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Design and Control of CUK Converter FED Brushless DC Motor Drive

Amit Dodke
Research Scholar, PEPS, SDCOE, Wardha(M.S.),India

R.G.Shriwastava
Associate Professor & Head. Elect. Deptt. BDCOE, Sewagram (M.S.), India

K.N.Sawalakhe
Assistant Professor &Head. Elect. Deptt. SDCOE, Wardha (M.S.), India

Abstract – This paper explain the operation of DC-DC converter for feeding a BLDC motor drive as a cost effective solution for low power applications. The single phase supply is fed to uncontrolled bridge rectifier. The output of bridge rectifier is fed to a PFC DC-DC converter which is used to control the voltage of DC link capacitor which feds the Voltage Source Inverter. The BLDC motor is fed from Voltage Source Inverter. Voltage of a DC link capacitor of Cuk converter is controlled to achieve the speed control of BLDC motor. A MATLAB Simulation is studied to simulate the model to study a wide range of speed control.

Index Terms – BLDC motor, cuk converter, Voltage Control, VSI

1. INTRODUCTION

Brushless DC (BLDC) motors are preferred as small horsepower control motors due to their high efficiency, silent operation, compact form, reliability, and low maintenance. However, the problems are encountered in these motor for variable speed operation. Over last decades continuing technology development in power semiconductors, microprocessors, adjustable speed drivers control schemes and permanent-magnet brushless electric motor production have been combined to enable reliable, cost-effective solution for a broad range of adjustable speed applications. Recent research has indicated that BLDC motor drives could become serious competitors to the induction motor for servo applications. BLDC motor is an ideal motor for low-medium power applications because of its high efficiency, high torque to inertia ratio, low maintenance and wide range of speed control. It consists of three phase windings on the stator and permanent magnets on the rotor. Being an electronically commutated motor, the commutation losses in the BLDC motor are negligible BLDC motor when fed by an uncontrolled bridge rectifier with DC link capacitor results in highly distorted supply current which results in low PF (Power Factor) and high THD (Total Harmonic Distortion); hence various improved power quality AC-DC converters are used in these drives. **S**olid-state ac–dc conversion of electric power is widely used in adjustable-speed drives (ASDs), switch-mode power supplies (SMPSs), uninterrupted power supplies (UPSs), and utility interface with nonconventional energy sources such as solar PV, etc., battery energy storage systems (BESSs), in process technology such as electroplating, welding units, etc., battery charging for electric vehicles, and power supplies for telecommunication systems, measurement and test equipment [1]. Conventionally, ac–dc converters, which are also called rectifiers, are developed using diodes and thyristors to provide controlled and uncontrolled dc power with unidirectional and bidirectional power flow. They have the demerits of poor power quality in terms of injected current harmonics, caused voltage distortion and poor power factor at input ac mains and slow varying rippled dc output at load end, low efficiency and large size of ac and dc filters. In light of their increased applications, a new breed of rectifiers has been developed self-commutating devices.

2. PROPOSED CONTROL SCHEME

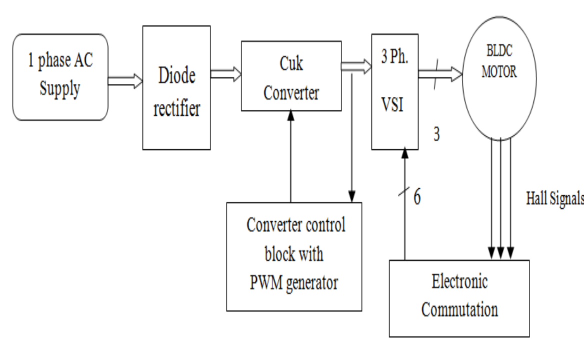

Figure 1: Block diagram for Cuk converter fed BLDC motor drive

The proposed scheme for the Sensor less BLDC motor drive fed by a ta based PFC converter operating in DICM mode is shown in Fig. 1. The front end Cuk DC-DC converter maintains the DC link voltage to a set reference value. Switch of the Cuk converter is to be operated at high switching frequency for effective control and small size of components like inductors. A sensor less approach is used to detect the rotor position for electronic commutation A high frequency MOSFET of suitable rating is used in the front end converter for its high frequency operation whereas an IGBT's (Insulated Gate Bipolar Transistor) are used in the VSI for low frequency operation The proposed scheme maintains high power factor and low THD of the AC source current while controlling rotor speed equal to the set reference speed. A voltage follower approach is used for the control of DC-DC converter operating in DICM.

The DC link voltage is controlled by a single voltage sensor. V_{dc} (sensed DC link voltage) is compared with V_{dc}* (reference voltage) to generate an error signal which is the difference of V_{dc}* and V_{dc}. The error signal is given to a PI (Proportional Integral) controller to give a controlled output. Finally, the controlled output is compared with the high frequency saw tooth signal to generate PWM (Pulse Width Modulation) pulse for the MOSFET of the cuk converter.

3. CUK CONVERTER

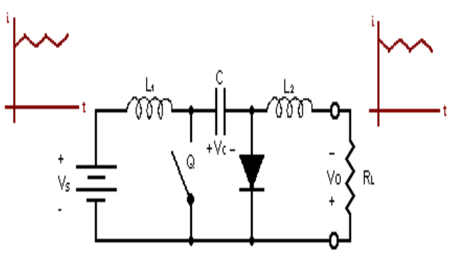

Figure 2: Cuk Converter Circuit Representation with input and output current waveforms

The Cuk converter is named for Slobodan Cuk of the California Institute of Technology. It is the result of applying the duality principle to the buck-boost converter to use a capacitor instead of an inductor as the primary energy storage device. As a result, the DC transfer function is nominally the same as that of the Buck-Boost converter,

$V_o = DV_s/ (1\text{-}D)$
Where,
D represents the PWM duty cycle of the transistor Q.
V_s represents the source voltage.
V_o represents the output voltage.

An advantage of the Cuk converter topology is that the current pulsing occurs within the converter itself and both the input and output currents are not pulsed. Furthermore, if integrated magnetics are used, the input or output current can (theoretically) be nullified as the ripple is transferred to the other side of the converter. Because only one capacitor suffers the losses associated with (internal) current pulsing, the Cuk converter is more efficient than a filtered Buck-Boost converter.

4. DESIGN OF PFC CUK CONVERTER

Th e proposed PFC Cuk converter is designed bldc motor drive with main considerations on the speed control of the A PQ improvement at ac mains. The dc link voltage of the PFC converter is given as

$$Vdc = Vin\ D/(1 - D) \quad (1)$$

Where Vin is the average output of the DBR for a given ac input voltage (Vs) related as

$$Vin = 2\sqrt{2}Vs/\pi. \quad (2)$$

The Cuk converter us es a boost inductor (Li) and a capacitor (C1) for energy transfer. Their values are given as

$$Li = DVin/ \{fs(\Delta ILi)\} \quad (3)$$

$$C1 = DIdc/\{fs\Delta VC1\} \quad (4)$$

Where ΔILi is a specified inductor current ripple, ΔVC1 is a specified voltage ripple in the intermediate capacitor (C1), and Idc is the current drawn by the PMBLDCM from the dc link. A ripple filter is designed for ripple-free voltage at the dc link of the Cuk converter. The inductance (Lo) of the ripple filter restricts the inductor peak-to-peak ripple current (ΔILo) within a specified value for the given switching frequency (fs), whereas the capacitance (Cd) is calculated for the allowed ripple in the dc link voltage (ΔVCd) [7], [8]. The values of the ripple filter inductor and capacitor are given as

$$Lo = (1 - D)Vdc/ \{fs(\Delta ILo)\} \quad (5)$$

$$Cd = Idc/(2\omega\Delta VCd). \quad (6)$$

The PFC converter is designed for a base dc link voltage of Vdc = 200 V at Vs = 220 V for fs = 20kHz, Is = 4.5 A,

ΔILi = 0.45 A (10% of Idc), Idc = 3.5 A, ΔILo = 3.5 A (≈ Idc), ΔVCd = 4 V (1% of Vo), and ΔVC1 = 220 V (≈ Vs).

The design values are obtained as Li = 2.5 mH, C1 = 0.66 μF,

Lo = 4.3 mH, and Cd = 2200 μF.

5. CONTROL OF CUK CONVERTER FED BLDC MOTOR DRIVE

The PFC converter and the sensor less BLDC motor drive are modelled for the proposed drive scheme. The control scheme of the PFC converter consists of following three blocks.

5.1. Reference Voltage Generator

The speed of BLDC motor is proportional to the DC link voltage of the VSI, hence a reference voltage generator is required to produces an equivalent voltage corresponding to the particular reference speed of the BLDC motor. The reference voltage generator produces a voltage by multiplying the speed with a constant value known as the voltage constant (Kb) of the BLDC motor.

5.2. Speed Controller

An error of the Vdc* and Vdc is given to a PI (Proportional Integral) speed controller which generates a controlled output corresponding to the error signal. The error voltage Ve at any instant of time k is as;

Ve(k) = Vdc*(k) – Vdc(k)
and the output Vc(k) of the PI controller is given by,

Vc(k) = Vc(k-1) + Kp.(Ve(k) – Ve(k-1)) + Ki.Ve(k)

where Kp is the proportional gain and Ki is the integral gain constant

5.3. PWM Generator

The output of the PI controller Vc is given to the PWM generator which produces a PWM signal of fixed frequency and varying duty ratio. A saw tooth waveform is compared with the output of PI controller as shown in Fig. 3 and PWM is generated as;

If md(t)<Vc(t) then S=1 else S=0 (10)

Where S denotes the switching signals as 1 and 0 for MOSFET to switch on and off respectively.L_2, and the diode, D, have been swapped so that the output polarity is the same as the input polarity. This can be an advantage in certain applications, because the negative terminals of both the input also requires a high side switch (either a P-Channel FET or an N-Chanel FET with a high side driver). This topology can work well when integrated with another topology (such as the buck-boost) to generate both positive and negative output rails.

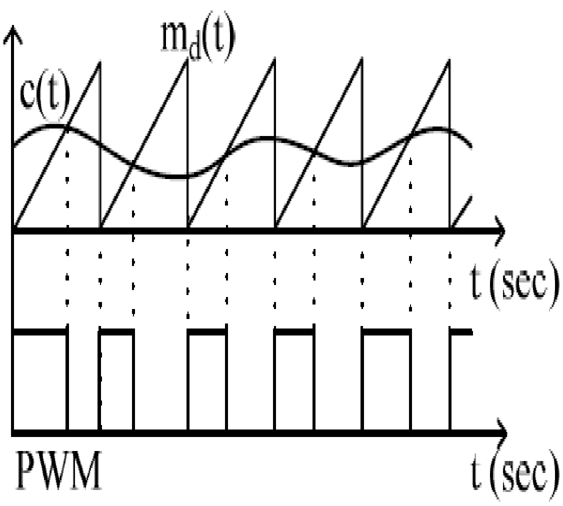

Figure 4. Generation of PWM signal by comparing a saw tooth waveform with the controller output

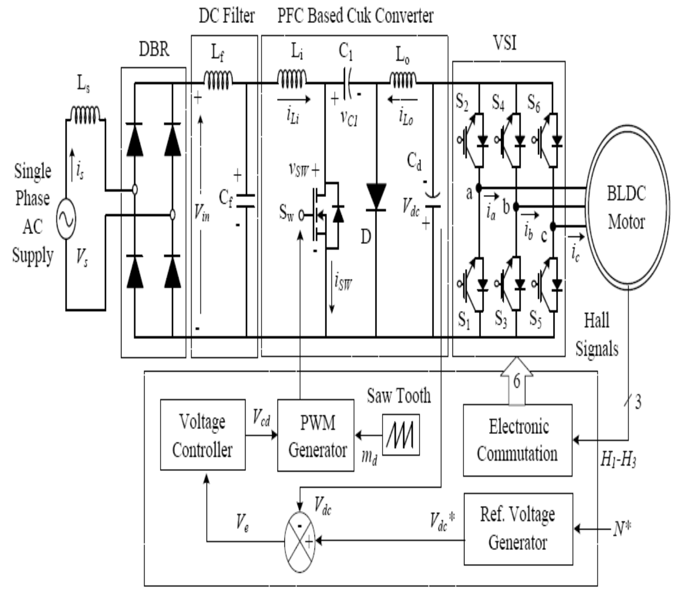

Figure 5. Cuk converter fed BLDC Motor Drive

6. SUITABILITY OF CUK CONVERTER

There are very few publications regarding PFC in PMBLDCMDs despite many PFC topologies for switched mode power supply and battery charging applications. Here we studied an application of a PFC converter for the speed control of a PMBLDCMD. For the voltage controlled drive, a Cuk dc–dc converter is used as a PFC converter because of its continuous input and output currents, small output filter, and wide output voltage range as compared to other single switch converters [1]. Moreover, apart from PQ improvement at ac mains, it controls the voltage at dc link for the desired speed of the Air-Conditioners.

7. RESULTS

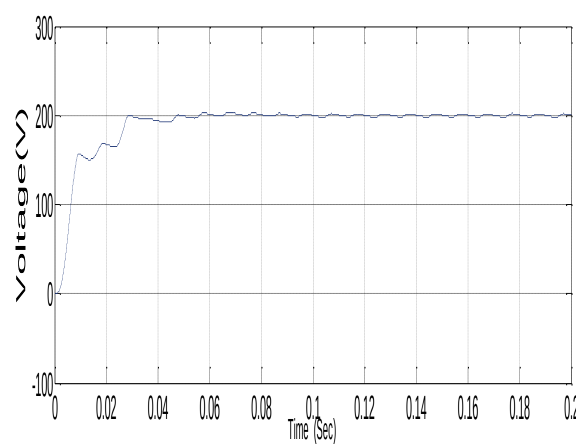

Figure 6 output of cuk converter

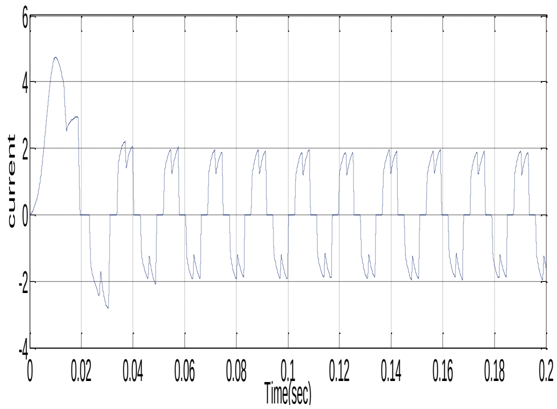

Figure 7 stator current

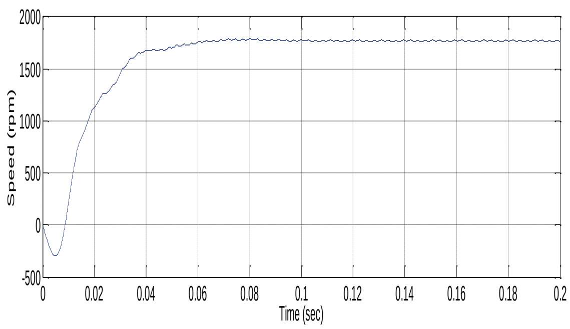

Figure 8 speed in rpm

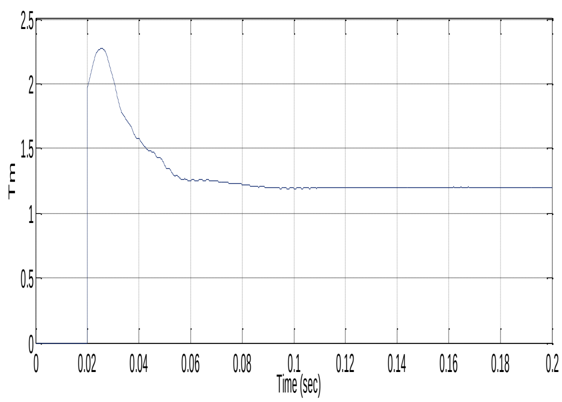

Figure 9 Electromagnetic torque

8. CONCLUSION

A simple control using a voltage follower approach has been used for voltage control and power factor correction of a PFC Cuk converter fed BLDC motor drive. A novel scheme of speed control using a single voltage sensor has been proposed of speed. The performance of the proposed drive system has also been evaluated for varying input AC voltages and found satisfactory. The power quality indices for the speed control and supply voltage variation have been obtained within the limits by International power quality standard IEC 61000-3-2. The proposed drive system has been found a suitable candidate among various adjustable speed drives for many low power applications.

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