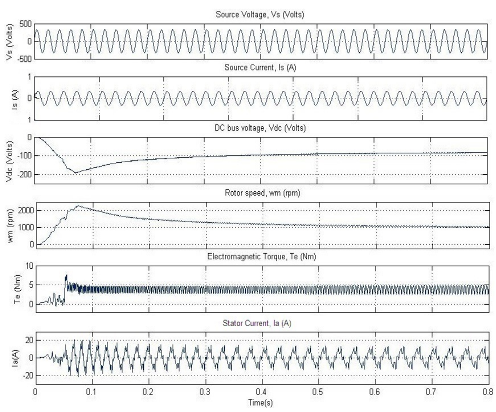

Figure 4: Dynamic Characteristics of the drive during start-up from V_{dc}= 0V to 75V

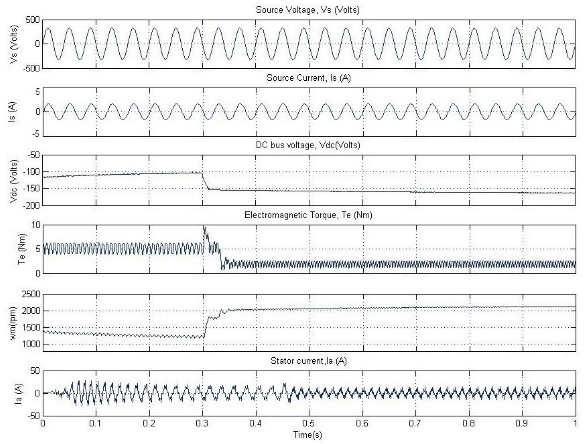

Figure 5: Dynamic Characteristics of the drive during step-change in Vdc from 100V to 150V

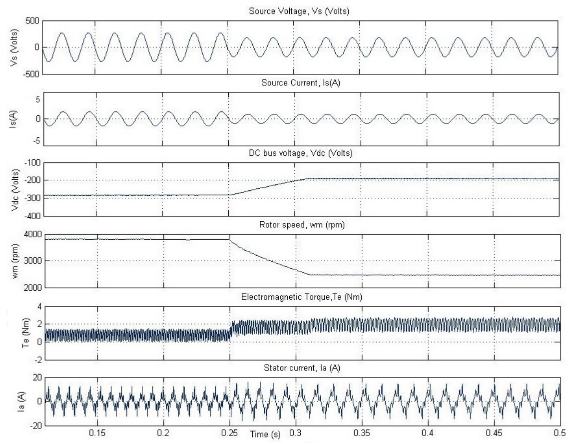

Figure 6: Dynamic Characteristics of the drive during a step-change in Vs from 270V to 180V

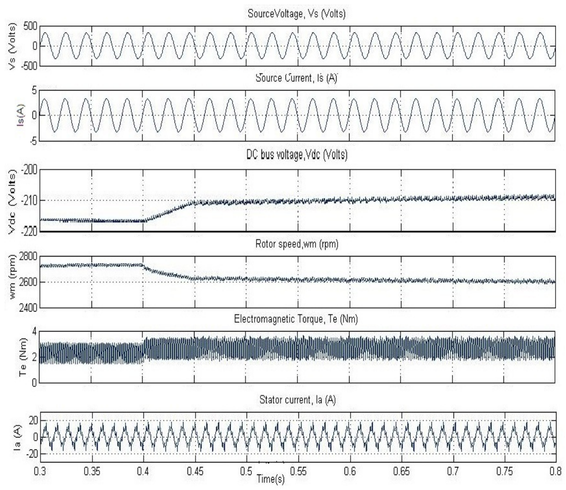

Figure 7: Dynamic Characteristics of the drive during step-rise in load torque from 0.4Nm to 0.8Nm

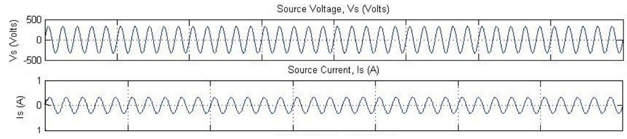

Figure 8: Unity Power Factor operation

Fig. 4 illustrates the dynamic behaviour during starting with a step-change in the dc-bus voltage from 0V to 75V; Fig. 5 demonstrates the dynamic performance during speed control with a step change in the dc-bus voltage from 100V to 150V; Fig. 6 illustrates the dynamic performance of the drive during a source voltage fluctuation from 270V to 180V. With the dc-bus voltage, V_{dc} being controlled smoothly over the complete operating range, a satisfactory performance is obtained in the drive. Fig. 7 illustrates the dynamic characteristics during a step-change in load torque from 0.4Nm to 0.8 Nm of the drive. Fig.8 confirms the UPF operation of the drive.

Conclusion

Performance assessment of a CSC PFC converter-fed sensor-less BLDC motor drives has been reported in this paper. Variable dc-bus voltage method is employed for speed control. Switches of the VSI are operated at the line frequency using electronic commutation of the BLDC motor; considerably reducing their switching losses. Sensor-less Back-EMF Zero-Crossing Detection technique is employed to generate the switching pulses for the VSI switches. This minimizes the total dimensions of the drive, improves the economy and drive efficiency, needless the requirement of Hall-effect position sensors. An innate power factor correction is obtained as the PFC converter is developed to work in DCM. The power quality indicators obtained lie inside the tolerable range of IEC 61000-3-2.

REFERENCES

[1] Bist, V. and Singh, B.: A PFC-based BLDC motor drive using a Canonical Switching Cell Converter. IEEE Trans. Ind. Info. 10(2014) 1207-1215.

[2] Singh, P.K., Singh, B. and Bist, V.: Brushless DC motor drive with power factor regulation using Landsman converter. IET Power Electron. 9 (2016) 1-11.

[3] Singh, B. and Bist, V.: A BL-CSC converter-fed BLDC motor drive with power factor correction. IEEE Trans. Ind. Electron. 6(2015) 172-183.

[4] Singh, S. and Singh, B.: Power quality improvement of a position sensorless controlled PMBLDCM drive using Boost Converter. 2014 IEEE 6th India International Conference on Power Electronics (IICPE), Kurukshetra, India.(2014).

[5] Bist, V. and Singh, B.: PFC Cuk converter-fed BLDC Motor Drive. IEEE Trans. Power Electron. 30(2015) 871-888.

[6] Singh, B. and Singh, S.: Single-phase power factor controller topologies for permanent magnet brushless DC motor drives. IET Power Electron. 3(2010) 147–175.

[7] Singh, B., Singh, N. B., Chandra, A., Al-Haddad, K. , Pandey, A. and Kothar,i D. P.: A review of single-phase improved power quality AC-DC converters, IEEE Trans. Ind. Electron. 50(2003) 962-981.

[8] Garcia, O., Cobos, A. J., Prieto, R., Alou, P. and Uceda, J.: Single phase power factor correction-a survey. IEEE Trans. Power Electron. 18(2003) 749-754.

[9] Singh, B. and Bist, V.: Power Factor Correction (PFC) converters feeding brushless DC motor drive. Int. J Eng. Sci. Technol. 7(2015)65-75.

[10] Singh, S. and Singh, B.: Power quality improved PMBLDCM drive for adjustable speed application with reduced sensor Buck-Boost PFC converter. 2011 4th International Conference on Emerging Trends in Engineering and Technology (ICETET), Port Louis, Mauritius. (2011) 180-184.

[11] Singh, B. and Bist, V.: Power quality improvements in power factor correction Luo converter fed brushless direct current motor drive. Int. Trans. Ele. Energy Sys. 25(2014) 898-919.

[12] Singh, B. and Bist, V.: DICM and DCVM of a PFC-based SEPIC-fed PMBLDCM drive. IETE J. Res. 59(2013) 141-149.

[13] Singh, B. and Bist, V.: An improved power quality based Sheppard–Taylor converter fed BLDC motor drive. J. The Institution of Engineers (India) Series B, Springer, 96(2014) 327-337.

[14] Bist, V., Singh, B., Chandra, A. and Al-Haddad, K. An adjustable Speed PFC Bridgeless-SEPIC fed brushless DC motor drive. 2015 IEEE Energy Conversion Congress and Exposition (ECCE), Montreal, QC, Canada (2015) 4886-4893.

[15] Bist, V. and Singh, B.: A reduced sensor PFC BL-Zeta converter based VSI fed BLDC motor drive. Ele. Power Sys. Res. Elsevier, 98(2013).

[16] Singh, B., Bist, V., Chandra, A. and Al-Haddad, K.: Power quality improvement in PFC Bridgeless-Luo converter fed BLDC motor drive. 2013 IEEE Industry Applications Society Annual Meeting, Lake Buena, Vista, FL, USA. (2013) 1-8.

[17] Bist, V. and Singh, B.: A PFC based Bridgeless Sheppard-Taylor converter fed Brushless DC Motor Drive. 2014 International Conference on Innovative Applications of Computational Intelligence on Power, Energy and Controls with their Impact on Humanity (CIPECH14), Ghaziabad, India. (2014) 262-267.

[18] Acarnley, P. P. and Watson, J. F.: Review of position sensorless operation of brushless permanent magnet machines, IEEE Trans. Ind. Electron. 53(2006) 352-362.