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Performance Improvement of a BLDC Motor using Interleaved Buck Converter

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***Abstract*— Brushless DC motors are widely used motors for many of the industrial applications. The motor is powered by a DC electric source with an integrated inverter power supply. The cuk converter used for supplying the inverter produces high output power ripples, which in turn affect the output of the inverter circuit. Hence the motor operation is degraded. In this paper the BLDC motor is powered by an interleaved buck converter, whose output power has much less ripples, which in turn improves the motor performance.**
The simulation of the proposed model was done in MATLAB/SIMULINK.

Keywords*— Brushless DC motor, Power ripple, Interleaved buck converter.

I. INTRODUCTION

Brushless DC motors are widely used, due to their improved performance such as high efficiency, high torque, high power factor, simple control and lower maintenance compared to other types of motors. These motors are mainly used in applications such as electric vehicles, actuators, robotics etc. The Brushless DC motors are known as electronically commutated motors, that are powered by a DC electric source via an integrated inverter power supply, which produces AC electric power to drive the motor. Unlike DC motors they do not have brushes or commutator segments. So these motors have very low wear and tear, thus requiring less maintenance. Brushless DC motors uses either internal or external position sensors in order to sense the position of the rotor. According to the position of rotor the windings in the stator are excited with the help of voltage source inverter.

The switch mode regulation is provided by the DC-DC converter used for supplying the voltage source inverter. With the help of this converter the unregulated DC voltage is converted to a regulated DC voltage so that the speed of the motor is controlled. The performance of the DC-DC converter plays an important role in the performance of the motor. By replacing Cuk converter, which produces high output power ripple with an interleaved buck converter improves the performance of the motor. Interleaved buck converter is the parallel combination of two buck converters, in which the discontinuous mode of operation of one converter is replaced by the other. The output ripple is actually the small unwanted residual periodic variation of the direct current output of a power supply, which has been derived from alternating current source.

This paper describes simulation study of Brushless DC motor fed by Cuk converter and Interleaved Buck converter. It is done for same supply voltage and reference speed. The simulation work is done in MATLAB/SIMULINK environment.

II. CUK CONVERTER

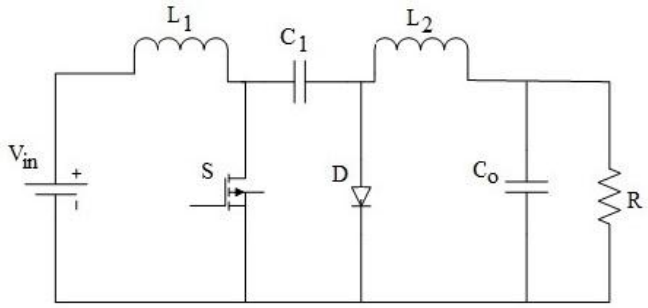

Fig. 1. Circuit diagram of Cuk converter

It is a DC – DC converter whose output voltage magnitude is greater than or less than that of input voltage magnitude. It is actually a boost converter followed by a buck converter with a capacitor to couple energy.

The Cuk converter is studied in four different modes of operation, continuous conduction mode (CCM) and in discontinuous conduction mode (DCM). In continuous conduction mode the current in inductors L_1 and L_2 are continuous, and the voltage across the intermediate capacitor (C_1) remains continuous in one switching period. The discontinuous mode of operation is classified into two broad categories. That are discontinuous inductor current mode and discontinuous capacitor voltage mode. In discontinuous inductor current mode the current through the inductor L_1 and L_2 becomes discontinuous in their respective modes of operation. And in discontinuous capacitor voltage mode the voltage across the capacitor (C_1) becomes discontinuous in one switching period.

III. PROPOSED MODEL BLOCK DIAGRAM

The block diagram of the proposed model for the control of BLDC motor is shown in Figure 2. The system is supplied with single phase ac supply which is converted to DC using a diode bridge rectifier and is filtered by using a filter. Then the

DC is passed through a DC-DC converter (Interleaved buck converter) so that the output power ripple of the circuit is reduced. Then the DC is supplied to a voltage source inverter in order to produce excitation signals to the motor. Here the converter is functioning according to the duty ratio provided. Proportional Integral controller is used to achieve closed loop operation and AT89S8253 processor is used to get switching signals for the inverter.

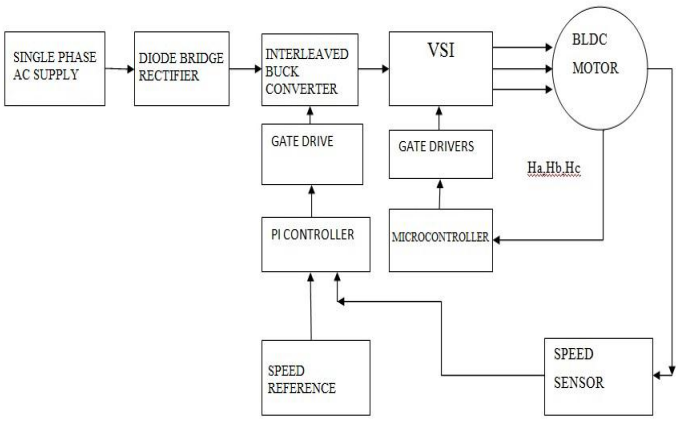

Fig. 2. Block diagram of the proposed model

IV. PROPOSED CONVERTER - INTERLEAVED BUCK CONVERTER.

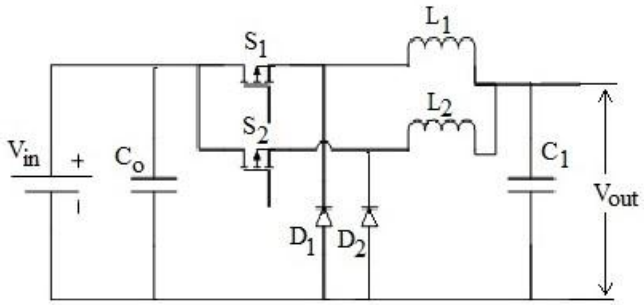

Fig. 3. Interleaved buck converter.

It is the parallel combination of two buck converters. The circuit part constituting switch S_1, inductor L_1 and diode D_1 forms the first buck converter and the circuit part constituting switch S_2, inductor L_2 and diode D_2 forms the second buck converter.

Here, initially the first buck converter is operated by turning ON the switch S_1 and the time at which the output voltage of first converter becomes zero, the second converter is turned ON. That is the switch S_2 is turned ON when the output voltage of second converter falls to zero, the first converter is turned ON thus the operation continues. This mode of operation of the circuit produces less output power ripple.

The output voltage equation of the converter is

$$V_{out} = \frac{V_{in}}{1 - \frac{D}{2}}$$

V_{in} is input voltage.
D is duty cycle.

CONVERTER DESIGN

Maximum voltage in the circuit

V_m = 25 volt

Maximum current in the circuit

I_m = 2.5 amp

Change in inductor current is 10% of I_m

Therefore ΔI_L = 0.25 amp

ΔI_L is change in inductor current (L_1 or L_2)

Duty cycle is selected as 0.8
Frequency is 10 kHz

The maximum value of inductor voltage is V_m
Thus

$$V_m = V_L$$

The value of inductor can be calculated as

$$L = \frac{V_L \times \frac{D}{2}}{\Delta I_L \times f}$$

$$L = \frac{25 \times 0.8}{0.25 \times 10000}$$

10 mH.

The maximum value of capacitor current is I_m
ΔV_c, Change in capacitor voltage is 1% of V_m
Duty cycle is selected as 0.8
and frequency is 10kHz

The value of capacitor can be calculated as

$$C = \frac{I_c \times D}{\Delta V_c \times f}$$

$$C = \frac{2.5 \times 0.8}{0.25 \times 10000}$$

=1000 μF.

V. SIMULATION AND RESULTS.

Simulation Of Cuk Converter Fed Bldc Motor

The simulation work was done in MATLAB/SIMULINK. The motor parameters used for simulation are shown in the table below.

Parameter	Specification
Rated voltage V_{dc}	24 Volt
No. of poles P	4
Stator resistance/phase	2.5 ohm
Stator inductance/phase	8.5 mH
Torque constant	0.18144Nm/Area

Table 1. Motor parameters

The simulation time was 10 seconds. The circuit input voltage was 50V. The overall simulation diagrams are shown below.

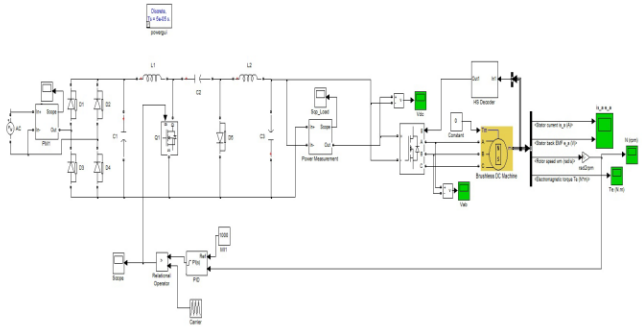

Fig. 4. Simulation diagram of Cuk converter fed BLDC motor.

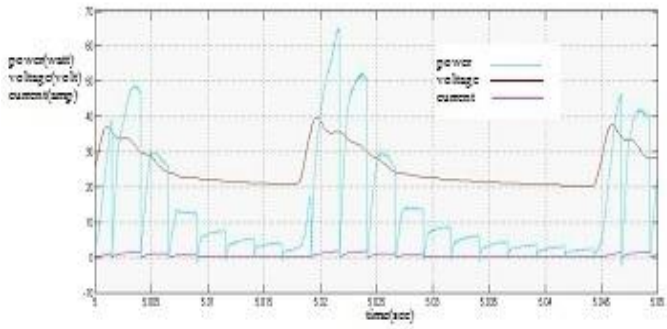

Fig. 5. Output power, voltage, current waveforms of Cuk converter fed BLDC motor

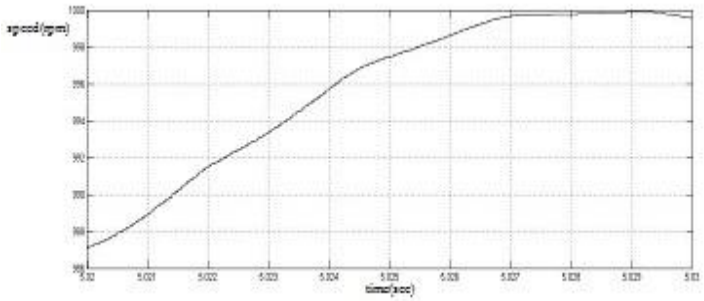

Fig. 6. Rotations per minute waveform of Cuk converter fed BLDC motor

The simulation of both circuit, cuk converter fed BLDC motor and interleaved buck converter fed BLDC motor is done successfully for the same input voltage.

The simulation with cuk converter fed BLDC motor shows that the output power of cuk converter varies to about 20 watt.

(The ripple in output power is mainly due to the ripple in output voltage).

The voltage variation is about 4 volt.

The current variation is about 0.5 Ampere. (Fig 5).

Here for the set speed of 1000 rpm, the motor attains its rated speed in 5 seconds from rest (Fig 6).

SIMULATION OF INTERLEAVED BUCK CONVERTER FED BLDC MOTOR

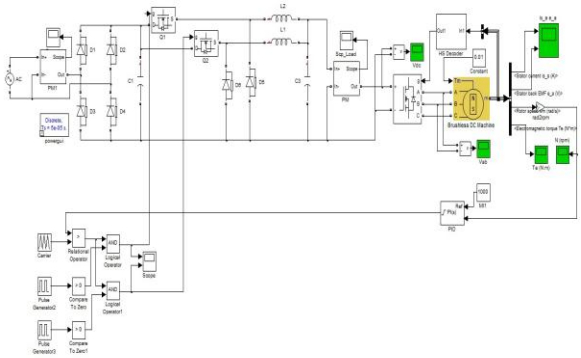

Fig. 7. Simulation diagram of interleaved buck converter fed BLDC motor.

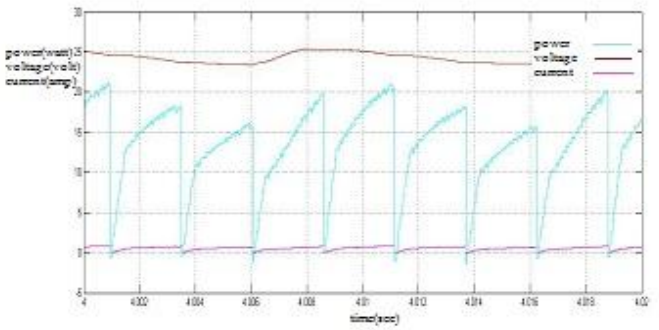

Fig. 8. Output power, voltage, current waveforms of interleave buck converter fed BLDC motor

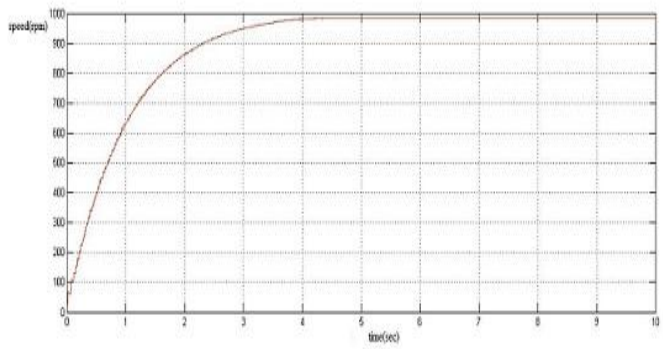

Fig. 9. Rotations per minute waveform of interleave buck converter fed BLDC motor

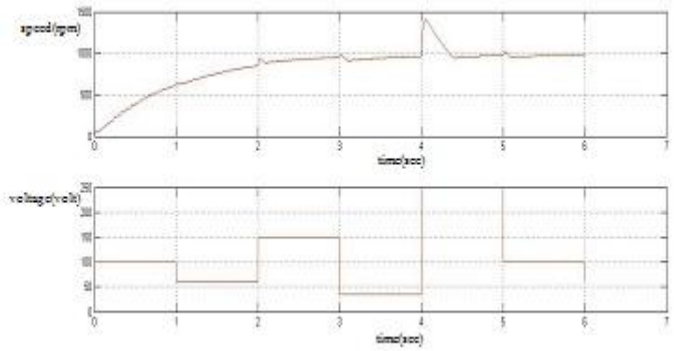

Fig. 10. Transient response in speed for varying supply voltage

Simulation with interleaved buck converter fed BLDC motor, it can be inferred that the power ripple generated by interleaved buck converter is only about 5 watt.
The voltage ripple produced by the circuit is only 2 volt and the current fluctuation is about 0.1 ampere. (Fig 8).
Here for the set speed, the motor attains its rated speed within 4 seconds and the operation of motor is much smoother than above. (Fig 9).

Transient response of motor set at 1000rpm for varying supply voltage is shown in Fig 10, it can be inferred that for a rise in supply voltage from 50 volt to 100 volt there is not much deviation from its current running speed and when the supply voltage is increased to about 250 volt ,the motor speed increases to about 1350 rpm and settles to 1000 rpm in 0.4 sec. Thus the motor speed increases according to the hike in voltage and settles to the normal operating condition within small time. Similarly the motor speed is decreased slightly according to the dip in voltage and settles to the normal operating condition.

VI. CONCLUSION

The operation of Brushless DC motor fed by Cuk converter and Interleaved buck converter is modeled in MATLAB/SIMULINK and the waveforms were observed in various operating conditions. It can be observed that the output power ripple of BLDC motor fed by interleaved buck converter is reduced to about 75% than that of BLDC motor fed by cuk converter. Total harmonic distortion of voltage and current at motor input is found to be 33.30% .Thus by using an interleaved buck converter the output voltage ripple of the inverter circut can be reduced. And the comparison of waveforms of two circuits are done for the same input voltage and speed

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