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Four quadrant operation of BLDC motor drive using a non inverting buck boost converter

Annie Bincy CA[1☼], Salitha K[2]

1. PG Student, Department of Electrical Engineering, Rajagiri School of Engineering & Technology, India
2. Asst. Professor, Department of Electrical Engineering, Rajagiri School of Engineering &Technology, India

☼Corresponding author: PG Student, Department of Electrical Engineering, Rajagiri School of Engineering & Technology, India; Email: anniebincy@gmail.com

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ABSTRACT

Brushless DC motors are widely used in many applications such as traction, appliances, instrumentation and aerospace. Thus operation of BLDC motor in all four quadrants becomes very essential. Motor is operated in all quadrants of torque-speed plane without any power loss and energy is conserved during the generation period. Using a two switch non- inverting buck-boost converter, operating either in buck mode or boost mode by controlling only one switch at a time, all the quadrants of operation is achieved. MATLAB/SIMULINK was used for simulation and experimental setup was achieved successfully with energy storage.

Keywords: BLDC motor, non inverting converter, flywheel, switching mode regulators

1. INTRODUCTION

BLDC motors have rotor with permanent magnet and stator with windings. As the name implies, brushes are absent in it and windings are connected to the control circuit. A voltage source inverter is used to feed the brushless DC motor. To control a BLDC motor, it is essential to measure the speed and position of the rotor, because phases of inverter which are active at any time must be commutated depending on the position of the rotor. Hall Effect sensors are embedded into the stator to sense the rotor position. Electronic commutation is used in it. To sense the rotor position sensorless methods are also used. Brushless DC motors have the advantages of high efficiency, high speed of operation, no sparking, less maintenance, long life, operation from a low volt DC supply, is widely used in the areas of aviation, instrumentation, domestic appliances, traction etc.

When high efficiency, lower weight or smaller size is required in applications, linear regulators can be replaced by switch mode regulators. A switch mode regulator converts an unregulated dc voltage to regulated dc output voltage.DC converters such as buck, boost, buck boost, zeta, SEPIC (Single Ended Primary Inductor Converter), and cuk converters are generally used.CUK(boost converter followed by a buck converter) and buck boost converters are inverting converters(output voltage is negative with respect to input voltage).Three popular non inverting converters used in automotive start-stop systems and industrial personal computers are SEPIC, zeta and two switch buck boost converters. All this three converters, experience high current stress and high conduction loss when operated in buck boost mode. This can be eliminated by utilizing a proposal, two switch non inverting buck boost converter (buck converter followed by a boost converter)which uses only one switch at a time for either buck or boost operation.

In this paper, four quadrant operation of BLDC motor is explained using a two switch non inverting buck boost converter. MATLAB/SIMULINK is used for simulation and AT89S8253 controller is used for the experimental setup to control the motor in all quadrants of operation.

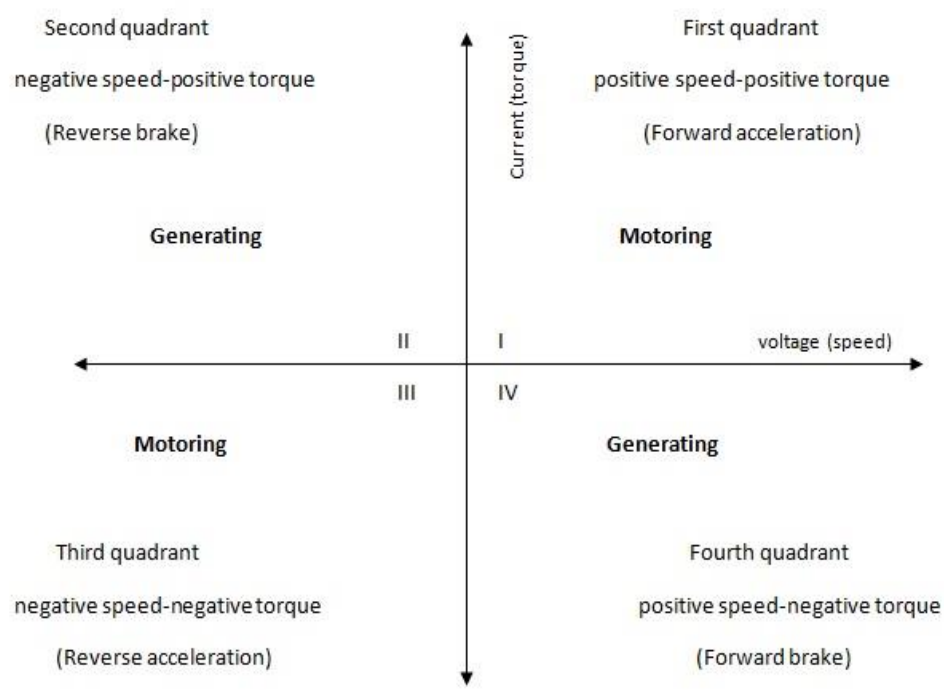

Figure 1 Quadrants of operation

2. FOUR QUADRANT OPERATION

There are four possible modes of operation or quadrants using a BLDC motor as shown in figure 1. When a BLDC motor is operating in first quadrant, supplied voltage is greater than back emf developed and motor is allowed to rotate in clockwise direction. This is said to be in forward accelerating mode. At second quadrant, the value of supplied voltage will be lesser than

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the back emf developed. Motor is said to be in reverse braking mode. Third and fourth quadrants of operation are similar to first and second quadrants respectively, with only change in direction of rotation, that is, motor rotates in counter clockwise direction. The BLDC motor is made to rotate in clockwise direction initially. When the stop command or speed reversal command is received by the controller, the motor goes to the clockwise generation mode and rotor comes to an idle position. Continuous energisation of the main phase is essential instead of waiting for the exact idle position. Therefore it is important to know the instant when the rotor of the motor is positioned for reversing.

Hall Effect signals from the Hall Effect sensors give the position of the rotor at every instant. From the hall sensor output, it is decided whether the motor has reversed its direction. Sequences of energisation of phase windings are changed to change the direction of rotation.

3. PROPOSED SCHEME

Figure 2 shows the proposed scheme for the control of BLDC motor drive in four quadrants. The drive consists of a DC power source, non inverting converter, and MOSFET based voltage source inverter, relay circuit and control unit.

3.1. Non inverting converter

Figure 3 shows the circuit diagram for a two switch non inverting buck boost converter. The two switch buck boost converter is used as the non inverting converter. It is a cascaded combination of a buck converter followed by a boost converter. Two active switches are used for controlling the modes of operation. Design is same as that of buck boost converter. Due to this topology, this converter can operate in buck, boost, buck-boost mode of operations. Sensorless operation of BLDC motor is possible using this converter.

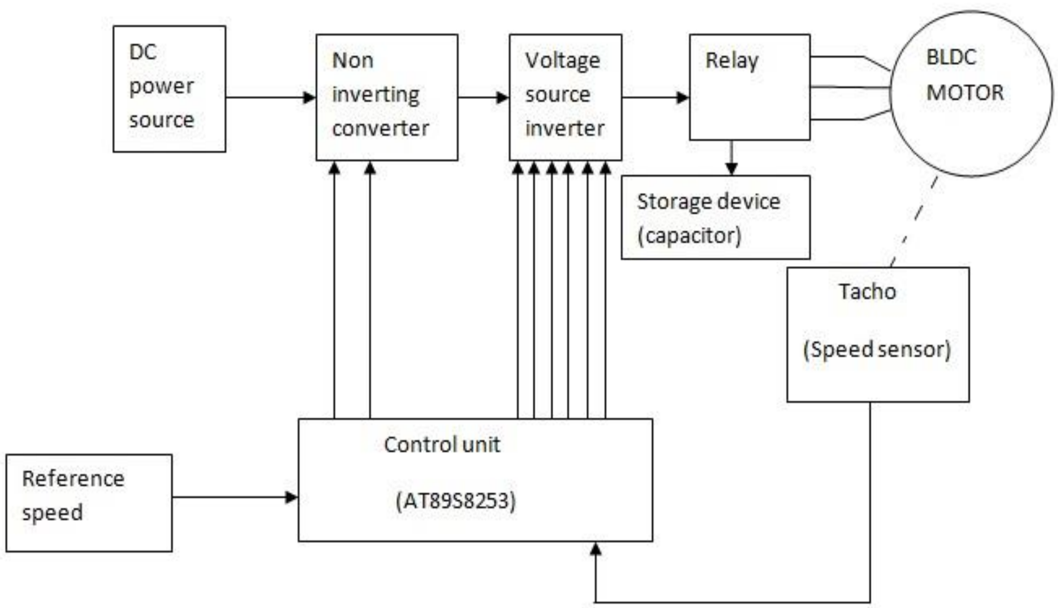

Figure2 Proposed Scheme

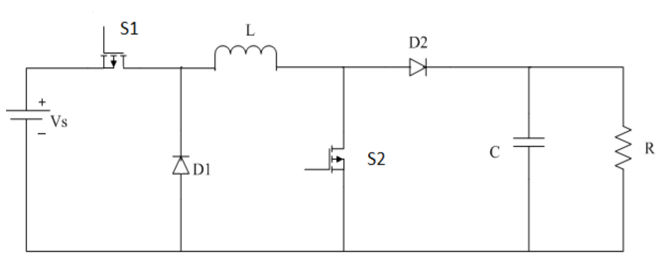

Figure 3 Two switch non inverting buck boost converter

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In buck mode of operation, switch S2 is always off and diode D2 is always on. Switch S1 and diode D1 forms the buck switch leg while in boost mode of operation, switch S1 is always on and diode D1 is always off. Boost switch is formed by switch S2 and diode D2.In buck boost mode of operation, both switches S1 and S2 are controlled. Since two switches are using, conduction losses as well as switching losses are more. Hence buck boost mode of operation is not used.

Table1 Switching patterns

SL.NO.	S1	S2	D1	D2	COMPLEXITY	OPERATION
1.	PWM	Off	On/off	On	Simple	Buck
2.	On	PWM	Off	On/off	Simple	Boost
3.	PWM	PWM	On/off	On/off	Moderate	Buck Boost

Table 1 shows the mode of operation and level of complexity for each mode of operation. In the table, S1 stands for switch 1, S2 stands for switch 2, D1 stands for diode 1 and D2 stands for diode 2.

3.2. Voltage source inverter

MOSFET based voltage source inverter is used. It supplies input voltage to the BLDC motor. Six switches are used which are commutated based on the Hall Effect sensor outputs.

3.3. Relay

During first and third quadrant relay contacts are open. At the time of braking, contacts of relay are energized and the kinetic energy which is wasted as heat energy is stored in the storage device (capacitor).

3.4. Control unit

The controller used in the proposed scheme is AT89S8253 controller. This is a 40 pin chip that contains 4 input/output ports, 256 bit RAM and 8Kbyte of PROM.A high logic level will reset the microcontroller pins. In this controller program can be reloaded/erased 1000 times even after embedded into the chip.

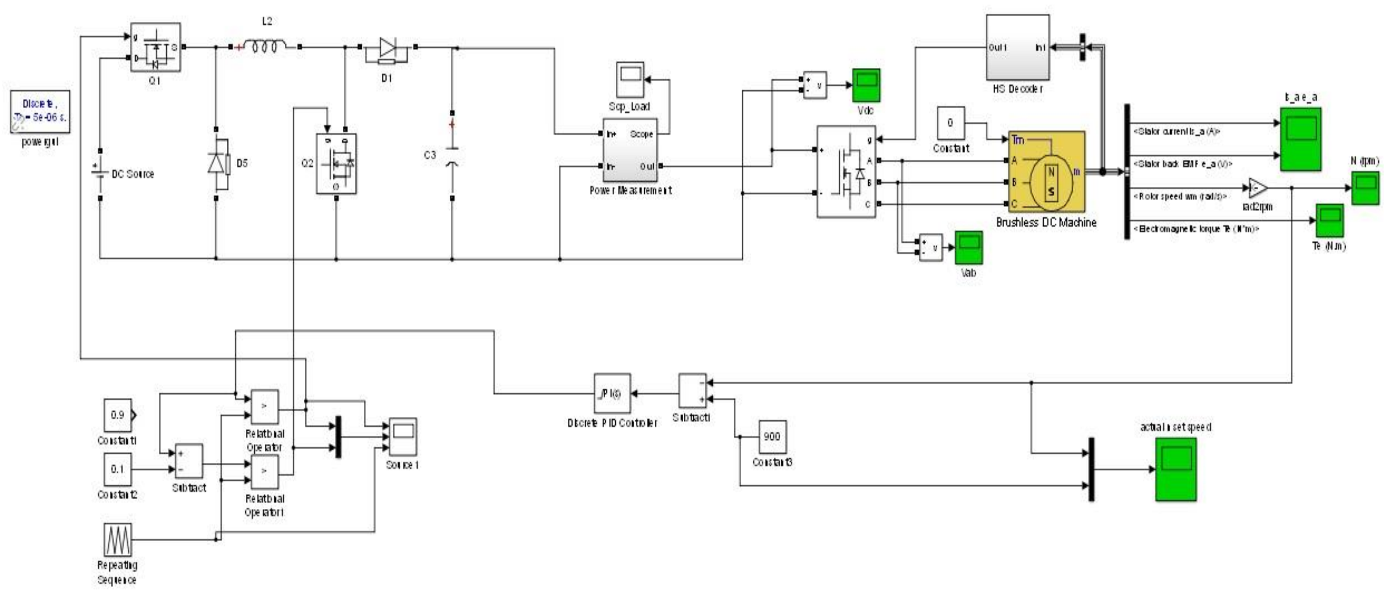

Figure 4 Simualtion circuit for non inverting converter fed BLDC motor with four quadrant operation

3.5. BLDC motor drive

BLDC motor is fed by a voltage source inverter (VSI).Switches of VSI are controlled by the Hall Effect sensor outputs from the motor. Thus a continuous operation of the motor is ensured. Actual speed of the motor is sensed by a tacho circuit and is compared with the reference speed. The error generated is given to the PI controller. The values of proportional gain (Kp) and integral gain (Ki) are determined by trial and error method.PWM method is used to generate switching signals for the two switches of non inverting converter

4. SIMULATION

The figure 4 shows the circuit used for simulation. The input given was 24V.

4.1. First quadrant

In this quadrant, motor will run in clockwise direction. Figure 5 shows the dc output voltage from non inverting converter. At first, boost operation is done and voltage is incremented to about 78V and buck operation is carried out after dat.

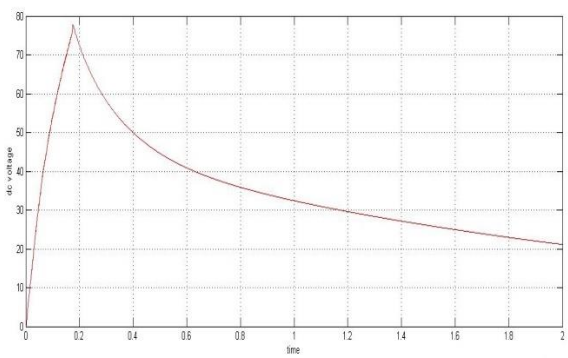

Figure 5 DC output voltage from non inverting

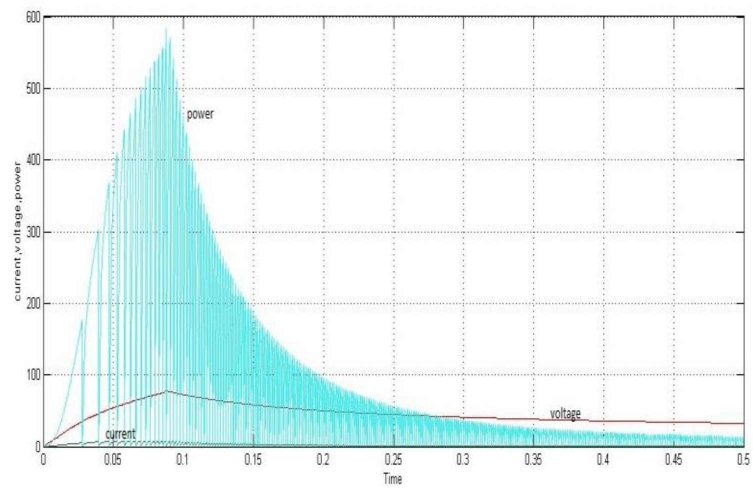

Figure 6 Current, voltage, power waveforms converter

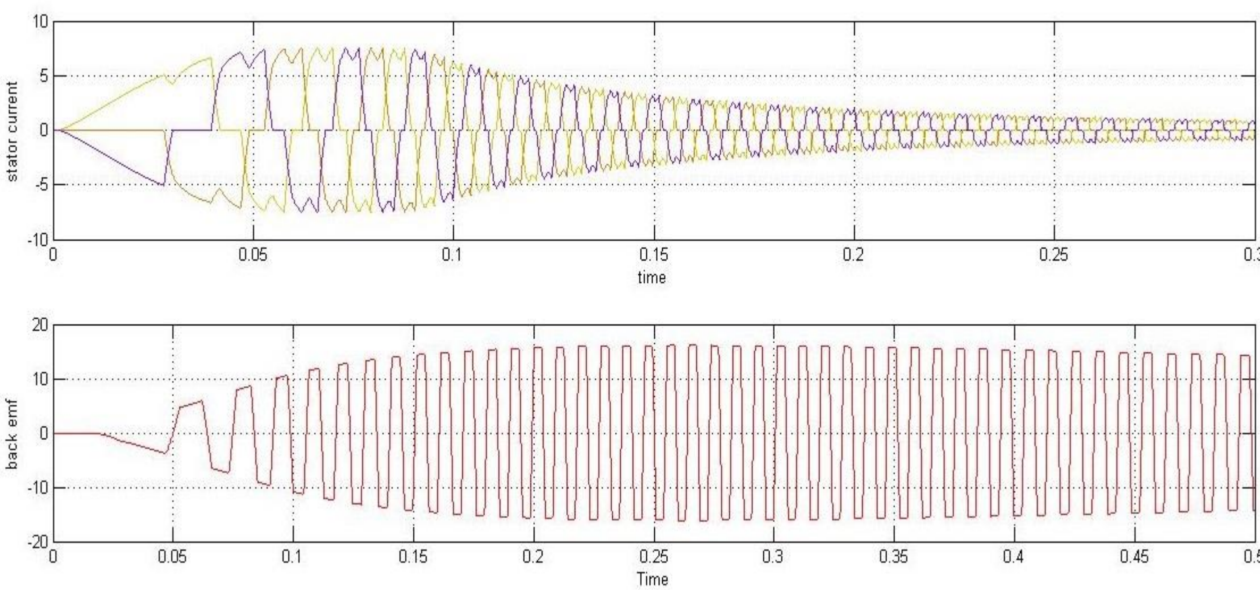

Figure 7 Stator current and back emf waveforms of BLDC motor

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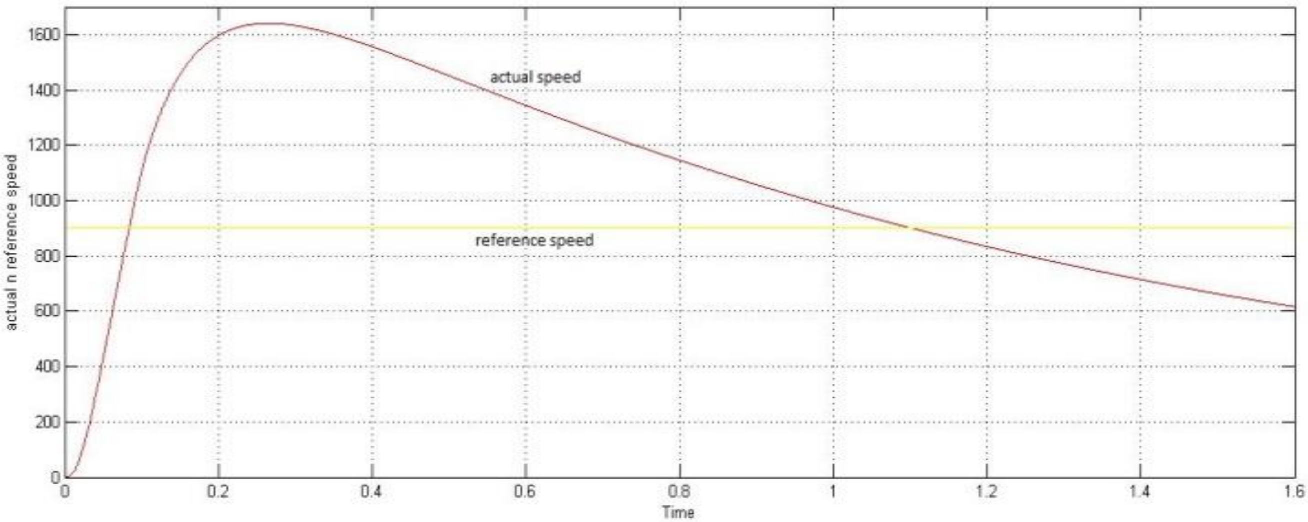


Figure 8 Actual and reference speed of the motor

Figure 6 shows the current, voltage and power waveforms of the converter. It can be seen that both the current and voltage are positive. So resulting power is also positive in this quadrant of operation. Figure 7.shows the stator current in three phases and back emf waveforms of BLDC motor. It can be observed that, the three phase current transients for a short period and settles to about 1V during steady state. And back emf of BLDC motor which is trapezoidal in shape also transients at the beginning. Reference speed and actual speed of the motor is shown in the figure 8.

4.2. Second quadrant

Figure 9 shows the voltage, current, and power waveforms during second quadrant. Motor acts like a generator at this quadrant of operation. It can be viewed that voltage is positive and current is negative. So power generated at second quadrant is negative, that is, from load to source.

4.3. Third quadrant

Motor runs in counter clockwise direction. This is achieved by changing the phase sequence from ABC to ACB. Figure 10 shows the dc output voltage from non inverting converter.

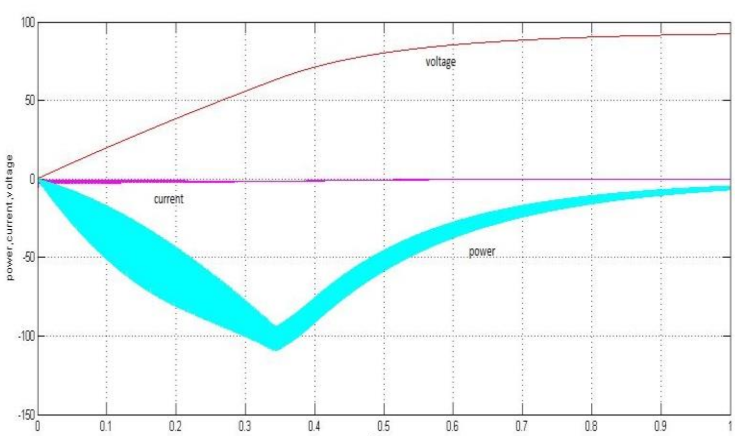


Figure 9 Voltage, current and power waveforms

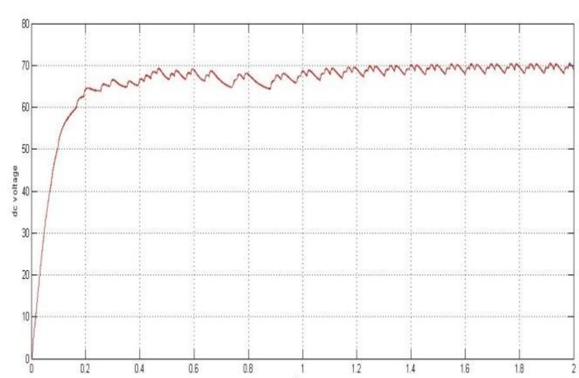


Figure 10 DC voltage from non inverting converter

It is clear from the figure that, voltage gets boosted to about 68V at 0.2 sec and maintains this voltage after dat.

4.4. Fourth quadrant

During fourth quadrant, motor act as a generator and rotates in counter clockwise direction. Figure 11 shows the output voltage across the capacitor which is observed to be higher than obtained during motoring operation.

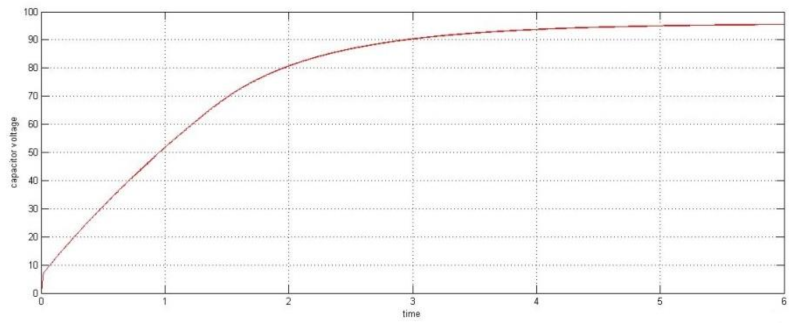


Figure 11 Voltage across the capacitor

5. HARDWARE IMPLEMENTATION

Hardware implementation of four quadrant operation of BLDC motor drive using a non inverting buck boost converter is shown in figure 12. It consists of a battery for input supply to non inverting buck boost converter, MOSFET drive circuit, non inverting converter circuit and a BLDC motor with flywheel attached to it. Energy which is wasted as heat in second and fourth quadrant is stored using a capacitor and is given to an LED (50mA). Flywheel energy storage system is used to store rotational energy. The amount of energy stored in a flywheel is proportional to the square of its rotational speed. Flywheels are used in many applications like, to maintain constant angular velocity in the crankshaft of a reciprocating engine, to control the orientation of mechanical systems, and in riveting machines to store the energy from the motor and release it during riveting operations.

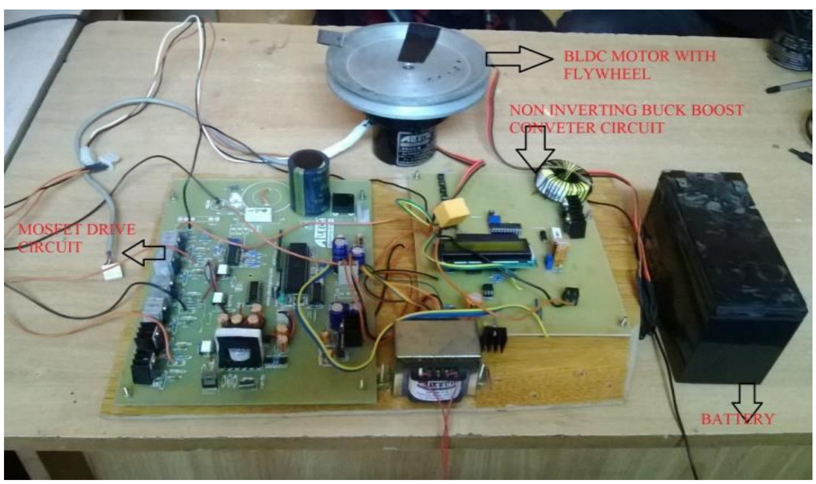
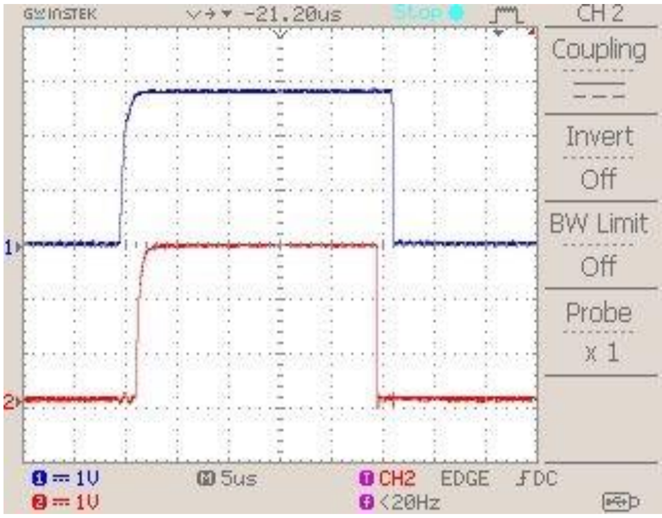


Figure 12 Hardware implementation of four quadrant operation of BLDC motor drive with four quadrant operation using a non inverting converter

Figure 13 shows the gate pulses for the switches of non inverting buck boost converter. Blue color waveform is for buck switch and red color is for boost switch. Gate pulses given to the low side switches for voltage source inverter is given in figure 14. Phase A is given by red color waveform and phase B by blue color. Figure 15 shows the Hall Effect sensor output waveforms of phase A (blue color) and phase B (red color). Line to line voltage waveform of phase A and phase B is given in figure 16.



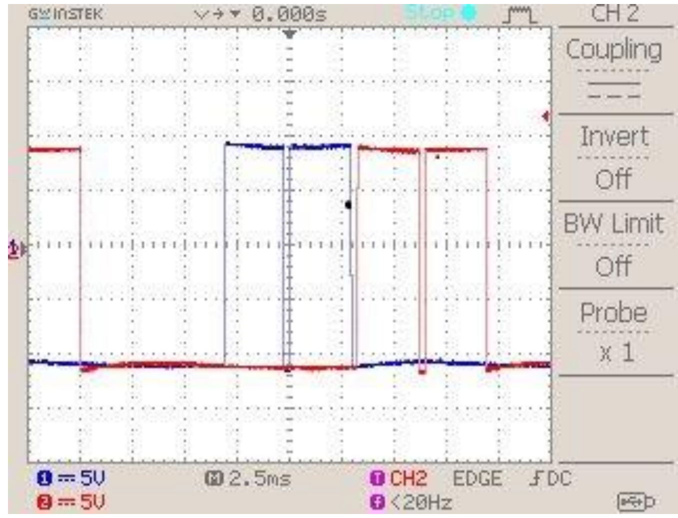
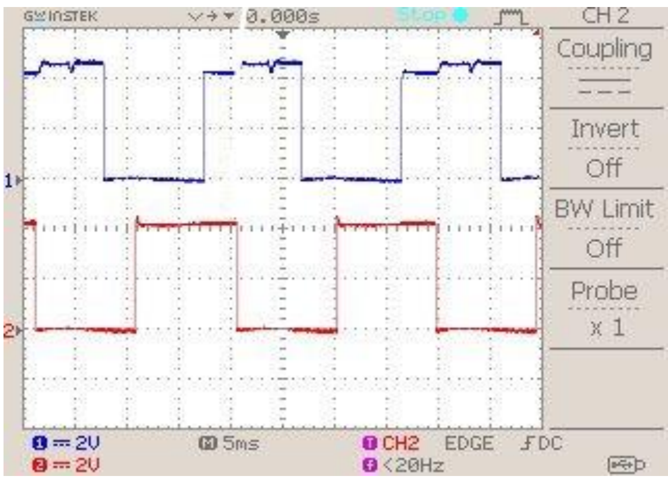


Figure 13 Gate pulses for non inverting converter

Figure 14 Gate pulses for voltage source inverter



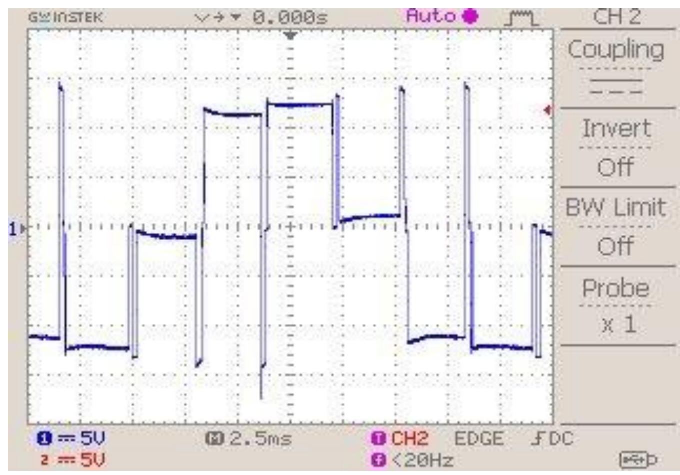


Figure 15 Hall effect sensor outputs

Figure 16 Line to line voltage of BLDC motor.

6. CONCLUSIONS

Four quadrant operation of a BLDC motor drive using a non inverting buck boost converter was simulated in MATLAB/SIMULINK and experimental setup showing each quadrants of operation was done successfully. It can be concluded that by using a non inverting buck boost converter either as buck or boost converter, switching losses as well as conduction losses can be reduced as only one switch is being used. And also back emf developed in a BLDC motor is proportional to the speed of the motor and the field strength developed and this back emf act as a resistance and resists the current flow. As speed/field of the motor is increased, back emf also increases, and less current is delivered to the motor. AT89S8253 controller works well for the four quadrant operation of BLDC motor. Flywheel stores the rotational energy and during second and fourth quadrants of operation, this energy is stored to a capacitor and a LED is glowed using this stored energy.

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