Hardware implementation of 120^0 & 180^0 mode of Inverter operation of PMBLDC motor for vehicular application

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Abstract : In today's world the development of electric vehicle is now growing rapidly. The prominent feature like reliable and easy to drive in motor control causes Brushless Direct Current (BLDC) motor becomes a potential candidate among the all motors. The BLDC motor which is driven by inverter requires sequential phase voltage. Various topologies for the inverter have been listed in various literatures; however the efficient use of power electronics switches and smooth phase voltage needs to be focused as far as the vehicular application concern. In this paper the inverter configuration for the BLDC motor which is driven for the vehicular application have been developed in MATLAB-Simulink as well hardware environment with the help of 8 bit microcontroller Ardiuno board. The results of hardware implementation of both the modes of inverter operation are satisfactory.

IndexTerms - PMBLDC, BLDC, Hall sensor, PWM, 120^0, 180^0.
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I. INTRODUCTION

The ever-increasing environmental concerns as well as strategic and economic considerations have prompted the search for more efficient road vehicles [1]. Conventional dc motors have many attractive properties such as high efficiency and linear torque-speed characteristics. The control of dc motors also simple and does not require complex hardware. However the main drawback of the dc motors are 1.The need of periodic maintenance due to commutator and brushes. The brushes of the mechanical commutator eventually wear out and need to be replaced, 2. Spark. So, the conventional DC motors can be easily replaced by Brushless DC motor to overcome these disadvantages[2]. Even though the name Brushless DC motor it's a kind of permanganate magnet synchronous motor. The Brushes and commentators of DC motor are replaced by electronic switches i.e. MOSFETs, IGBTs to drive the voltage fed inverters. The basic advantages of BLDC motor are listed below. 1. High torque-volume ratio 2. High efficiency, 3. Higher speed range 4. High dynamic response. Due to above advantages the PM motors are best suited for the vehicular applications[3]. In this paper the Software as well as hardware implementation of the inverters which are faded to PMBLDC motors are developed and gives the satisfactory results in 120^0 and 180^0 modes of operation. This paper is organized as follows. Section II gives the basic in formations about the PMBLDC motors basics and its drive. In section III the brief description have been given for the inverter configuration for 120^0 and 180^0 mode of operation. The simulink model has been developed in section IV for the inverter operation in MATLAB Simulink environment. The Hardware implementation of the said configuration of inverter has been developed in section V which also discusses the results of the same.

II. PMBLDC MOTOR'S BASICS

The operation of BLDC motor is based on fundamental principle of magnetism [4], which tells us that similar poles repel each other, while opposite poles attract. Consider the configuration in figure 1.
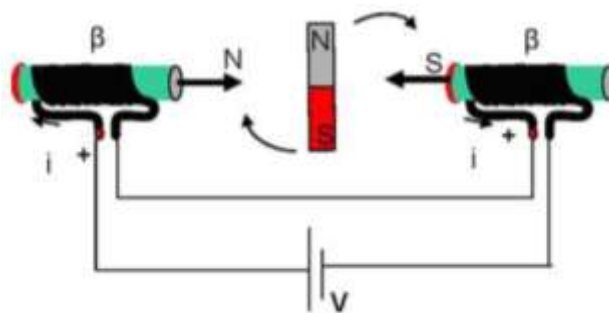

Figure 1 Basic principle of PMBLDC motor

when the current is passing through two coils, it generates a magnetic field with a polarity that creates torque on the central magnet here in our case rotor. When a current is passed in the direction shown, the central magnet rotates clockwise. When the rotor reaches a certain position, the current is changed so that the torque continues further in the same direction. When necessary, the current direction is changed again to continue generation of the torque. However, instead of two coils, actual BLDC motors typically use six coils positioned 60 degrees apart.

Torque production in PMBLDC
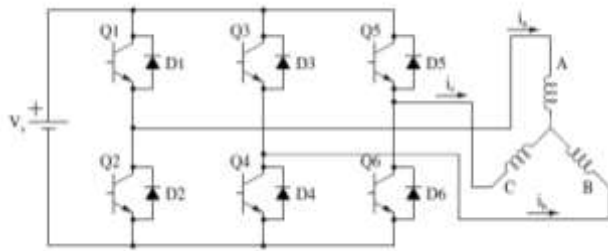

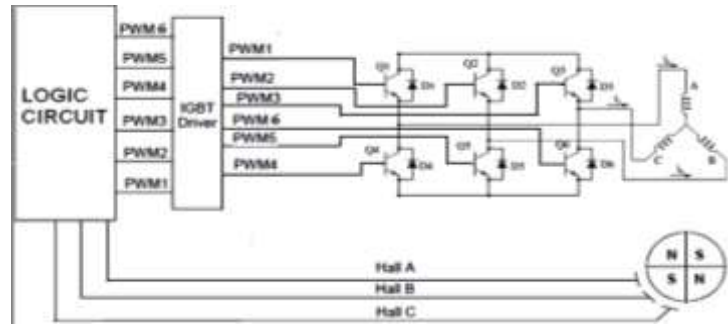Figure 2 Inverter configuration of PMBLDC   Figure 3 PMBLDC motor drive

The total amount of torque created on the rotor is calculated using the Lorentz force formula in scalar form [5]:

$$Torque\ T = r * F = r * (i * L * \beta * sin\ \theta) \qquad (1)$$

Where,

T= Electromagnetic torque in N.m.

r = moment arm of the rotor

i = current passing through stator coils

L = length of coil

β = magnetic field of the rotor

θ = angle between the current direction and the magnetic field of the rotor

PMBLDC drive model for vehicular application

PMBLDC motor drive model has been given as in Fig. 2 & Fig. 3 which presents the motor with the IGBT driver circuit for the operation of PMBLDC motor. The torque ripple owing to phase current commutation can be reduced by providing a varying input voltage at the time of commutation [6].

Table 1 Hall sensor and switch logic

Switching Interval	Position Sensors			Switches Closed	
	H1	H2	H3		
0° − 60°	1	0	1	Q1	Q4
60° − 120°	1	0	0	Q1	Q6
120° − 180°	1	1	0	Q3	Q6
180° − 240°	0	1	0	Q3	Q2
240° − 300°	0	1	1	Q5	Q2
300° − 360°	0	0	1	Q5	Q2

Depending upon the output of the hall sensors the IGBT/ switches must be closed for the generation of the torque. From the various literature the switches must be turned on (close) as per the hall sensor position mentioned in Table 1.

III. INVERTER OPERATION FOR PMBLDC

120^0 mode of conduction

The brushless de motor is often supplied from either a 180^0 or 120^0 voltage-source inverter. The analysis of the brushless dc motor with a 120^0 inverter is more difficult since the current in the phase to be switched off may take on various waveforms. In particular, during the 60' switching interval when the transistors associated with a phase current are un gated, this current may be negative (N), positive (P), or zero (Z) depending upon the rotor speed, dc source voltage and the advance in firing angle. The status of the current being switched off is used to classify the modes of operation possible during motor operation of a brushless dc motor with a 120^0 inverter supply. It is shown that six modes of operation are possible for the system considered [7].

180^0 mode of conduction

The analysis of the 180' inverter - permanent-magnet synchronous machine combination (brushless dc motor) is quite straightforward since the applied voltages are known [7].

IV. SIMULINK MODEL OF INVERTER OPERATION

Here the open loop configuration of BLDC motor is simulated in MATLAB SIMULINK model. The simulation diagram is shown in figure 4. The model contains BLDC motor, Inverter and Logical block diagram. The rotor position is estimated using the hall sensor output. As per the hall sensor signal patterns windings of motor are energized. The switching table to energies windings of BLDC motor is shown in table 1.
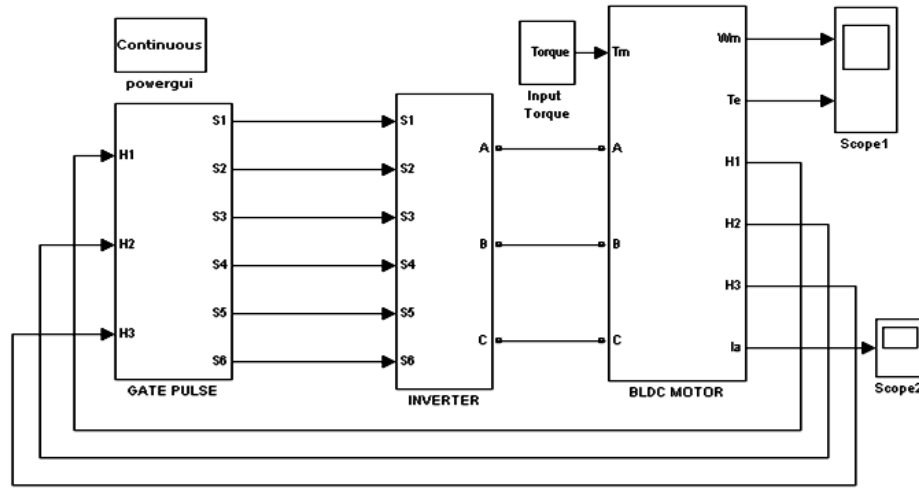
Figure 4 MATLAB-Simulink Implementation

V. HARDWARE IMPLEMENTATION

Here the tested Simulink open loop configuration of BLDC motor has been implemented for the Hardware configuration. The hardware implementation has been shown in figure 5. The whole setup contains 1) Controller 2) Driver circuit 3) Inverter and 4) DSO for checking the waveforms of each inverter legs. The various parameters used for the construction of hardware are listed in Table 2 for the further reference.
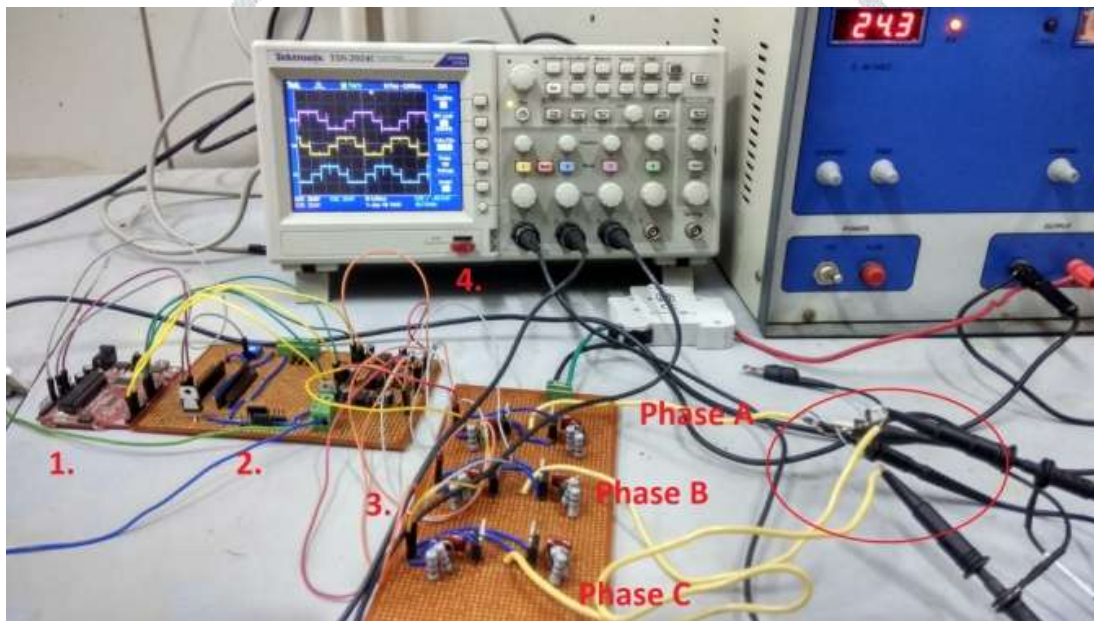

Figure 5 Hardware Setup

Table 2 Hardware setup details [8-10]

Driver IC Deteils		MOSFET Details		Controller	
V OFFSET	600V max.				
IO+/-	130 mA / 270 mA	IRFZ44N			
VOUT	10 - 20V	VDSS	55V	Name	ATMEGA328P-PU
ton/off (typ.)	680 & 150 ns	RDS(on)	17.5mΩ	Type	Ardiuno
Deadtime (typ.)	520 ns	ID	49A	Bit	8

VI. RESULTS & DISCUSSIONS

Inverter output of simulink environment.

The output of the inverter which is modeled in Simulink is given in Fig 6. and Fig.7. From the waveforms the upper leg and lower leg switching configuration is easy noticed as they are being turned on/off in pattern marked as S1,S3,S5 as upper legs and S2,S4,S6 as lower leg switches.
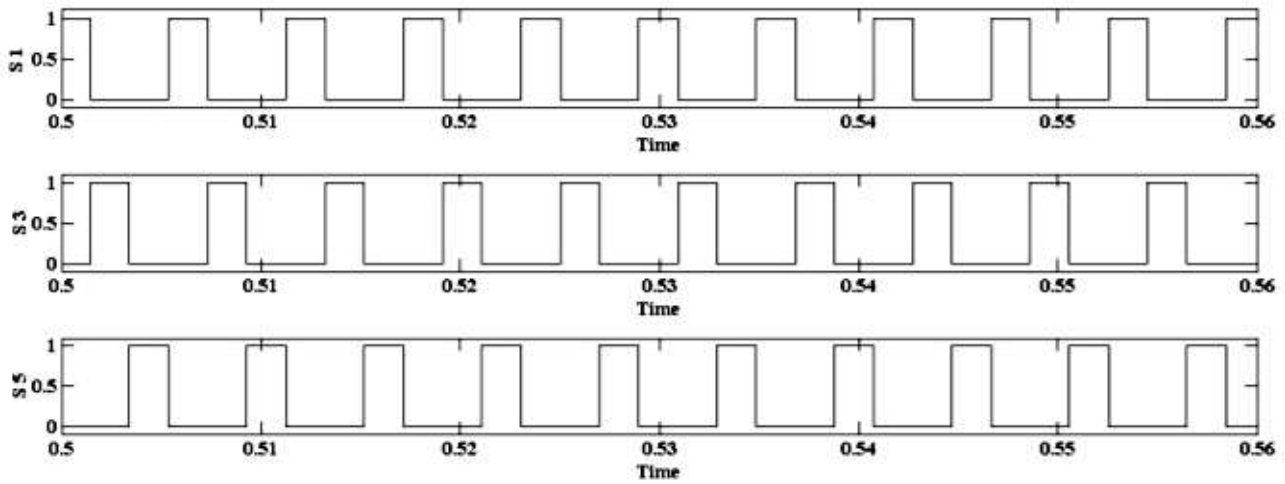
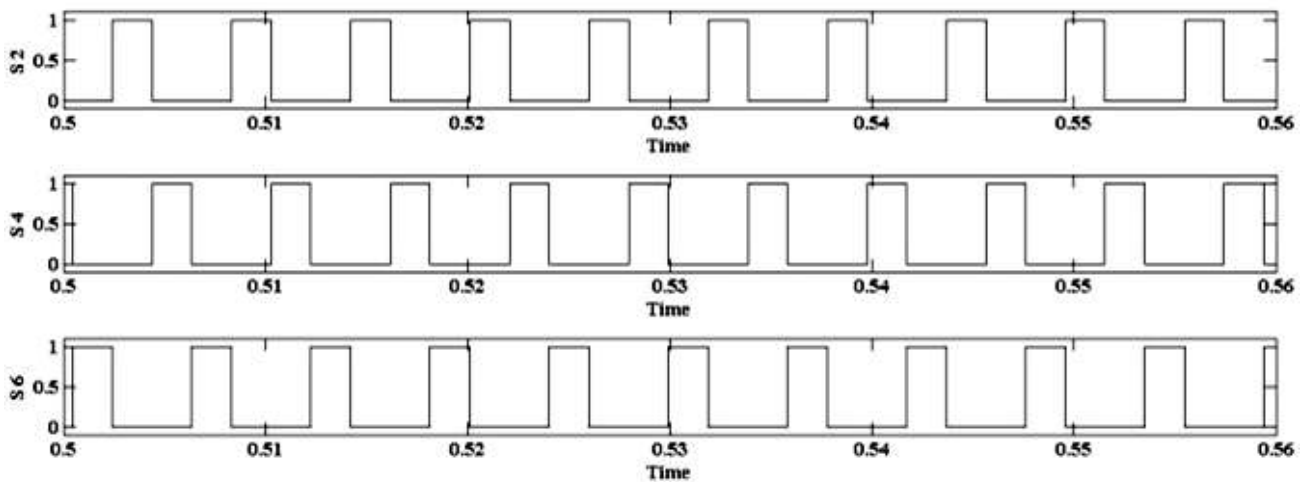Figure 6 Upper leg switches pulses

Figure 7 Lower leg switches

Inverter output of hardware implementation

6.2.1. *120^0 mode of conduction*

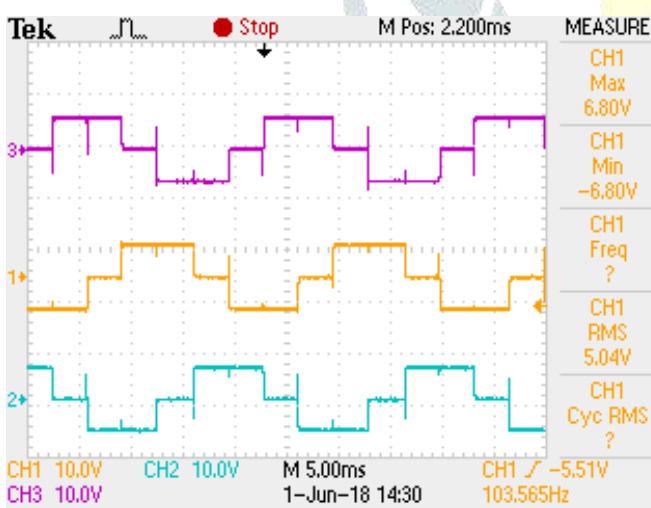Figure 8 Phase Voltage of Inverter phases   Figure 9 Pole voltage of inverter
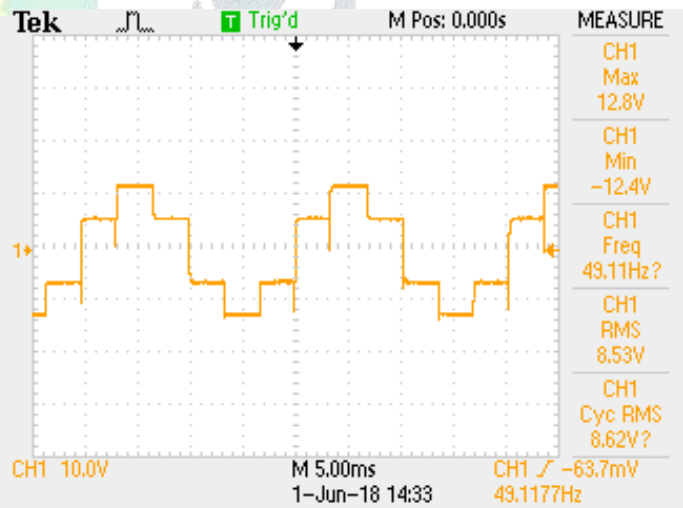
Fig. 8 shows the output of the inverter which are connected to PMBLDC motor phases A, B and C. They are nearly matches the output of typical 120^0 mode of conduction and are able to faded to the PMBLDC motor. While Fig. 9 shows the pole voltage of the motor phase.

   6.2.2. *180^0 mode of conduction*

Fig.10 shows the output of the inverter which are connected to PMBLDC motor phases A, B and C. They are nearly matches the output of typical 120^0 mode of conduction and are able to faded to the PMBLDC motor. While Fig. 11 shows the pole voltage of the motor phase.

Based on the software and hardware implementation results, this stetergy will for the generation of inverter output voltages in both the modes is quite useful for the vehicular applications.
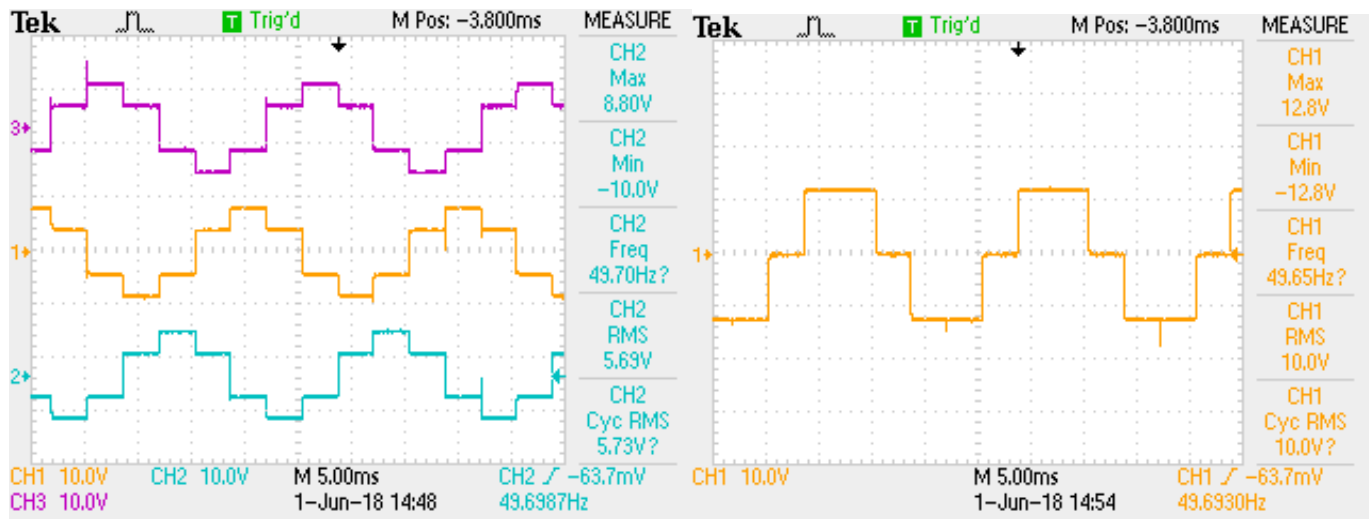
Figure 10 Phase Voltage of Inverter phases   Figure 11 Pole voltage of Inverter

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