Simulation study of a fuzzy based bridgeless -CSC converter fed sensorless BLDC motor drive

Ashitha Baby, Jayasri R Nair

Abstract— **This paper presents the performance of a fuzzy based bridgeless canonical switching cell (CSC) converter fed sensorless brushless DC (BLDC) motor drive for power factor correction (PFC). The use of CSC not only controls the DC link voltage but also makes the inverter to operate at low frequency so that switching losses are minimized. Moreover, the use of front end CSC improves the power factor at AC mains. The speed of BLDC motor is controlled by varying the DC bus voltage. The system needs only a single voltage sensor for the DC bus voltage sensing; hence the system cost is reduced. The sensorless method consider the back emf and DC bus voltage. The fuzzy logic control strategy has been implemented for the converter control. The bridgeless configuration of CSC converter offers low conduction losses due to partial elimination of the diode bridge rectifier at the front end. The entire performance has been evaluated using MATLAB-Simulink.**

Index Terms— **BLDC Motor: BL-CSC Converter: DICM: Fuzzy Logic: PFC: Sensorless**

I. INTRODUCTION

In recent years the BLDC motor is widely used in many low and medium power applications, because of its high energy density, high torque/inertia ratio, high efficiency and low maintenance due to the absence of the commutator and brush assembly. The BLDC motors are used in household appliances like washing machine, water pumping and air conditioning etc. and also in industries like robotics and industrial tools and motion control equipment.

This paper presents the improvement of power quality using fuzzy based canonical switching cell converter with voltage follower approach.

The key point behind sensorless operation of BLDC motor is the detection of actual position of the rotor at standstill correctly and starting the motor successfully. One of the major problem faced by sensorless BLDC is the initial start-up, since most of the sensorless techniques are based on back-EMF voltage detection, which disappears at standstill.

No attention has been paid to the canonical switching cell (CSC) converter, even though it has excellent performance as a power factor pre-regulator, a small component count (as compared to the non-isolated Cuk converter) and good light load regulation. A combination of switch (S_w), capacitor(C_1) and 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 CSC converter which offers partial elimination of diode bridge rectifier 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.

II. PFC FUZZY BASED BL-CSC CONVERTER FED SENSORLESS BLDC MOTOR DRIVE

Fig. 1 shows the proposed fuzzy based BL-CSC converter based VSI fed sensorless BLDC motor drive. As shown in this figure, the DBR is eliminated in this BL-CSC converter; thereby reducing the conduction losses associated with it. This BL-CSC converter is designed to operate in a discontinuous inductor current mode (DICM) such that the currents flowing through inductors L_{i1} and L_{i2} are discontinuous, whereas the voltage across the intermediate capacitors, C_1 and C_2 remain continuous in a switching period. An approach of variable DC link voltage for controlling the speed of BLDC motor is used. The proposed configuration exhibits the minimum conduction losses due to the conduction of minimum number of components during each half line cycle.

III. OPERATING PRINCIPLE OF PFC BL-CSC CONVERTER

This bridgeless converter is designed such that two switches operates for positive and negative half cycles of supply voltages.

The operation of the proposed fuzzy based BL-CSC converter for positive and negative half cycle of the supply voltage shown in Fig. 1. During the positive half cycle of the supply voltage, the input side current flows through switch S_{w1}, inductor L_{i1}, and a fast recovery diode D_p. Similarly, switch S_{w2}, inductor L_{i2}, and diode D_n conduct for a negative half cycle of supply voltage. The proposed converter is operating in DCIM i.e. the inductor (i_{Li1} and i_{Li2}) are discontinuous and the voltage across the intermediate

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capacitor V_{C1} and V_{C2}) remain continuous with a permissible amount of voltage ripple in a complete switching period.

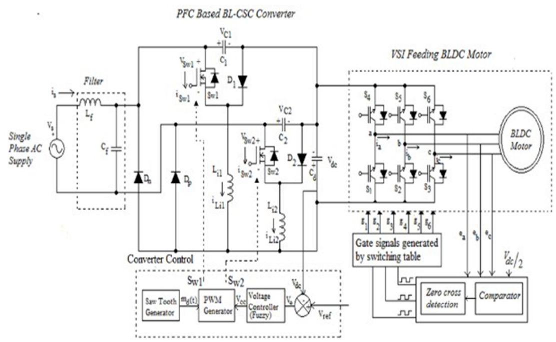

Fig. 1. Proposed fuzzy based BL-CSC converter fed sensorless BLDC motor drive.

IV. DESIGN OF PFC BL-CSC CONVERTER

The design of CSC is similar to a Cuk converter. When the inductors of the Cuk converter are stretched and combined to form a single inductor then the topology obtained is CSC converter. The combination of a switch, diode and a capacitor comprises of switching cell and is used for the design of various converters.

The converter is designed for an output voltage of 24 V, the power output, P_{out} 70W. Input voltage is set to 8 V with a supply frequency of 50Hz. Switching frequency of MOSFET is 20kHz.

The duty ratio D is given as,

$$D = \frac{V_{dc}}{V_s + V_{dc}} \quad (1)$$

where V_{dc} is the output voltage. The value of inductor is to be calculated in discontinuous inductor current mode.

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 linear function of V_{dc} as,

$$P_i = \left(\frac{P_{max}}{V_{dcmax}}\right) V_{dc} \quad (2)$$

Where V_{dcmax} represents maximum DC link voltage and P_{max} is the rated power for the PFC converter.

The critical value of input inductor L_{ic} is expressed as,

$$L_{icmin} = \left(\frac{V_{smin}^2}{P_{max}}\right)\frac{D}{2 f_s} \quad (\quad (3)$$

To achieve a discontinuous current conduction, the value of input inductors L_{i1} and L_{i2} , must be selected lower than L_{icmin} . Therefore the values of L_{i1} and L_{i2} are selected around $1/_{3rd}$ L_{icmin}.

The expression for intermediate capacitance C_1 and C_2) is given as,

$$C_1 = C_2 = \frac{V_{dcmax} \times D}{\eta(\sqrt{2}\ V_{smax} + V_{dcmax}) f_s R_L} \quad (4)$$

where η is the permitted ripple voltage across intermediate capacitors (C_1 and C_2), V_C is the intermediate capacitor's voltage and R_L is the emulated load resistance and is given as $R_L = V_{dc}^2 / P_i$

The value of DC link capacitor is calculated as,

$$C_d = \left(\frac{P_{min}}{V_{dcmin}}\right)\frac{1}{2\omega \Delta V_{dcmin}} \quad (5)$$

where ω = f_L, f_L is the line frequency and V_{dcmin} is the permitted ripple in the DC link voltage.

Using this design equations, the inductor and capacitor values were obtained as, inductors $L_1 = L_2$ 4.22 µH, input capacitor C_1 = C_2 = 23.51 µF and DC link capacitor C_d = 2200 µF.

V. CONTROL OF PFC FUZZY BASED BL-CSC CONVERTER FED SENSORLESS BLDC MOTOR DRIVE

The control of the proposed PFC based BL-CSC converter fed BLDC motor drive is divided into two parts. This includes the control of PFC converter for DC link voltage control and the electronic commutation of BLDC motor.

A. *Control of front-End PFC converter*

A voltage follower approach is used for the control of BL-CSC converter operating in DCIM. A single voltage sensor is required for controlling the DC link voltage for speed control of BLDC motor and inherent power factor correction is achieved at the AC mains. Fig. 2 shows a complete block diagram for the control of DC link voltage.

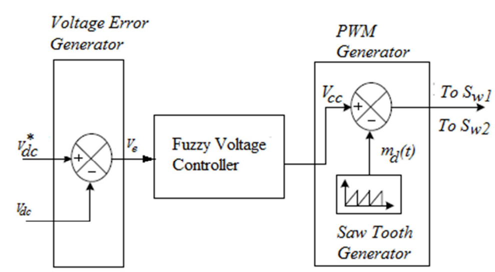

Fig. 2. Control of PFC BL-CSC converter feeding BLDC motor drive.

This control scheme consists of a voltage error generator, voltage controller and a PWM generator.

The 'Voltage Error Generator' compares this reference DC link voltage V_{dc}^*) with the sensed DC link voltage V_{dc}) to generate an error voltage (V_e) given as,

$$V_e(k) = V_{dc}^*(k) - V_{dc}(k) \quad (6)$$

where 'k' represents the k^{th} sampling instance.

The error voltage, is given to a voltage fuzzy controller to generate a controlled output voltage V_{cc}).

Finally the PWM signals are generated by comparing the output of fuzzy controller V_{cc}) with high frequency saw-tooth signals m_d) given as,

$$\text{For } V_s > 0; \begin{Bmatrix} \text{if } m_d < V_{cc} \text{ then } S_{w1} = 'ON' \\ \text{if } m_d \geq V_{cc} \text{ then } S_{w2} = 'OFF' \end{Bmatrix}$$

$$\text{For } V_s < 0; \begin{Bmatrix} \text{if } m_d < V_{cc} \text{ then } S_{w1} = 'ON' \\ \text{if } m_d \geq V_{cc} \text{ then } S_{w2} = 'OFF' \end{Bmatrix} \quad (7)$$

where S_{w1} and S_{w2} represent the gate signals to PFC switches S_{w1} and S_{w2} respectively.

B. *Control of BLDC Motor*

In the sensorless variant of the BLDC motor, there are no Hall-effect sensors. Instead, as the motor rotates, the back

EMF in the three coils varies in a trapezoidal form. Sensors work well, but add cost, increase complexity (due the additional wiring) and reduce reliability (due in part to the sensor connectors that are prone to contamination from dirt and humidity). Sensors cannot be used in applications where the rotor is in closed housing and the number of electrical entries must be kept to a minimum such as in a compressor or in applications where the motor is immersed in a liquid such as some pumps.

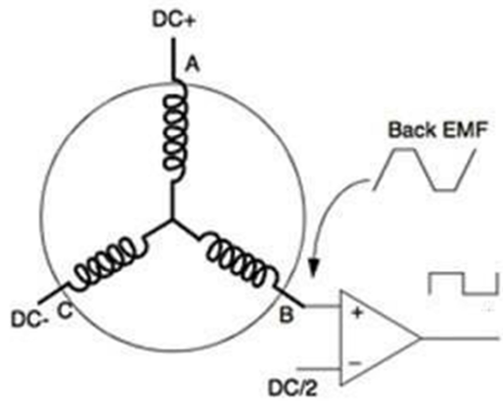

Fig. 3. Simple comparator circuit for measuring back EMF.

There are several techniques for measuring the back EMF. The simplest is to compare the back EMF to half the DC bus voltage using a comparator. The noisy motor neutral point causes problems for the sensorless system. The proposed back EMF detection method tries to avoid the neutral point voltage. If a proper PWM strategy is selected, the back EMF voltage referred to $V_{dc}/2$ signal can be extracted directly from the motor terminal voltage. This $V_{dc}/2$ signal is used as the zero crossing reference voltage for back EMF sensing. In this case, the comparator is connected to coil B; a complete system would have a comparator connected to every coil. In Fig. 3, coil A is positively energized, coil C is negatively energized and coil B is open. The back EMF rises and falls as the energizing sequence for this phase is implemented. This method consists of comparing the BEMF voltage to half the DC bus voltage by using comparators assuming that the zero crossing events occur when the BEMF is equal to $V_{dc}/2$.

The advantage with this method is that it is more flexible in terms of measurement. When speed varies, the winding characteristics may fluctuate, resulting in variation of back EMF. In such a situation, the DSP has complete control over the determination of zero crossing point. Also, digital filters are implemented to filter out the high frequency switching noise components from the back EMF signal. The commutation algorithm used is the standard BLDC control algorithm. The commutation occurs 30 electrical degrees after the back EMF zero crossing. Due to easy programmability of the microcontroller, the system has much flexibility to operate the motor.

VI. SIMULATION RESULTS

The simulation work is done in MATLAB/Simulink. The overall simulation diagram is shown in Fig. 4. The output voltage of the simulation as 24 V in these we are giving the input voltage as 8V.

The simulation parameters used as per the converter design values. The filter values are obtained by trial and error method.

The Fig. 6 to 8 shows the simulation results.

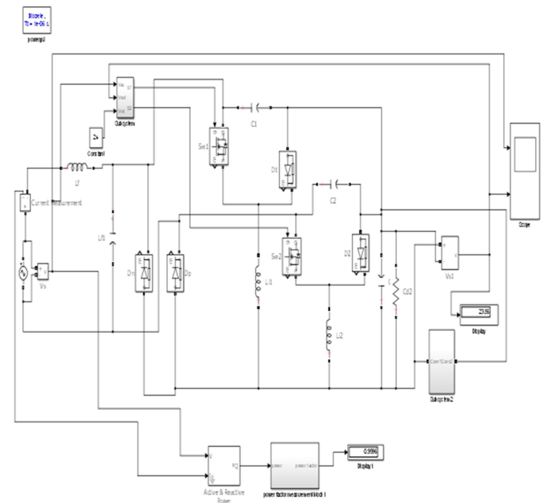

Fig. 4. Simulation Diagram of a Fuzzy based BL-CSC converter fed sensorless BLDC motor drive.

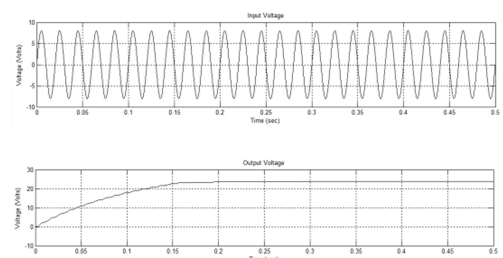

Fig. 5. Waveforms for Input and Output Voltages.

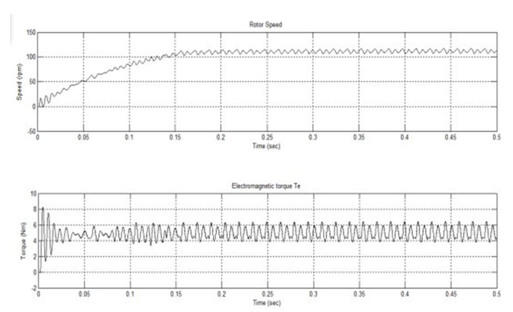

Fig. 6. Waveforms for Speedt and Torque

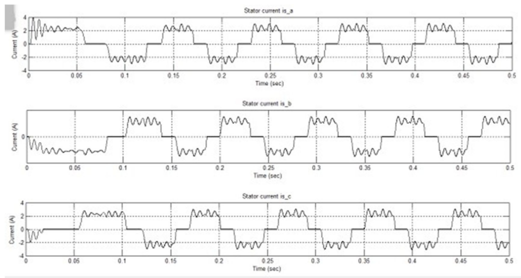

Fig. 7. Waveforms for Stator currents.

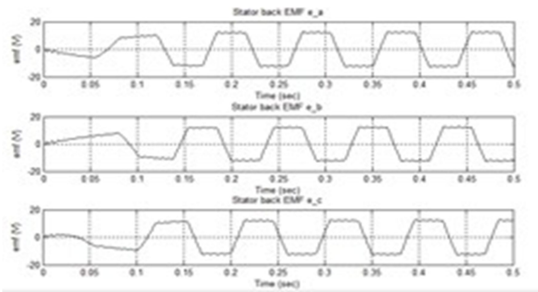

Fig. 8. Waveforms of Back EMFs.

VII. CONCLUSION

BLDC motor is the most widely used machine in industries due to its various advantages. The advantages of high efficiency, high reliability, high ruggedness, low EMI problems and excellent performance over a wide range of speed control have made this motor popular in the industry. 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 PFC converter. Sensorless BLDC motor drive has been used for avoiding the problems of hall sensors. Fuzzy logic controller has been used for provide fast response time than PI controllers. The speed control of BLDC motor and power factor correction at AC mains has been achieved using a single voltage sensor. Power factor of the proposed system is 0.9996. 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 BLDC motor has been controlled by controlling the DC link voltage of the VSI. A satisfactory performance of the proposed converter has been obtained.

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