Simulation and Hardware Implementation on Performance Improvement of BLDC Motor using Interleaved Buck Converter

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***Abstract*— Brushless DC motors (BLDC) are widely used motors for many of the industrial applications, automobile applications etc. The motor is powered by a DC electric source (with help of a converter) and an integrated inverter power supply which provides sequence of pulses to the motor. The performance of the converter mainly contribute to the performance of the motor. The cuk converter used for supplying the inverter produces high output power ripples, which in turn affect the output of the inverter circuit and there by affecting the motor performance. 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 upgrade the motor performance.**

The simulation of the proposed model was done in MATLAB/SIMULINK. And performance improvement achieved was verified by hardware implementation and testing.

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

I. INTRODUCTION

Due to the improved performances such as high efficiency, high torque, high power factor, simple control and lower maintenance compared to other types of motors, brushless DC motors are widely used. These motors are mainly used in applications such as electric vehicles, actuators, robotics etc. These motors are also known as electronically commutated motors, which are powered by a DC electric source via an integrated inverter power supply. This integrated inverter power supply 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. Internal or external position sensors are used by BLDC motors 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. The unregulated DC voltage is converted to regulated DC voltage with the help of this converter and thus 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. The parallel combination of two buck converters forms the interleaved buck converter, 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. The hardware implementation of the simulation work on BLDC motor fed by interleaved buck converter is done. Control and monitoring of the system has been achieved by AT89S8253 processor.

II. CUK CONVERTER

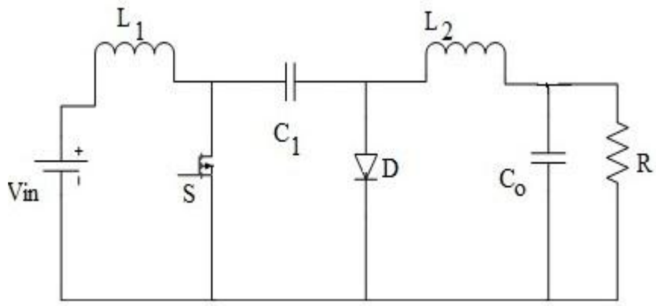

Fig. 1. Circuit diagram of Cuk converter

It is a DC – DC converter whose output voltage magnitude can be varied by varying the duty ratio. For duty ratio less than 0.5 the cuk converter act as buck converter and for duty ratio greater than 0.5 the converter act as boost converter. 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 CONVERTER - INTERLEAVED BUCK CONVERTER

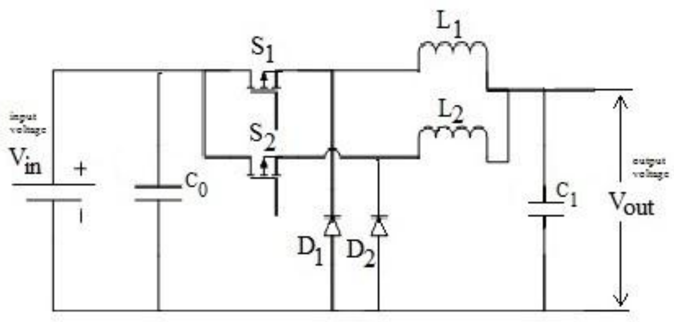

Fig. 2. Circuit diagram of Interleaved buck converter.

Interleaved buck converter is the parallel combination of two buck converter as shown in the figure above. The circuit constituting switch S_1, inductor L_1 and diode D_1 forms the first buck converter and the circuit constituting switch S_2, inductor L_2 and diode D_2 forms the second buck converter.

The two converters here are operated alternatively such that 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 by turning ON the switch S_2 . Similarly when the output voltage of second converter becomes zero, the first converter is turned ON thus the operation continues. This mode of operation of the circuit produces a continuous output voltage there by reducing the voltage ripples which in turn reduces output power ripple.

Output voltage equation of interleaved buck converter is

$$V_{output} = \frac{V_{input}}{1 - \frac{D}{2}}$$

V_{input} input voltage
D duty cycle
CONVERTER DESIGN

Maximum voltage that can be provided to the circuit is

$$V_{max} = 25 \text{ volt}$$

Maximum current provided to the circuit is

$$I_{max} = 2.5 \text{ amp}$$

Change in inductor current can be 10% of I_{max}
Therefore change in inductor current in L_1 or L_2 is

$$\Delta I_L = 0.25 \text{ amp}$$

Duty cycle selected is 0.8
Frequency selected is 10 kHz

Maximum value of inductor voltage is V_{max}

$$V_{max} = V_L$$

The value of inductor can be calculated as

$$L = \frac{V_L * \frac{D}{2}}{\Delta I_L * freq}$$

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

10 mH

Maximum value of capacitor current is I_{max}
Change in capacitor voltage ΔV_c, is 1% of V_{max}

Selected duty cycle is 0.8
Selected frequency is 10 kHz

The capacitor value can be calculated as

$$C = \frac{I_c * D}{\Delta V_c * freq}$$

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

1000 µF

IV. PROPOSED MODEL BLOCK DIAGRAM

The proposed model block diagram for the control of BLDC motor is shown in Figure 3. The system is supplied with single phase AC supply .The AC supply is converted to DC using a diode bridge rectifier and is filtered by using a filter. Then the filtered DC is passed through a DC-DC converter (Interleaved buck converter) so that the output power ripple produced by the circuit is reduced. Then the filtered continuous DC is supplied to a voltage source inverter in order to produce excitation signals to the motor. Here the converter is operated 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.

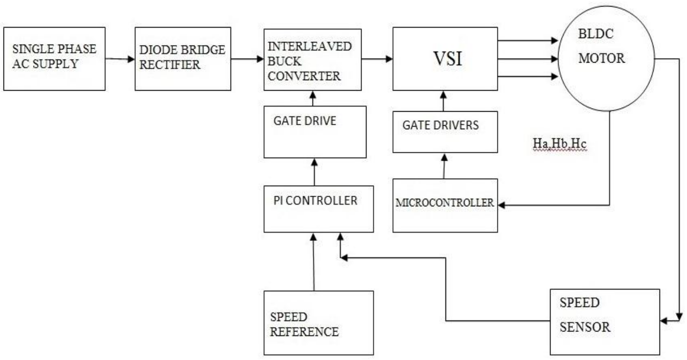

Fig. 3. Block diagram of the proposed model

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.

Parameters	Specifications
Rated voltage of motor V_{dc}	24 Volt
Number. of poles P	4
Stator resistance/phase	2.51 ohm
Stator inductance/phase	8.51 mH
Torque constant	0.18144Nm/Area

Table 1. Motor parameters and specifications

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

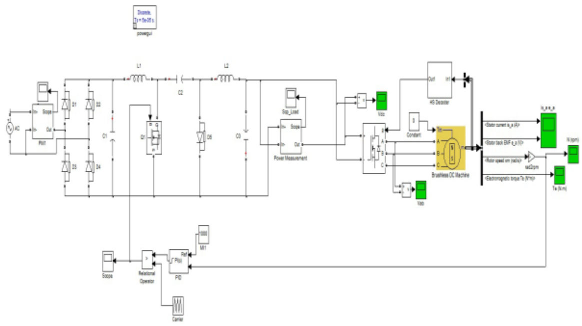

Fig. 4. Simulation of Cuk converter fed BLDC motor.

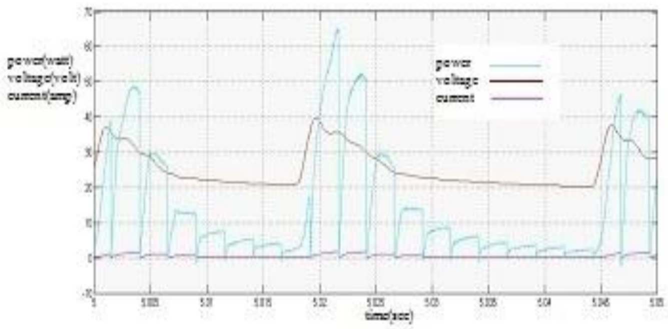

Fig. 5. Output power, voltage, current waveforms of Cuk converter fed BLDC motor

The simulation of cuk converter fed BLDC motor and interleaved buck converter fed BLDC motor is done successfully for the same input voltage.
From Fig.5. it can be understood that the output power of cuk converter varies to about 19 watt.
(The ripple in output power is mainly due to the ripple in output voltage).
The voltage is varied to about 4.5 volt and the current variation is about 0.6 Ampere.
Here for the set speed of 1000 rpm, the motor attains its rated speed by 5 seconds from rest.

SIMULATION OF INTERLEAVED BUCK CONVERTER FED BLDC MOTOR

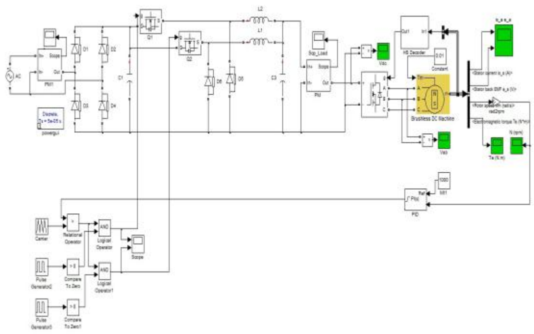

Fig. 6. Simulation of interleaved buck converter fed BLDC motor.

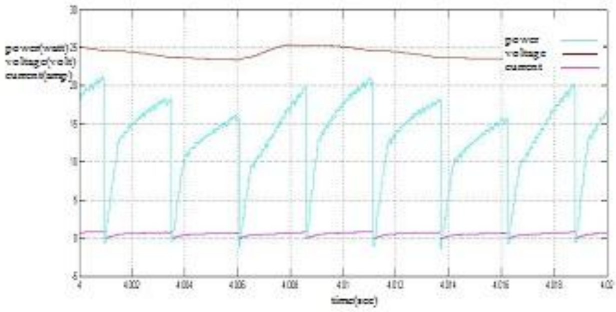

Fig. 7. Output power, voltage, current waveforms of interleave buck converter fed BLDC motor

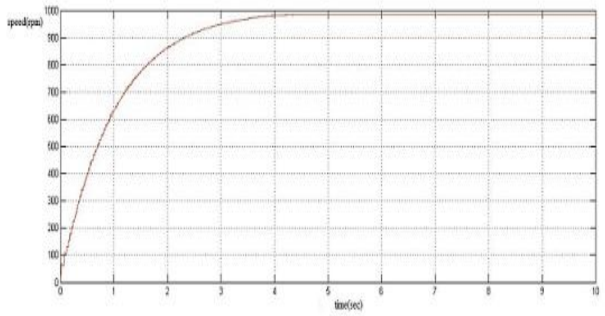

Fig. 8. Rotations per minute waveform of interleave buck converter fed BLDC motor

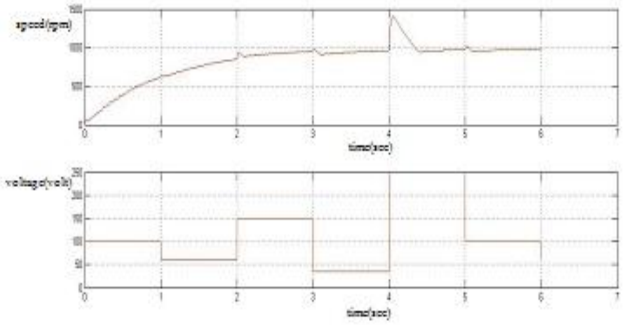

Fig. 9. Transient response in speed for varying supply voltage

From Fig.7, it can be inferred that the power ripple generated by interleaved buck converter is only about 4.5 watt.

The voltage ripple produced by the circuit is only 2.2 volt and the current fluctuation is about 0.11 ampere. (Fig 8).

From Fig.8, for the set speed of 1000rpm, the motor attains its rated speed within 4 seconds and the operation of motor is much smoother than that of the motor fed by cuk converter.

Transient response of motor set at 1000 rpm is shown in Fig 9. From the figure 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 0.45sec. 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. HARDWARE IMPLEMENTATION OF INTERLEAVED BUCK CONVERTER FED BLDC MOTOR

This project aims to develop a circuit, which reduces the ripples in the power fed to BLDC motor than that of ripples produced by the cuk converter.

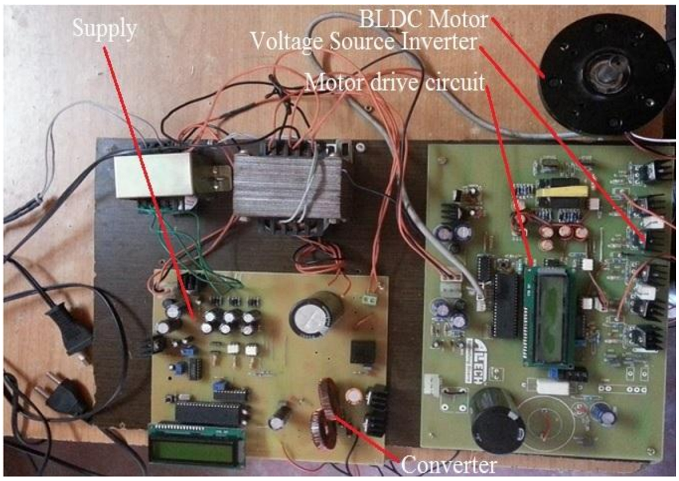

Fig. 10. Experimental setup diagram

Here 24 Volt single phase AC supply converted to DC with the help of a diode bridge rectifier. The obtained DC voltage is filtered out and is passed through the DC – DC converter (Interleaved Buck Converter). Thus obtained continuous voltage which has less voltage ripple is provided to voltage source inverter. From the voltage source inverter the sequence of pulses are provided to the stator of BLDC motor according to the position of rotor. The motor terminal voltage and current are sensed and is given to AT89S8253 microcontroller. Based on the algorithm coded in the microcontroller, it generates the gating pulses which are given to the converter switches through the driver circuit. The output waveforms obtained from the CRO is shown below.

VII. EXPERIMENTAL RESULTS

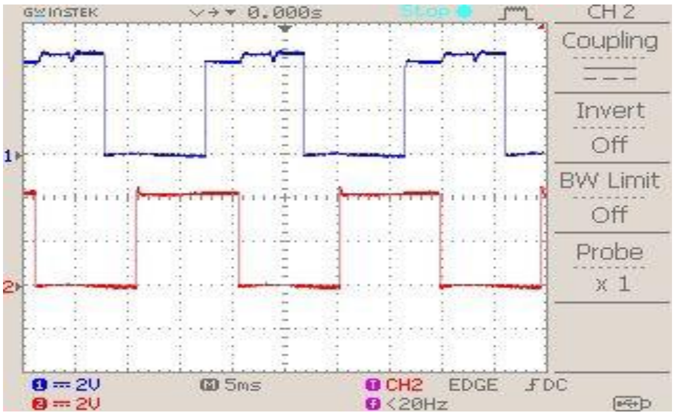

Fig. 11. Hall sensor outputs for phase A(blue) and phase B(brown)

Fig.11. shows the hall sensor outputs which are given to the phase A and phase B of the voltage source inverter. The amplitude of the signal is 2 volt.

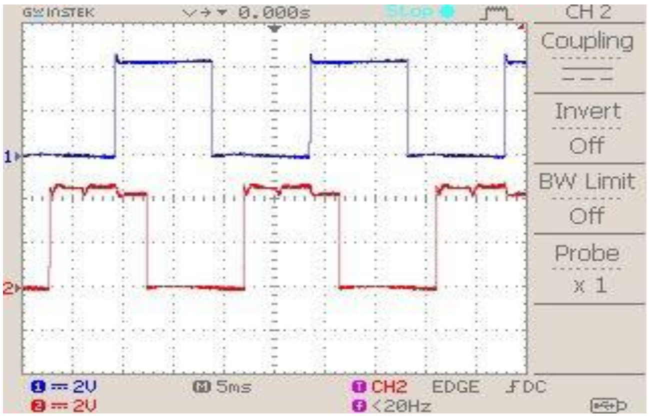

Fig. 12. Hall sensor outputs for phase A(blue) and phase C(brown)

Above figure shows the hall sensor outputs which are given to the phase A and phase C of the voltage source inverter. The amplitude of the signal is 2 volt.

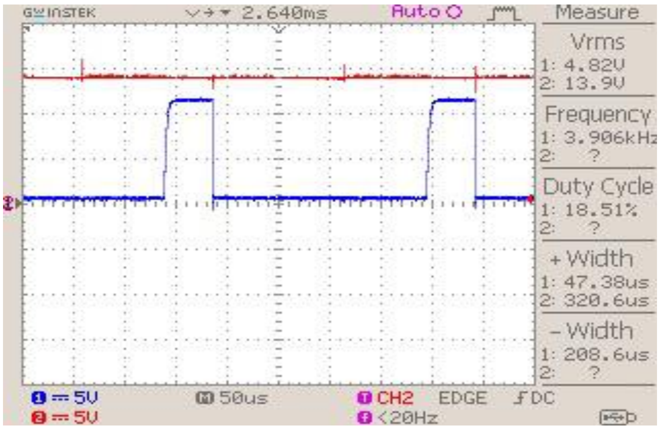

Fig. 13. Voltage of interleaved buck converter(brown) and gate pulses(blue) to the switch.

From Fig.13. The rms value of output voltage (brown colour) of interleaved buck converter is obtained as 13.9 volt. Gate pulses of 4.82 volt is provided to the single switch of the converter (blue colour). Here the output voltage has less ripples.

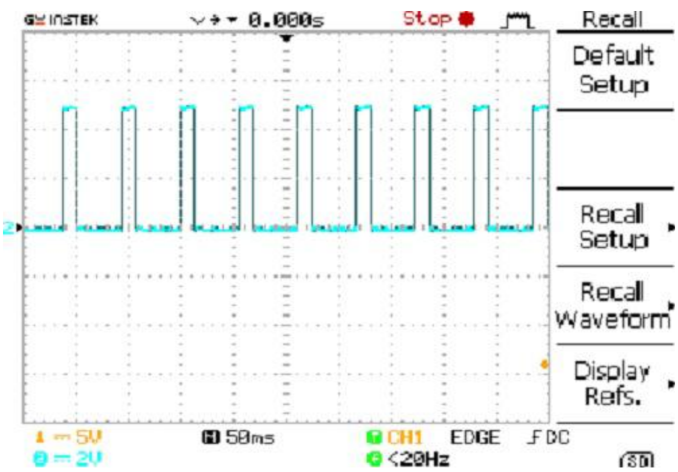

Fig. 14. Tacho pulses obtained from the motor

The tacho pulses (voltage pulses) obtained from the motor for the set speed of 1080 rpm is shown in Fig.14. Number of voltage pulses in 100 milliseconds multiplied by sixty gives the speed of motor in rpm. As the speed of the motor increases the number of voltage pulses in a second increases.

Here from the figure there are nine voltage pulses in fifty milliseconds. Thus in hundred milliseconds there are eighteen voltage pulses.

Thus 18 × 60 = 1080 rpm.

VIII. 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. From the simulation waveforms 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. Performance improvement achieved was verified by hardware implementation and testing. Through hardware implementation and testing it is understood that the output voltage ripple produced by interleaved buck converter is very less than that of cuk converter. Total harmonic distortion of voltage and current at motor input is found to be 32.33 % .

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