

Speed control of BLDC Motor with Four Switch Three Phase Inverter using Digital Signal Controller

¹M .S. Aspalli, ²Farhat Mubeen Munshi, ³Savitri.L.Medegar

Dept of EEE, PDA College of Engineering Gulbarga, Karnataka, India.

maspalli@yahoo.co.in, m.farhat03@gmail.com, savitrim4@gmail.com

Abstract- The main purpose of this paper is to develop a low cost drive system for BLDC motor with reduced switches and minimum hardware. Due to the characteristics of the Brushless DC motor such as high efficiency, high power factor, high torque, low maintenance and ease of control, it is widely used in variable speed drives and industrial applications. The flexibility of the drive system can be increased by using dsPIC Digital Signal Controller which combines the features of Microcontroller and Digital Signal Processor on a single chip. The BLDC motor is excited by a Four Switch Three Phase Inverter with minimum number of switches which in turn reduce the associated amount of switching losses. It results in low electromagnetic interference, less complexity of control and reduced interference circuits. A simulation is carried out using MATLAB/SIMULINK and in the experimental work, a prototype model of hardware is developed.

Keywords: BLDC Motor, Four Switch Three Phase Inverter, dsPIC30F4011 Digital Signal Controller

I. INTRODUCTION

BLDC motors are a type of AC motors which are widely used in various applications which include fan, pump or actuator applications. These are also employed in household appliances such as refrigerators, washing machines, computer peripherals etc. These motors are replacing Brushed DC motors and induction motors. BLDC motor is commutated by an electronic commutator using power semiconductor switches. Due to the absence of brushes and commutators, BLDC motors require less maintenance and operate much more quietly than DC motors. This led their use in modern motor control applications. The main drawbacks of induction motors are high inertia which slows down the dynamic response and high rotor losses. In contrast BLDC motors have low inertia, allowing for faster dynamic response to reference commands. Due to the permanent magnet rotor construction, they are more efficient which results in lower rotor losses. Power converters are employed with solid state devices which are commonly used as on/off switches. These switches are not ideal and have switching losses and conduction losses which in turn reduce the efficiency of the drive. These losses can be minimized by reducing the number of switches in converters or by using high performance processors. BLDC motors are excited by six switches which produce six commutation sequences. However a low cost drive system is an important consideration in the design and development of modern motor control drives. Many researchers developed four switch BLDC motor drives. B.K lee *et al* [2] introduced direct current controlled PWM using high speed and high cost DSP.

Using current regulation six commutation modes are obtained. C.T. Lin *et al* [3] developed sensorless scheme for BLDC motor drive using FPGA controller and asymmetric PWM scheme. Sensorless controllers impose problems during motor startup as no back EMF is present when the motor is at stand still and sensorless schemes cannot be used for exact rotor position and low speed applications. On the other hand FPGA controllers are complex and require good knowledge of programming and DSP processors are high cost which makes overall system costly. Because of these reasons, this paper presented a cost effective BLDC motor drive with four switch three phase inverter and dsPIC digital signal controller which is a low cost embedded solution with microcontroller and DSP features on a single chip. Rotor position is determined by three Hall Effect sensors which are embedded in the stationary part of the motor. This paper deals with the design and development of four switch inverter controlled BLDC motor drive.

II. FOUR SWITCH THREE PHASE INVERTER

The circuit diagram of the FSTPI fed BLDC motor is shown in Fig 1. The power inverter has 4 MOSFET switches, Q₁, Q₂, Q₃ and Q₄ and dc link capacitors. The two phases 'a' and 'b' are connected to the two legs of the inverter and the third phase 'c' of the motor is connected to the centre point of dc link capacitors, C₁ and C₂. The capacitances C₁ and C₂ are equal and the voltages across the two capacitors are equal. V_{dc} is the total link voltage of dc link ($V_{dc} = V_{C_1} + V_{C_2}$).

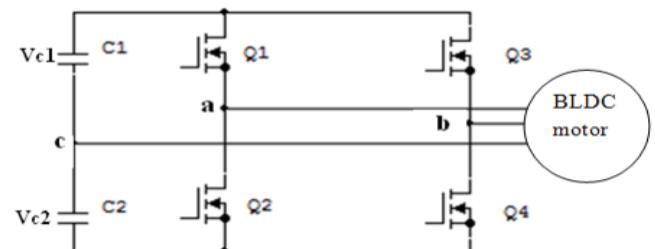


Fig 1: Four switch three phase inverter

A BLDC motor operates such that at a time only two phases are active and conducting current and the third phase is inactive. The Back Electromotive Force should have trapezoidal shape with 120° conduction and 60° non conducting regions and the quasi square wave currents are needed to generate constant output torque so, it is required to have accurate rotor position. This can be obtained by three hall sensor signals. However, in the four-switch inverter, there are

two legs (with two switches in each leg) which are connected to two motor windings and third phase of the motor is always connected to the midpoint of the dc-link capacitors, so that a small amount of current is always flowing. One high side and one low side power switches must be turned on but not simultaneously in the same leg. The four PWM signals are required to turn on the four switches in the inverter. The PWM waveforms are generated by using dsPIC digital controller. The voltage PWM scheme for FSTPI must have six commutations. These are (S,0), (1,0), (1,S), (S,1), (0,1) and (0,S). The symbols in parenthesis are commutation signals of two controllable phases (phase A and B). “S” means the high side and low side power devices in the same leg are OPEN. “1” means the high side power device in this phase is switching in PWM and “0” means the low side device in this phase is switching in PWM.

III. BLOCK DIAGRAM OF PROPOSED SYSTEM

The proposed system block diagram is shown in fig 2. It consists of diode bridge rectifier, four switch three phase inverter, digital signal controller and three phase BLDC motor. The power input is in the form of single phase 230Volts AC voltage which is converted into DC voltage by using diode bridge rectifier. The Four switch three phase inverter converts DC voltage into variable AC voltage.

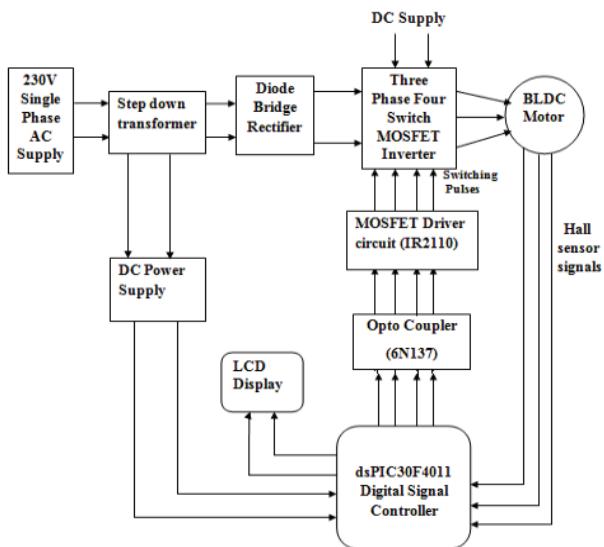


Fig 2: Block diagram of complete system

A dsPIC30F4011 Digital Signal Controller acts as controller to control the whole of the system. It reads the position feedback depending upon three hall sensor signals from motor and finally generates four gate firing pulses. With three sensors we can obtain six commutation sequences. At the end of each cycle, dsPIC generates four PWM signals and sends to opto couplers that isolate the control circuit and power circuit. These outputs are given to the MOSFET driver IC's. The switch drivers isolate and amplify the dsPIC commands and send to MOSFET inverter. Difference between the actual and reference speeds is given as input to the controller. Based on

this data, controller controls the duty cycle of the PWM pulses which corresponds to the voltage amplitude required to maintain the desired speed. The inverter generates trapezoidal back EMF waveforms and quasi square wave currents to commutate the motor. Torque is produced because of the interaction of the magnetic field generated by the stator coils and the permanent magnets. Table I shows switching sequences for Four switch Inverter. Table II shows the relationship between hall sensor signals and phase voltages.

Table I. Switching Sequences for Four Switch Converter

Hall sensor (h1,h2,h3)	Modes	Active phases	Silent Phases	Switching Devices
010	Mode I	C & B	Phase A	S ₄
110	Mode II	A & B	Phase C	S ₁ and S ₄
100	Mode III	A & C	Phase B	S ₁
101	Mode IV	B & C	Phase A	S ₃
001	Mode V	B & A	Phase C	S ₂ and S ₃
011	Mode VI	C & A	Phase B	S ₂

Table II. Hall sensor signals and phase voltages

Hall sensor A	Hall sensor B	Hall sensor C	Phase A	Phase B	Phase C
1	0	0	+V _{DC}	-V _{DC}	NC
1	1	0	+V _{DC}	NC	-V _{DC}
0	1	0	NC	+V _{DC}	-V _{DC}
0	1	1	-V _{DC}	+V _{DC}	NC
0	0	1	-V _{DC}	NC	+V _{DC}
1	0	1	NC	-V _{DC}	+V _{DC}

IV. SIMULATION & ITS RESULTS

The block diagram of complete simulation system is shown in fig 3. Digital computer simulation model of FSTPI fed BLDC motor drive has been developed by using MATLAB/SIMULINK software. The input to the trapezoidal permanent magnet brushless DC motor module is three phase terminal voltage. The outputs from the motor module are the three phase currents, motor speed and rotor position information. The trapezoidal back Electromotive force is generated using rotor position whose amplitude is proportional to the speed. The decoder block generates four PWM pulses from the hall sensor signals information. These pulses are applied to the gates of four switch three phase MOSFET inverter. By controlling the PWM duty cycle, speed of the motor can be controlled by PI controller depending upon the speed error. The three back EMFs R, Y, B generated are shown in fig 4. The amplitude of voltage is set at 50V. The three hall sensor signals are shown in fig 5. The speed waveform is shown in fig 6 under reference speed of 1000RPM. Rectangular phase current waveforms of phases R, Y and B are shown in fig 7.

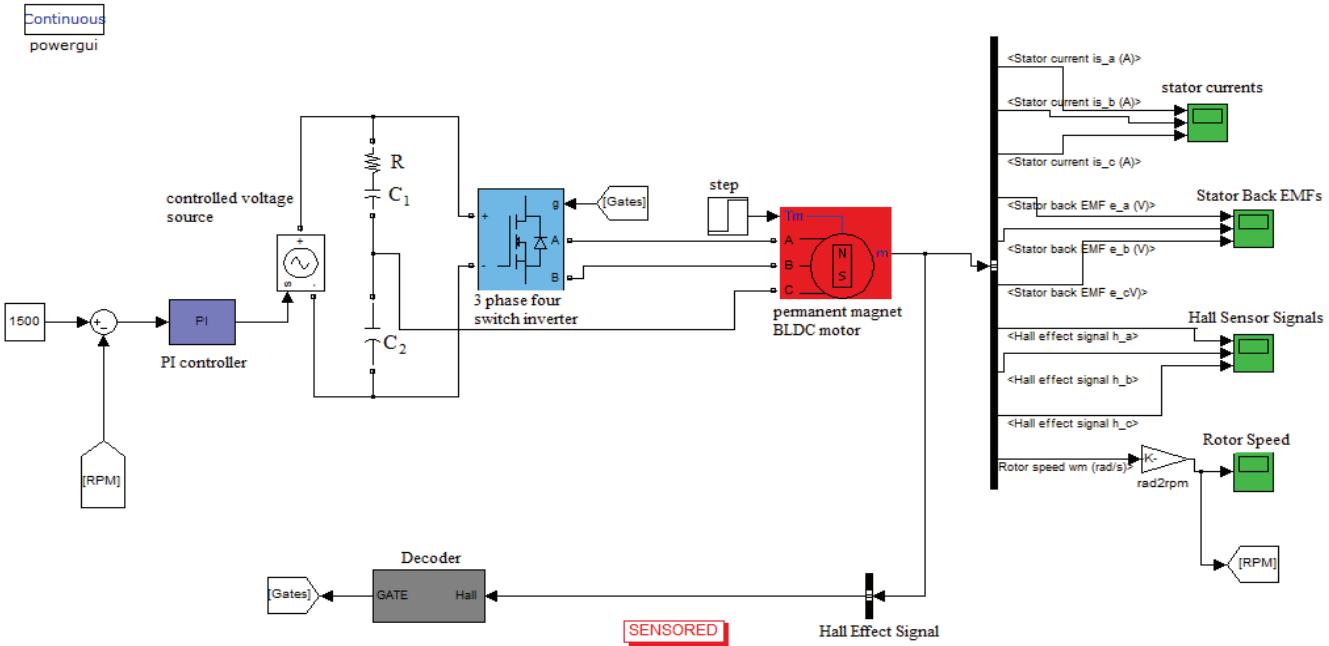


Fig 3: Block diagram of complete simulation system

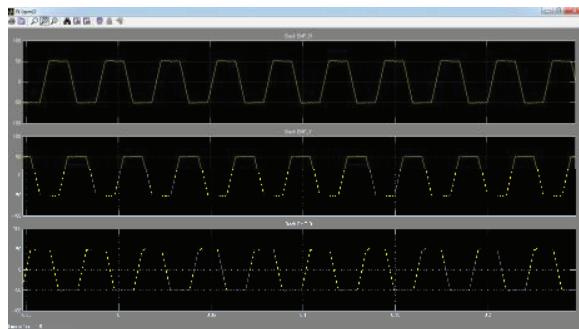


Fig 4: Back EMF waveforms of three phases_ R, Y, B



Fig 6: Speed waveform

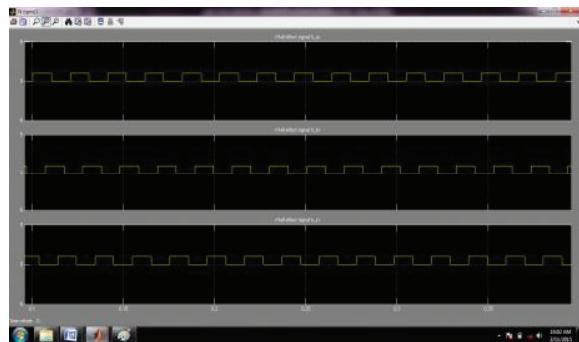


Fig 5: Hall Sensor Signals

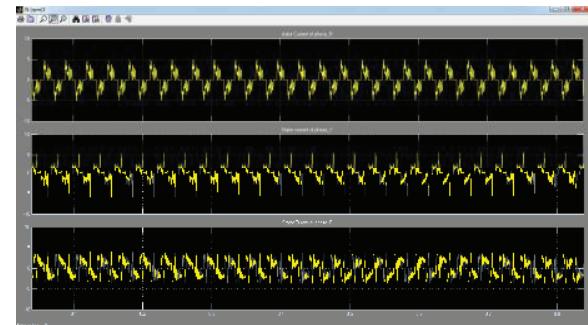


Fig 7: Rectangular phase current waveforms of phases R, Y and B

V. HARDWARE & ITS RESULTS

A prototype model of hardware is designed in order to implement four switch three phase inverter fed BLDC motor drive. Table III shows hardware required for the proposed design. BLDC motor is controlled in open loop and closed loop.

TABLE III: Details of components used in this experiment

Components	Ratings
BLDC Motor	24V, 60W, 3000rpm, 8 poles
Controller	dsPIC30F4011 Digital Signal Controller
MOSFET(Nchannel)	IRF840-500V, 8A
MOSFET driver	IR2110
Rectifier diodes	IN4007,1A
Opto isolators	6N137

TABLE IV: Experimental results of open loop speed control

DUTY CYCLE	ACTUAL SPEED (RPM)
25	551
30	671
40	957
50	1200
60	1458
65	1604
70	1732
75	1836
80	1976
82	2050

In open loop speed control of BLDC motor, the duty cycle of PWM pulses is varied. The table IV shows the experimental results of open loop speed control. Fig 8 shows the graph of Duty cycle versus actual speed in open loop BLDC motor speed control. In closed loop speed control, the set speed is changed. Table V shows the experimental results of closed loop control of BLDC motor. Fig 9 shows the graph of Set speed Versus Actual speed. From the graph it is observed that the current speed (actual speed) is closely equivalent to set speed and remains constant after set speed of 2280RPM. A Digital Storage Oscilloscope has been used to store the waveforms of Back EMFs, Stator currents, Hall sensor signals and PWM gate pulses. Fig 10 to fig 12 show Hall sensor signals. Fig 13 to fig 16 show four gate pulses to the four MOSFETs of inverter and fig 17 to 19 show stator currents and back EMF of R phase is shown in fig 20. The experimental setup is shown in fig 21.

TABLE V: Experimental results of closed loop speed control

SET SPEED (RPM)	ACTUAL SPEED (RPM)
900	902
1075	1076
1200	1198
1415	1413
1890	1893
1980	1977
2280	2279
2462	2363
2576	2363
2730	2363
2875	2363
2900	2363

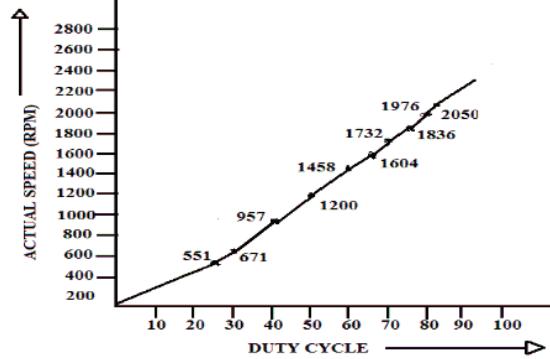


Fig 8: Graph of open loop BLDC Motor control showing duty cycle Vs actual Speed

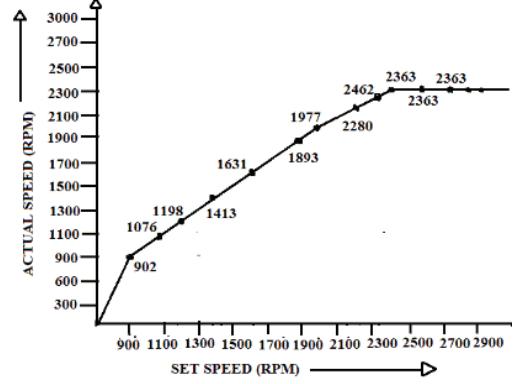
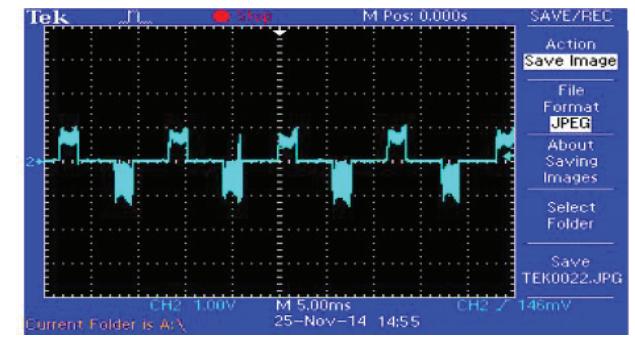
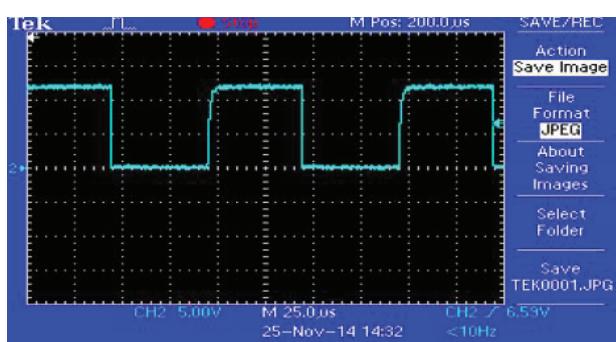
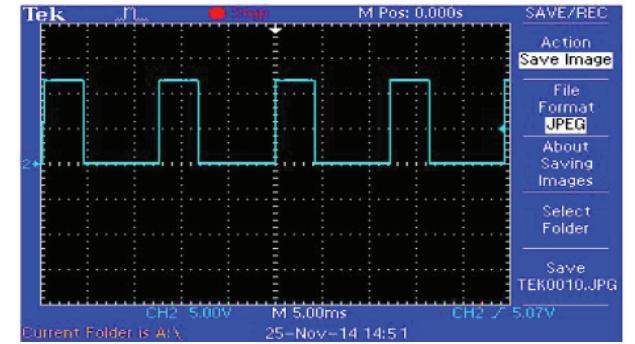
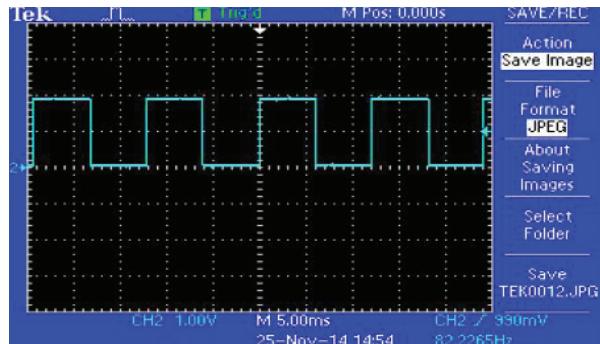
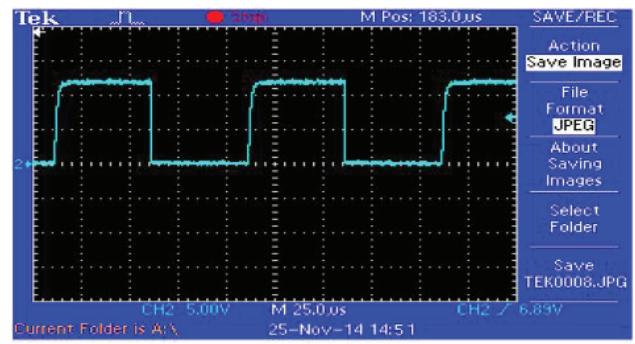
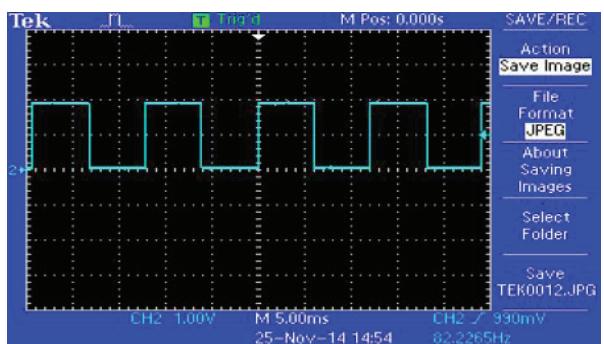
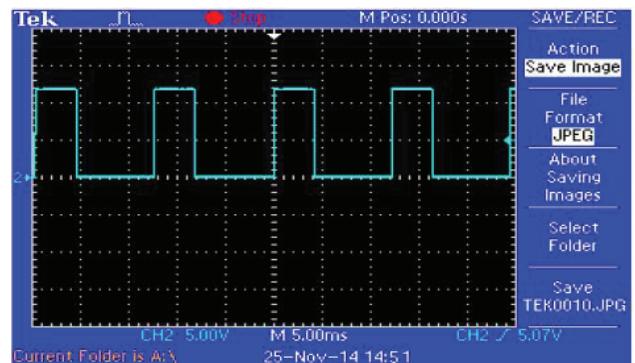
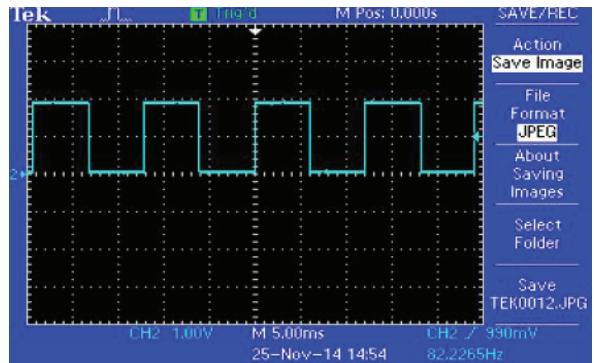


Fig 9: Graph of closed loop BLDC Motor control showing duty cycle Vs actual Speed



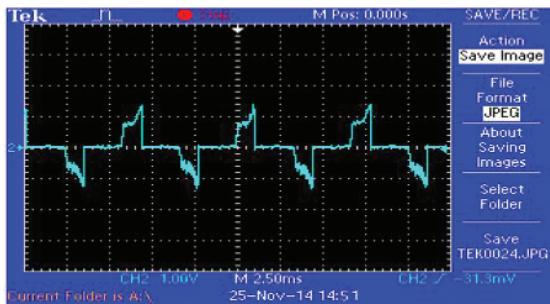


Fig 18: Current of Phase Y

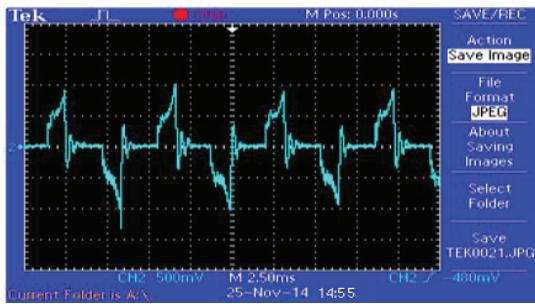


Fig 19: Current of Phase B

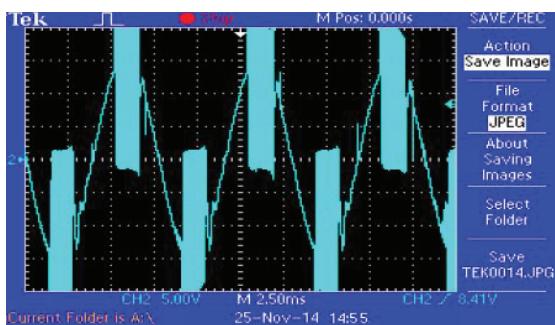


Fig 20: Back EMF of Phase R



Fig 21: Complete photograph of hardware set up

VI. CONCLUSION

Four Switch Three Phase Inverter fed BLDC motor speed controlled by high speed high performance dsPIC Controller is designed and implemented. The performance of the drive is analyzed and tested. In the first step, a software simulation is carried out using MATLAB/SIMULINK and in the second step, a prototype model of hardware has been built and tested successfully. It is observed that the hardware results very closely resemble the simulation results. Therefore we can say that cost effective design can be achieved by employing Four Switch Three Phase Inverter which has lesser switching losses, lower Electromagnetic Interference, with reduced circuit complexity which in turn minimizes associated hardware circuits. Further a 16 bit dsPIC30F4011 digital signal controller is an ideal low cost solution to control BLDC motor with features of Microcontroller and Digital Signal Processor integrated on a single chip.

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