A CSC Converter fed Sensorless BLDC Motor Drive

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Abstract:
The Brushless Direct Current (BLDC) motors have been widely used in applications such as industrial automation and customer applications because of their advantages such as high efficiency, silent operation, compact form, reliability, and low maintenance. This paper presents a sensorless operation of Brushless Direct Current (BLDC) motor. Sensor reduction for any motor drive plays a major role in selection of drive system. For reduction of sensor, the DC-DC converter operates in discontinuous inductor current mode inorder to achieve unity power factor at ac mains. The BLDC motor is electronically commutated for reducing the switching losses in VSI due to low frequency switching.

Keywords: Brushless DC (BLDC) motor, CSC, Sensorless Control, Zero Crossing

INTRODUCTION
Brushless dc motor (BLDC) have certain applications including automated industrial equipments, aerospace, medical and instrumentation. Compared with a dc motor BLDC motor has certain advantages. They have lower acoustic noise, high reliability and efficiency, high speed range, smaller and lighter, greater dynamic response etc. BLDC motor is electronically commutated by semiconductor switches instead of using brushes. The BLDC motors are generally driven by three phase voltage source inverters(VSI) or current source invertersCSI can be controlled based on rotor position information obtained from hall effect sensors, resolvers or encoders. The position sensors such as hall effect sensors have certain drawbacks like increase in cost, complexity in control, reduces the system reliability and acceptability. So sensorless control of BLDC motor is beneficial to the improvement of the efficiency of motors and reduction in motor loss. The sensorless techniques are detection of back emf of the motor, sensing of conducting state of freewheeling diode, integration of back emf method etc [1-3].

Generally in BLDC motors boost converters are used for the speed control by controlling the PWM pulses of VSI. Due to the higher level of switching frequency at the inverter switches, it has a higher amount of switching losses. In the Sepic and Cuk converter fed BLDC motor drive the speed of the motor is controlled by controlling the dc link voltage thereby switching losses can be reduced, but it requires two sensors, which increases the cost of the system. The CSC converter requires a single sensor which is a cost effective solution for low power applications.

PROPOSED CONVERTER
A front end power factor correction converter (PFC) is used after diode bridge rectifier for improving power quality and achieving unity power factor at ac mains. The mode of operation of PFC converter is a critical issue it directly affects the cost of overall system. The two basic modes of operation of PFC converter are continuous inductor current mode (CICM) and the discontinuous inductor current mode(DICM). A PFC converter operating in DICM uses a voltage follower control which requires sensing of dc link voltage for voltage control and inherent PFC is achieved at ac mains. This paper presents a BLDC motor drive using a CSC(Canonical Switching Cell) converter for PFC as shown in Fig. 1. A power factor correction circuits has two functions they are power factor correction and voltage control. Here CSC converter is used for both the functions.
The CSC converter used in the proposed BLDC drive system operating in DICM. In DICM the inductor current becomes discontinuous in a switching period. The CSC converter have three modes of operation. These are explained as follows:

Mode 1: In this mode the CSC converter is in ON position, then the inductor current charges the input current and the capacitor C1 discharges the energy to the dc link capacitor, the DC link capacitor is charging as well as supplies energy to the load.

Mode 2: Here the CSC converter is in off position, the inductor L1 discharges the stored energy to the DC link capacitor through diode D.

Mode 3: The diode D becomes reverse biased when the inductor is going to be zero, the capacitor C1 is continuous to charging, then the dc link capacitor discharges the energy to the VSI fed BLDC motor drive.

Fig. 2. shows waveforms of CSC converter.
DESIGN AND CONTROL OF CSC CONVERTER

The CSC converter is similar to the Cuk converter. The CSC converter includes a switch, diode and a capacitor. It is used for the design of various DC-DC converters [4-5]. Fig. 3. shows a CSC converter.

\[
V_i = \frac{2\sqrt{2}}{\pi} V_s \quad \text{where } V_s \text{ is the the supply voltage.} \quad (1)
\]

Duty ratio of the converter is given as, \[ D = \frac{V_{dc}}{V_i + V_{dc}} \quad \text{where } V_{dc} \text{ is the dc link voltage.} \quad (2) \]

The critical value of inductance is given as, \[ L_c = \frac{V_i D}{2i_{in} f_s} \quad (3) \]

The inductor value of the CSC converter is taken as follows to be operated in DICM is \[ L < \frac{L_c}{10} \quad (4) \]

The value of the capacitor \( C_1 \) is given as \[ C_1 = \frac{V_{dc} D}{f_s R \Delta V_{c1}} \quad \text{where } \Delta V_c \text{ is the voltage ripple across the capacitor.} \quad (5) \]

The design of the capacitor \( C_d \) is as follows, \[ C_d = \frac{1}{2\omega L \Delta V_{dc}} \quad (6) \]

where \( \Delta V_{dc} \) is the permitted ripple in dc link voltage and \( \omega = 2\pi f_p \), \( f_p \) is the line frequency.

For a 500 W drive system with input voltage 220V, switching frequency as 45 kHz, the values selected for drive working in DICM are \( L = 35\mu \text{H}, C_1 = 1.6\mu \text{F}, C_d = 4000\mu \text{F}. \)

The CSC converter is controlled by a voltage follower approach. The sensed dc link voltage \( V_{dc} \) and the reference dc link voltage is generated as follows:
\[ V_{dc} = k_b \omega^* \quad \text{where } k_b \text{ is the motor voltage constant and } \omega^* \text{ is the reference speed of the motor.} \quad (7) \]

The reference DC link voltage is compared with the measured DC link voltage and gives an error signal \( V_e(t) \) to the proportional integral (PI) controller as, \[ V_s(t) = V_{dc}(t) - V_{dc}(t) \quad (8) \]

The PI controller generates a controlled signal \( V_c(t) \) as, \[ V_c(t) = K_p V_e(t) + \int K_i V_{dc}(t) \quad (9) \]

where \( K_p \) and \( K_i \) are the gain values of PI controller.
SENSORLESS CONTROL

Profile with trapezoidal electromotive force type BLDC motors needs six discrete rotor position information for the inverter operation. The hall effect position sensors sensed these six signals, these are placed within the motors. It is clear that these hall sensors have certain disadvantages. So the sensorless approach for BLDC motor has attracted wide attention.

The proposed drive system uses a sensorless control of back EMF from line voltage difference. This back electromotive force method is based on the detection of zero crossings. Zero crossings of the back EMF are estimated indirectly from the terminal voltages measured with respect to the dc negative terminal. The advantage is that the need of neutral potential has been eliminated. Thereby it eliminates the common mode noise.

Consider a BLDC motor connected in star, three phase windings on the stator and the rotor consists of permanent magnets. Fig. 4. shows the BLDC motor is powered by a three phase inverter in which the devices are triggered with respect to the rotor position. The terminal voltage of phase A with respect to star point of the stator $V_{an}$ is given as,

$$V_{an} = R_a i_a + L_a \frac{di_a}{dt} + e_{an}$$

(10)

where $R_a$ is the stator resistance, $L_a$ is the phase inductance $e_{an}$ is the back emf $i_a$ is the phase current of the "A" phase. Similar equations can be written for the other two phases as

$$V_{bn} = R_b i_b + L_b \frac{di_b}{dt} + e_{bn}$$

(11)

$$V_{cn} = R_c i_c + L_c \frac{di_c}{dt} + e_{cn}$$

(12)

From above equations, the line voltage $V_{ab}$ can be determined as,

$$V_{ab} = V_{an} - V_{bn} = R(i_a - i_b) + L \frac{d(i_a - i_b)}{dt} + e_{an} - e_{bn}$$

(13)

Similarly,

$$V_{bc} = V_{bn} - V_{cn} = R(i_b - i_c) + L \frac{d(i_b - i_c)}{dt} + e_{bn} - e_{cn}$$

(14)

$$V_{ca} = V_{cn} - V_{an} = R(i_c - i_a) + L \frac{d(i_c - i_a)}{dt} + e_{cn} - e_{an}$$

(15)

subtracting $V_{bc}$ from $V_{ab}$ gives,

$$V_{abc} = V_{ab} - V_{bc} = R(i_a - 2i_b + i_c) + L \frac{d(i_a - 2i_b + i_c)}{dt} + e_{an} - 2e_{bn} + e_{cn}$$

(16)

when phases A and C are conducting then phase B is open as shown in the shaded region in the Fig. 4. From the Fig 4 $i_a = -i_c$ and $i_b = 0$. Therefore

$$V_{abc} = V_{ab} - V_{bc} = e_{an} - 2e_{bn} + e_{cn} = -2e_{bn}$$

(17)
The difference of line voltage waveform is an inverted representation of the back EMF waveform. From the Fig.4, it is evident that during this interval the back EMF $e_{bn}$ changes its polarity to another crossing zero. So it enables the detection of zero crossing. Similarly the difference of line voltages $V_{bcna}$ and $V_{ccab}$ enables the zero crossing of phase C and A respectively. The sensorless method used to estimate the zero crossings of back EMF from the terminal voltages of the motor from which the correct commutation instants are estimated. This paper proposes a simple and reliable method for the detection of the back EMF zero crossings for sensorless operation. This method does not involve any integrations and easy to implement.

**SIMULATION MODEL**

The sensorless method of BLDC motor is simulated in MATLAB software. Fig. 5. shows the circuit diagram of simulation of BLDC motor in sensorless mode. Fig.6. shows various waveforms of BLDC motor in sensorless mode.
From the line voltage differences zero crossings are detected using zero crossing detection model as shown in Fig.7. These zero crossings are decoded by using zero crossing decoding model as shown in the Fig.8.

Figure 5. Simulation of BLDC motor in sensorless mode

Figure 6. Waveforms of stator current, rotor speed, electromagnetic torque, stator back EMF
CONCLUSION

A sensorless operation has been proposed for the elimination of sensor. This is a simple technique, it is an amplified version of back EMF. Only three motor terminal voltages are used thereby it eliminates the use of motor terminal voltage. A power factor corrected BLDC motor drive has been designed using a CSC converter. A front end CSC converter has been used for dc link voltage control and achieving a unity power factor at ac mains. This proposed system has been found for low power applications.

REFERENCES


