HARDWARE IMPLEMENTATION OF PMBLDC DRIVE FOR AUTOMOTIVE APPLICATION USING MICROCONTROLLER

Thesis submitted in the partial fulfillment of the requirements for the award of degree of

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In

POWER SYSTEMS & ELECTRIC DRIVES

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CERTIFICATE

I hereby declare that the work which is presented in the thesis report entitled, **"Hardware Implementation of PMBLDC Drive for Automotive Application Using Micro-Controller"** *in partial fulfilment of the requirements for the award of the Master's degree in Power Systems & Electric Drives, submitted in Electrical and Instrumentation Engineering Department, Thapar University, Patiala, is an authentic record of my initial work carried out under the supervisions of Mr. Shakti Singh and Mr. SSSR Sarathbabu Duvvuri, EIED, THAPAR UNIVERSITY, PATIALA*

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ABSTRACT

The main purpose of this project is to achieve speed control of brushless dc (BLDC) motor drive for commercial applications. The flexibility of the drive is increased by using the digital controller. The motor selected for the project is Permanent Magnet brush-less dc motor (BLDC). The control algorithms are implemented using Microcontroller ATmega8, which enables single chip, cost effective, modular and increased performance solutions for BLDC drives.

For the software development; the input control information signals are position information from the Hall sensors, which are placed in BLDC motor and Duty cycle is based on the speed to be maintained.

The assembly code has generated by using the Microcontroller. The PWM signals of all the switches observed using CRO and the control logic has verified.

The 3-ф Inverter has designed using MOSFET's for feeding BLDC motor. The proposed system includes Hall sensor signals from motor, programmed microcontroller, MOSFET based power circuit and its driver MOSFET's are integrated and tested for the performance of the control system. The state of motor speed has been set by Hall signal frequency and duty cycle as digital input to microcontroller.

Table of Contents

CHAPTER 1 Page No

INTRODUCTION

1.1 Introduction 2

1.2 Brushless Motor 2

1.3 History of Brushless D.C 3

1.4 The importance of Electric Motor Drive 4

1.5 Fundamentals of Electric Motor Drive 4

1.6 Micro-Controller for Control applications 5

1.7 Proposed model 6

1.8 Reason to choose BLDC Motor 7

1.9 Objective of the Project 8

1.10 Literature Survey 8

1.11 Organization of the thesis 9

CHAPTER 2

BRUSHLESS DC MOTOR

2.1 Basic principal of BLDC motor 11

2.2 BLDC motor construction 12

2.3 Operation of fundamental BLDC motor 13

2.4 Torque generation 15

2.5 Hall Effect Sensors 16

2.7 Three Phase Inverter 17

2.8 The Pulse Width Modulation (PWM) 17

2.10 Advantages of PMBLDC Motor 18

CHAPTER 3

MICRO CONTROLLER

3.1 Introduction 20

3.2 Features 20

3.3 Interrupts 21

3.4 Input/ Output ports 21

3.5 Timer/ counter 21
3.6 Analog to Digital converter 22

CHAPTER 4

HARDWARE IMPLEMENTATION

4.1 PMBLDC Drive System 24
4.2 DC drive system using ATmega8 26
4.3 Hardware Circuitry 26
4.4 MOSFET driver circuit 26
4.5 Comparator 27
4.6 Buttons 28
4.7 Printed circuit board (PCB) 28
4.8 H- bridge 28
4.9 PMBLDC motor description 28
4.10 Bill of material 29

CHAPTER 5

SOFTWARE PROFILE

5.1 Flow charts 32
  5.1a Operation of PMBLDC motor 32
  5.1b Speed and direction control of PMBLDC motor 33

CHAPTER 6

RESULTS & CONCLUSIONS

6.1 Results 35
  6.1.1 Experimental results 35
6.2 Experimental setup 37
6.3 Conclusion 38
5.4 Scope of future work 38

REFERENCES

APPENDIX

List of Figures

Figure No.	Description	Page No.
Figure 1.1	Block diagram of Electric Motor Drive Control	5
Figure 1.2	Three Phase Inverter	6
Figure 1.3	12V brushless DC motor	8
Figure 2.1	BLDC Motor	11
Figure 2.2	BLDC Cross Section	12
Figure 2.3	Wave shape for the phase voltage with respect to hall sensor output	14
Figure 2.4	Steps for the rotation	14
Figure 2.5	Transverse section of a BLDC (Hall sensor)	16
Figure 2.6	Standard Form of PWM	18
Figure 3.1	ATmega8, 8-bit Microcontroller	20
Figure 3.2	ATmega8 pin diagram	22
Figure 4.1	Block diagram of the control system	24
Figure 4.2	MOSFET: - IRF540, IRF520, IRF9540N	26
Figure 4.3	Comparator pin diagram	27
Figure 6.1a	Inverter phase voltage waveform Van	35
Figure 6.1b	Inverter line voltage waveform Vab	35
Figure 6.2a	Inverter phase voltage waveform at 120 deg mode operation	35
Figure 6.2b	Inverter line voltage waveform at 120 deg mode operation	35
Figure 6.3	Stator voltage waveform of phase A, B & C	36
Figure 6.4	Hall sensor signal waveform	36
Figure 6.5	PWM gate signal to the MOSFETs	36
Figure 6.6	Line voltage of PWM inverter	36
Figure 6.7a	Motor and Comparator	37
Figure 6.7b	Controller, Inverter, Switches	37
Figure 6.7c	View of overall experimental set	37

List of Tables

Table No.	**Description**	**Page No.**
Table 4.1	Clockwise Rotation Sequence	25
Table 4.2	Anti-Clockwise Rotation Sequence	25
Table 4.3	Pin Description of comparator	27
Table 4.4	Bill of material	29

LIST OF ABBREVIATIONS

BLDC	Brushless Direct Current
PWM	Pulse Width Modulation
MOSFET	Metal Oxide Semiconductor Field Effect Transistor
PM	Permanent Magnet
MCU	Micro-Controller Unit
RPM	Rotation Per Minute
IC	Integrated Circuit
ADC	Analog to Digital Converter
PMBLDC	Permanent Magnet Brushless Direct Current
PCB	Printed Circuit Board
CW	Clockwise
CCW	Counter Clockwise

CHAPTER 1

Introduction

Chapter 1

1.1 INTRODUCTION

The economic constraints and new standards legislated by governments place increasingly stringent requirements on electrical systems. New generations of equipment, must have higher performance parameters such as better efficiency and reduced electromagnetic interference. System flexibility must be high to facilitate market modifications and to reduce development time. All these improvements must be achieved while at the same time, decreasing system cost. Brushless motor technology makes it possible to achieve these specifications. Such motors combine high reliability with high efficiency, and for a lower cost in comparison with brushed motors.

The use of Brushless DC (BLDC) motors is continuously increasing. The reason is obvious: BLDC motors are having a good weight/size to power ration, have excellent acceleration performance, requires little or no maintenance and generates less acoustic and electrical noise than universal (brushed) DC motors. [2c]

1.2 BRUSHLESS MOTOR

In a Universal DC motor, brushes control the commutation by physically connecting the coils at the correct moment. In BLDC motor, the commutation has controlled by electronics. The electronics can either have position sensor inputs that provide information about when to commutate or use the Back Electromotive Force generated in the coils. Position sensors are most often used in applications where the starting torque varies greatly or where a high initial torque is required. Position sensors are also often used in applications where the motor is used for positioning. Sensor-less BLDC control is often used when the initial torque does not vary much and where position control is not in focus, e.g. in fans. [2c]

1.3 HISTORY OF BRUSHLESS D.C MOTOR

The earliest evidence of a Brushless D.C. motor was in 1962 when T.G. Wilson and P.H. Trickey made a "DC Machine with Solid State Commutation". It was subsequently developed as a high torque, high response drive for specialty applications such as tape and disk drives for computers, robotics and positioning systems and in aircraft where brush wear was intolerable due to low humidity. Unfortunately, the technology to make such a motor practical for industrial use over 5 hp simply did not exist until a number of years later. With the advent of powerful and permanent magnet materials and high power, high voltage transistors in the early to mid 80,s the ability to make such a motor practical became a reality. The first large Brushless DC motors (50 hp or more were designed by Robert E. Lordo at POWERTEC Industrial Corporation in the late 1980s. Today, almost all of the major motor manufacturers make Brushless DC motors in at least some horsepower sizes and POWERTEC makes Brushless DC from 1/2 to 300 hp as a complete product line had has announced 500 Hp available in October, 1992. Brushless DC has had a substantial impact in some industry market areas, primarily Plastics and Fibers. The drives work on the same principle as all DC motors but the motor has built "inside out" with the fields (which are permanent magnets) on the shaft of the motor and the "armature" on the outside. The fields turn and the "armature" stays stationary. To duplicate the action of the commutator (which no longer needs to exist since the winding is now stationary), a magnetic encoder has mounted to the shaft of the motor to sense the magnetic position of the fields on the shaft. The controller "sees" the magnetic position information and determines through simple logic which motor lead should have current going to a winding and which motor lead should return the current from the winding.

The controller has power devices that connect the voltage on a capacitor bank to the correct motor lead at the correct time when the shaft encoder demands it. In this way the motor and Controller act in the same way as a brush DC motor but without the brushes. The controller has built in a very similar way to the controller used in an AC variable frequency drive or in an AC Vector drive because all three types use a PWM type of variable voltage control to their respective motors.[1]

1.4 THE IMPORTANCE OF ELECTRIC MOTOR DRIVE

Electric motors influence almost every aspect of modern living like in Refrigerators, Vacuum cleaners, air conditioners, fans, computer hard drives, automatic car windows. In addition, multitudes of other appliances and devices all use electric motors to convert electrical energy into useful mechanical energy. In addition to running the common place appliances used every day, electric motors are also responsible for a very large portion of industrial processes. Electric motors has used at some point in the manufacturing process of nearly every conceivable product that is produced in modern factories. Because of the nearly unlimited number of applications for electric motors, it is not hard to imagine that there are over 700 million motors of various sizes in operation across the world. This enormous number of motors and motor drives has a significant impact on the world because of the amount of power they consume. [3e]

1.5 FUNDAMENTALS OF ELECTRIC MOTOR DRIVE

The systems that control electric motors in the past suffered from very poor performance and were inefficient and expensive. In recent decades, the demand For greater performance and precision in electric motors, combined with the development of better solid state electronics and cheap microprocessors has led to the creation of modern adjustable-speed drives. An adjustable speed drive is a system that includes an electric motor as well as the system that drives and controls it. Any adjustable-speed drive can be view as five separate parts: the power supply, the power electronic converter, the electric motor, the controller, and the mechanical load. The power supply is the source of electric energy for the system. The power supply can provide electric energy in the form of AC or DC at any voltage level. The power electronic converter provides the interface between the power supply and the motor. Because of this interface, nearly any type of power supply can be used with nearly, any type of electric motor. The controller is the circuit responsible for controlling the motor output.

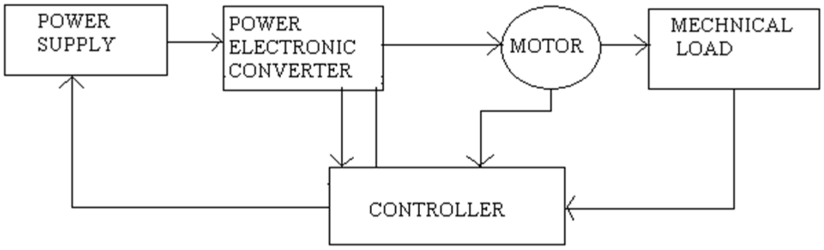


Figure 1.1: Block diagram of electric motor drive control

This has accomplished by manipulating the operation of the power electronic converter to adjust the frequency, voltage, or current sent to the motor. The controller can be relatively simple, or as complex as a microprocessor. The electric motor is usually, but not necessarily, a DC motor or an AC induction motor. The mechanical load is the mechanical system that requires the energy from the motor drive. The mechanical load can be the blades of a fan, the compressor of an air conditioner, the rollers in a conveyor belt, or nearly anything that can be driven by the cyclical motion of a rotating shaft. [3e]

1.6 MICRO-CONTROLLER FOR CONTROL APPLICATIONS

Motor drives have traditionally designed with relatively inexpensive analog components. The weaknesses of analog systems are their susceptibility to temperature variations and component aging. Another drawback is the difficulty of upgrading these systems. Digital control structures eliminate drifts and, by using a programmable processor, the up gradation can be easily accomplished by software.

Microcontrollers go further. Their high performance allows them to perform high-resolution control and minimize control loop delays. These efficient controls make it possible to reduce torque ripples and harmonics and to improve dynamic behavior in all speed ranges. The motor design has optimized due to lower vibrations and lower power losses such as harmonic losses in the rotor. Smooth waveforms allow an optimization of power elements and input filters. Overall, these improvements result in a reduction of system cost and better reliability. Switching electric machines from ordinary digital control to microcontroller significantly improves operating efficiency, saving energy while allowing the use of smaller, less expensive motors.

Microcontroller manages the torque and speed of motors by generating the appropriate magnetic vectors. However, it takes a considerable amount of processing power to solve the algorithms needed to generate the correct Pulse Width Modulated (PWM) outputs for motor. In addition, driving each inverter requires an individual encoder/position sensors interface block and six PWM outputs. [3e]

1.7 PROPOSED MODEL

Variable speed drives, employing a pulse width modulation (PWM) voltage-fed inverter, are being used for various purposes in consumer products and industrial applications widely now days. However, these models have to be implementing with economical cost and reliably. Any automatic systems includes both hardware and control approach where control approach plays an important role.

In the control approach, algorithms has designed and implemented to achieve the speed and direction control by varying the average voltage to the motor by using the PWM technique in proposed model. The inverter designed for proposed model carries MOSFET, which can operate at a high frequency and has less switching losses.

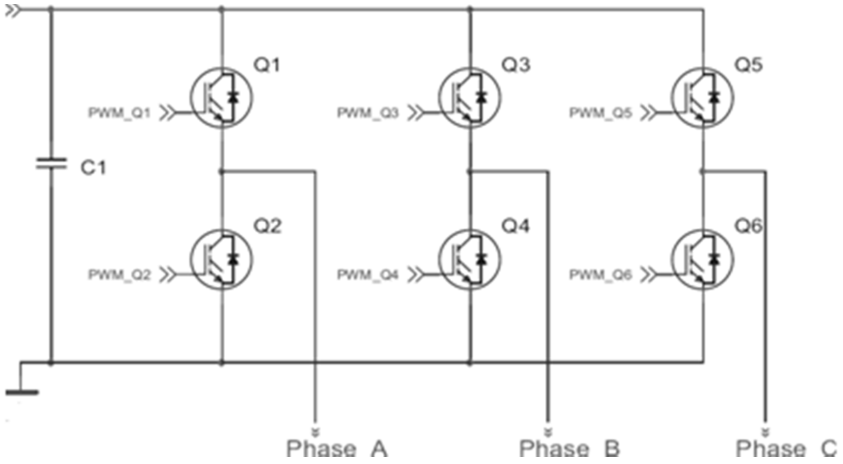


Figure 1.2: Three-Phase Inverter

1.8 REASON TO CHOOSE BLDC MOTOR

BLDC motors are very popular in a wide variety of applications. Compared with a DC motor, the BLDC motor uses an electric commutator rather than a mechanical commutator, so it is more reliable than the DC motor. In a BLDC motor, rotor magnets generate the rotor's magnetic flux, so BLDC motors achieve higher efficiency. Therefore, BLDC motors could use in high-end white goods such as domestic equipment, automobiles, information technology equipments, industries, public life appliances, transportation, aerospace, defense equipment, power tools, toys, vision and sound equipments and medical and health care equipment ranging from microwatt to megawatt. It has become possible because of their superior performance in terms of high efficiency, fast response, weight, precise and accurate control, high reliability, maintenance free operation, brushless construction and reduced size. [1c]

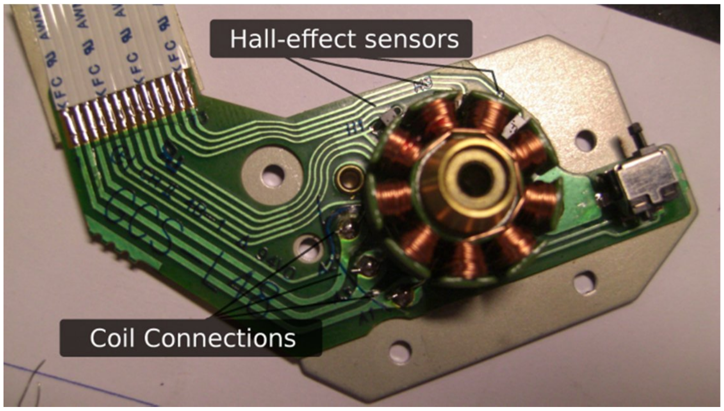


Figure 1.3: 12V brushless DC motor

1.9 OBJECTIVE OF THE PROJECT

To design a three-phase inverter for permanent magnet brushless DC (PMBLDC) motor drive for automotive application.

1. To implement speed control of BLDC motor using PWM strategy
2. To implement the direction control of BLDC motor using AVR ATmega8

1.10 LITERATURE SURVEY

Kenjo.T and Nagamori.S (1985) have discussed about the principle and fundamentals of permanent magnet brushless dc motor.

T.J.E. Miller (1989) have discussed about the square wave and sine wave permanent magnet brushless dc motor.

Kenjo (1990) have discussed about the microprocessor based control of PMBLDC motor.

C.B.Jacobian (1995). Discussed about the PWM operation and switching sequence.

Byeong-Seok Lee(1999) discussed about the variant of a low cost, four-quadrant converter topology for permanent magnet brushless DC (PMBDC) motor drive It has the advantage of variable dc input voltage to the machine through a buck-boost front-end power stage and hence low torque ripple at very low speed.

Gi-Taek Kim and Thomas A.lipo(1996) discussed about operation of the reduced number of switches for both rectifier and inverter. Moreover, the circuit capable for bidirectional power flow.

S.P.Natarajan(2000) has developed a high performance digital controller for PMBLDC motor using dedicated control IC MC33035 .It contains all the functions required to implement a full featured, open loop, three phase motor control system. But closed loop control cannot be done using this controller.

Abolfazl Halvaei Niasar (2002) discussed about the asymmetrical voltages and torque generated in commutation interval.

Juan W.Dixon and Ivan A.Leal(2002). It is based on the generation of quasi square wave current using only current controller for the three phases.

Yen-shin lai (2004) discussed about the BLDC drive fed by MOSFET based inverter for small power applications and he discussed about PWM techniques which reduces conduction losses and there by reduces heat dissipation.

1.11 ORGANIZATION OF THE THESIS

This thesis comprises of six chapters with introduction as the first chapter. The PMBLDC drive and its operation are explained in second chapter. The third chapter deals with the microcontroller ATmega8. The fourth chapter describes the hardware implementation of this project. The fifth chapter describes the software developed. The sixth chapter comprises of the results, conclusion and the scope for future work

Chapter 2

BRUSHLESS DC MOTOR

Chapter 2

2.1 BASIC PRINCIPLE OF BLDC MOTOR

Usually, motor stator winding is three-phase symmetry star connection type, which is similar to three-phase asynchronous motor. Since motor rotor is assembled with magnetized permanent magnet, in order to detect rotor polarity, a position sensor is built in motor. Motor driver, consisting of inverters and integrated circuit, is designed for: receiving start/stop/brake signals to control the motor operations; capturing position and forward/backward rotate signals to control the transistors state and make BLDC generate the continuous torque; receiving speed command and speed feedback signal to control and adjust rotate speed; protecting BLDC. The main circuit is a typical voltage source AC-DC-AC converter. Alternating the N-S pole of permanent magnet makes the position sensor generate H1, H2 and H3 waveform with 120° phase-different, which forms six condition codes: 010, 011, 001, 101, 100, and 110. Via some logic components, these codes control to conduct V6 – V1, V5 – V6, V4 – V5, V3 – V4, V2 – V3, V1 – V2 respectively, that is, load bus of U - >V, W - >V, W - >U, V - >U, V - >W, U - >W with DC voltage in turns.

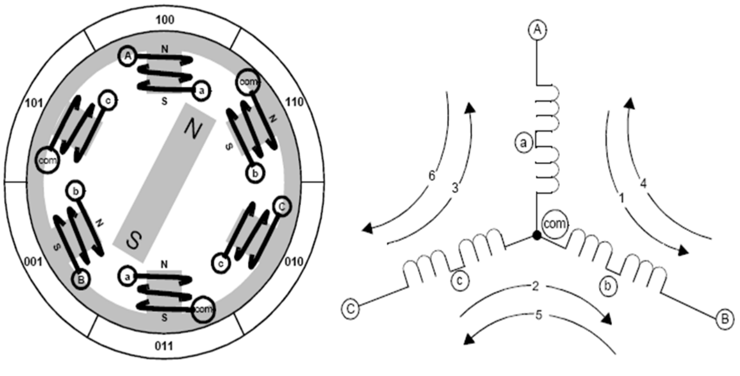


Figure 2.1: BLDC Motor

Therefore, each time the rotor revolves a pole-pair, the transistors V1, V2, V3, V4, V5 and V6 are conducted one by one according to their condition code and the magnetic field produced by stator winding rotates 60 electrical degree for that only two phases winding are loaded. Consequently, the rotor rotates 60 electrical degrees.

The new position signal of rotor will be captured via the sensor to form a new set of condition codes, thus to drive the corresponding transistors, which makes the rotor rotate 60 electrical degrees further. Circulating unceasingly, BLDC will generate a continuous torque to rotate the load continuously. [5c]

Here the control of a BLDC motor with Hall Effect position sensors has described. The implementation includes both direction and speed control.

2.2 BLDC MOTOR CONSTRUCTION

A brushless DC (BLDC) motor is a rotating electric machine, where the stator is a classic 3-phase stator like that of an induction motor, and the rotor has surface-mounted permanent magnets; see Figure 2-2. In this respect, the BLDC motor is equivalent to a reversed DC commutator motor, in which the magnet rotates while the conductors remain stationary. In the DC commutator motor, the commutator and brushes alter the current polarity. However, in the brushless DC motor, power transistors switching in synchronization with the rotor position perform polarity reversal. Therefore, BLDC motors often incorporate either internal or external position sensors to sense the actual rotor position, or the position can be detected without sensors. [1c]

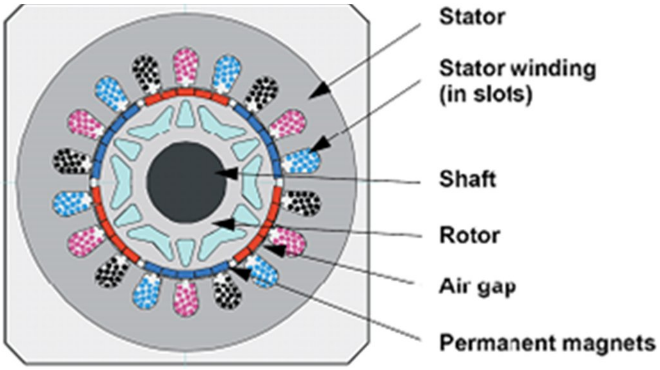


Figure 2.2: BLDC Cross Section

2.3 OPERATION OF FUNDAMENTAL BLDC MOTOR

To simplify the explanation of how to operate a three-phase BLDC motor a fundamental BLDC with only three coils is considered. To make the motor rotate the coils are energized in a predefined sequence, making the motor turn in one direction, say clockwise. Running the sequence in reverse order makes the motor run in the opposite direction.

One should understand that the sequence defines the direction of the current flow in the coils and thereby the magnetic field generated by the individual coils. The direction of the current determines the orientation of the magnetic field generated by the coil. The magnetic field attracts and rejects the permanent magnets of the rotor by changing the current flow in the coils and thereby the polarity of the magnetic fields at the right moment – and in the right sequence – the motor rotates.

Alternation of the current flow through the coils to make the rotor turn is referred to as commutation. A three-phase BLDC motor has six states of commutation. When all six states in the commutation sequence have been performed, the sequence is repeated to continue the rotation. The sequence represents a full electrical rotation. For motors with multiple poles, the electrical rotation does not correspond to a mechanical rotation. A four-pole BLDC motor uses two electrical rotation cycles to per mechanical rotation. Connecting the coils to the power and neutral bus induces the current flow. This will consider as square wave commutation or block commutation. An alternative method is to use a sinusoidal type waveform. The strength of the magnetic field determines the torque and speed of the motor. By varying the current flow thought the coils, the speed and torque of the motor can be varied. The most common way to control the current flow is to control the current flow through the coil. This can be accomplished by switching the supply voltage to the coils on and off so that the relation between on and off time defines the average voltage over the coil and thereby the average current. For BLDC motor, the commutation control has done electronically. The simplest way to control the commutation is to commutate according the outputs from a set of position sensors inside the motor. Usually Hall sensors are used. The Hall sensors change their outputs when the commutation should be changed. [2c]

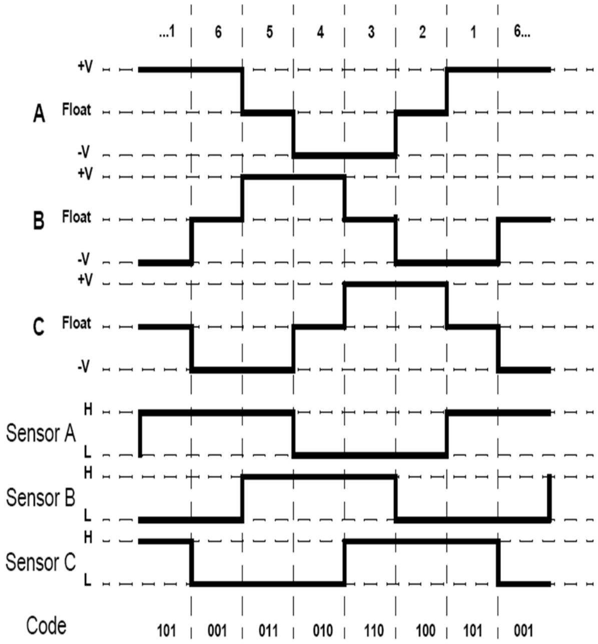


Figure 2.3: Wave shape for the phase voltage with respect to hall sensor output

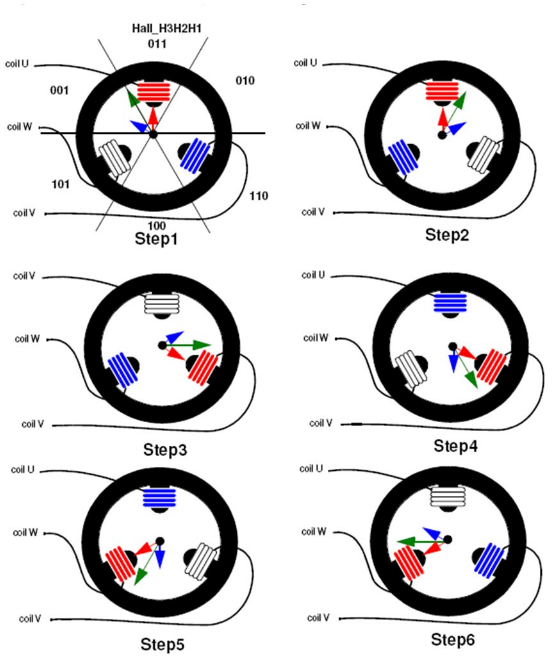


Figure 2.4: Steps for the rotation

2.4 TORQUE GENERATION

In this model, the torque T is the product if the theoretical motor constant K_t times the supplied current I. In a single pole system such as this, usable torque is only produced for 1/3 of the rotation. To produce the useful torque throughout the rotation of the stator additional coils or “phases” are added to the fixed stator.

The developed torque by each phase is the product of the motor constant K_t and the current I.

Sum of the torque is $T_A+T_B+T_C$ (1)

Assumption made is all the phases are perfect symmetry

$K_{t(motor)} = K_{t(A)} = K_{t(b)} = K_{t(C)}$ (2)

$I_{motor} = I_A = I_B = I_C$ (3)

At any given angle θ, the applied torque as measured on the rotor shaft is

$$T_{motor} = 2 * K_{t(motor)} * I_{motor} \quad (4)$$

The key to effective torque and speed control of a BLDC motor is based on relatively simple torque and back emf equations, which are similar to those of the motor. The back e.m.f magnitude can be written as ;

$E=2NlrB\omega$ (5)

In addition, the torque term as:

$$T = \left(\frac{1}{2} i^2 \frac{dL}{d\theta} \right) - \left(\frac{1}{2} B^2 \frac{dR}{d\theta} \right) + \left(\frac{4N}{\pi} B r l \pi i \right) \quad (6)$$

Where,

N is a number of winding turns per phase

L is the length of the rotor, r is the internal radius of the rotor

B is the rotor magnet flux density

ω is the motor angler velocity

I is the phase current

L is the phase inductance

Θ is the rotor position

R is the phase resistance

The first two terms in the torque expression are parasitic reluctance torque components. The third terms produce the mutual torque. Which is the torque production mechanism used in the case of BLDC motor. To sum up, the back e.m.f is directly proportional to the motor speed and the torque production is almost directly proportional to the phase current. These factors lead to following BLDC motor speed control. [3e]

2.5 HALL EFFECT SENSORS

For the estimation of the rotor position, the motor is equipped with three hall sensors. These hall sensors are placed every 120°. With these sensors, six different commutations are possible. Phase commutation depends on hall sensor values.

Power supply to the coils changes when hall sensor values change. With right synchronized commutations, the torque remains nearly constant and high. [3c]

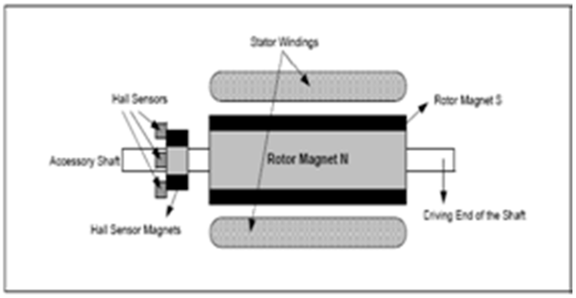


Figure 2.5: Transverse section of a BLDC (Hall sensor)

The above figure shows a transverse section of a BLDC motor with a rotor that has alternate N and S permanent magnets. Hall sensors have embedded into the stationary part of the motor. Embedding the Hall sensors into the stator is a complex process because any misalignment in these Hall sensors, with respect to the rotor magnets, will generate an error in determination of the rotor position. Based on the physical position of the Hall sensors, there are two versions of output. The Hall sensors may be at 60° or

120° phase shift to each other. Based on this, the motor manufacturer defines the commutation sequence, which should be followed when controlling the motor.

2.6 THREE PHASE INVERTER

The BLDC motor control consists of generating DC currents in the motor phases. This control is subdivided into two independent operations: first, stator and rotor flux synchronization, then control of the current value. Both operations are realized through the three-phase inverter depicted in the following scheme. The flux synchronization has derived from the position information coming from sensors. From the position, the controller defines the appropriate pair of MOSFET, which must be driven. The regulation of the current to a fixed 60 degrees reference can be realized in either of the two different modes. [2e]

2.7 PULSE WIDTH MODULATION (PWM)

The supply voltage chopped at a fixed frequency with a duty cycle depending on the current error. [18] Therefore, both the current and the rate of change of current can be controlled. The two-phase supply duration is limited by the two-phase commutation angles. The main advantage of the PWM strategy is that the chopping frequency is a fixed parameter; hence, acoustic and electromagnetic noises are relatively easy to filter.

There are also two ways of handling the drive current switching:

1. Hard chopping
2. Soft chopping

In the hard chopping technique both phase transistors are driven by the same-pulsed signal: the two transistors are switched-on and switched-off at the same time. The power electronics board is then easier to design and is also cheaper as it handles only three pulsed signals. A disadvantage of the hard chopping operation is that it increases the current ripple by a large factor in comparison with the soft chopping approach.

The soft chopping approach allows not only a control of the current and of the rate of change of the current but a minimization of the current ripple as well. In this soft chopping mode, the low side transistor has left ON during the phase supply and the high side transistor switches according to the pulsed signal. In this case, the power electronics board has to handle six PWM signals. [2e]

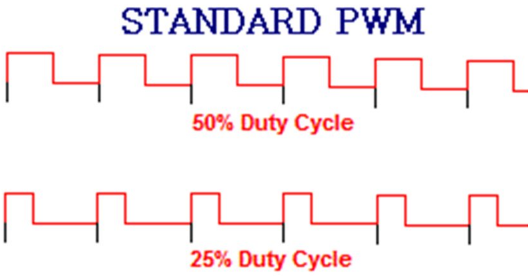


Figure 2.6 Standard Form of PWM

2.8 ADVANTAGES OF PMBLDC MOTOR

1. Improved efficiency since it eliminates the brush voltage drop and brush friction
2. No sparking due to the absence of brushes
3. Since the motor has no brush wear, its life is 5-10 times longer than the brushed dc motor.
4. Since the rotor is of permanent magnet, rotor losses are low.
5. Increased speed range has obtained since there are no mechanical limitations imposed by brush/commutator interface in a conventional motor.

Chapter 3

MICRO CONTROLLER

3.1 INTRODUCTION

Microcontroller offers more advantages than conventional microprocessors for implementing dedicated jobs. These IC's are also cost effective and could be used for any applications ranging from appliances to automobile engines to text or data processing equipment. At present these microcontrollers are used in washing machines, electronic toys, process control equipments, dot matrix printer's etc. ATmega8 is an 8-bit micro-controller that is readily available. It is very rigid and suitable for the industrial environment. [1d]

Figure 3.1: ATmrga8, 8-bit Microcontroller

3.2 FEATURES

1. High-performance, Low-power Atmel®AVR® 8-bit Microcontroller
2. 130 Powerful Instructions – Most Single-clock Cycle Execution
3. 32 × 8 General Purpose Working Registers
4. Three PWM Channels
5. 6-channel ADC
6. Programmable Serial USART
7. Power-on Reset and Programmable Brown-out Detection

The Atmel®AVR® ATmega8 is a low-power CMOS 8-bit microcontroller based on the AVR RISC architecture. By executing powerful instructions in a single clock cycle, the ATmega8 achieves through puts approaching 1MIPS per MHz, allowing the system designer to optimize power consumption versus processing speed. The Atmel®AVR® core combines a rich instruction set with 32 general-purpose working registers. All the 32 registers are directly connected to the Arithmetic Logic Unit (ALU), allowing two independent registers to be accessed in one single instruction executed in one clock cycle. [1d]

3.3 INTERRUPTS

ATmega8 has five interrupts of which two are external and three are internal. External hardware interrupts are INT0 and INT1 and two internal timer interrupts and one serial port interrupt are the internal interrupts. The external interrupts may be level triggered or edge triggered. Whenever timer overflows, the timer flag is raised, and a timer interrupt is generated. Interrupts can be enabled / disabled selectively or globally by interrupt enable register (IE). [1d]

3.4 INPUT/ OUTPUT PORTS

Microcontroller has six pin for ADC input configured at PORTC. PORTB is used as output port. PORTD is used as interrupt port. An external crystal is connected between PB6 and PB7. PC6 is connected to Vcc through a 22K resister. AV_{cc} is connected to pin 20 and AREF is connected to pin 21. This is the analog reference pin for the A/D converter. ATmega8 has two pin for the ground Pin 7 and 22. PD6 and PD7 pins are for the external interrupt. [1d]

3.5 TIMER/ COUNTER

1. ATmega8 has three timer /counter.
2. 8-bit timer/counter0
3. 16-bit timer/counter1
4. 8-bit timer/counter2 with PWM

3.6 ANALOG TO DIGITAL CONVERTER

The ATmega8 features a 10-bit successive approximation ADC. The ADC is connected to an 8-channel Analog Multiplexer, which allows eight single-ended voltage inputs constructed from the pins of Port C. The single-ended voltage inputs refer to 0V (GND). The ADC contains a Sample and Hold circuit, which ensures that the input voltage to the ADC is held at a constant level during conversion.

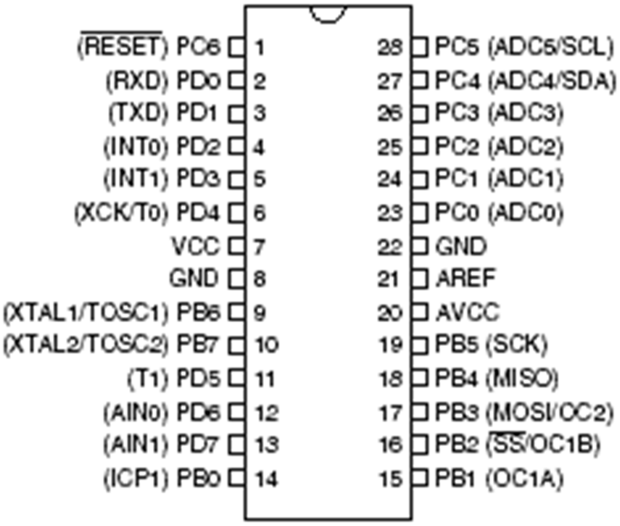


Figure 3.2: ATmega8 pin diagram

The ADC has a separate analog supply voltage pin, AVCC. AVCC must not differ more than ±0.3V from VCC. Internal reference voltages of nominally 2.56V or AVCC are provided On-chip. The voltage reference may be externally decoupled at the AREF pin by a capacitor for better noise performance. [1d]

Chapter 4

HARDWARE IMPLEMENTATION

Chapter 4

4.1 PMBLDC DRIVE SYSTEMS

A block diagram of PMBLDC drive system shown in Fig-4.1 consists of a three-phase inverter, position sensors, comparator and a digital controller. The inverter along with the position sensor arrangement is functionally analogous to the commutator of a conventional dc motor.

Unlike a brushed DC motor, the commutation of a BLDC motor is controlled electronically. To rotate the BLDC motor, the stator windings should be energized in a sequence. Rotor position should be known in order to switch the winding in sequence. A permanent magnet brushless dc motor incorporates some means of detecting the rotor position**.**

The PMBDLC motor detects the position of the rotor using the following methods:

1. Hall sensor
2. Back E.M.F detection

Normally hall sensors are used for position information in brushless dc motor. Three sensors are required for position information. With three sensors, six possible commutation sequences could be obtained. For every 60 electrical degrees of rotation, one of the Hall sensors changes the state. Therefore, it takes six steps to complete an electrical cycle. The rotor of a PMBLDC motor can have any number of poles. [4c]

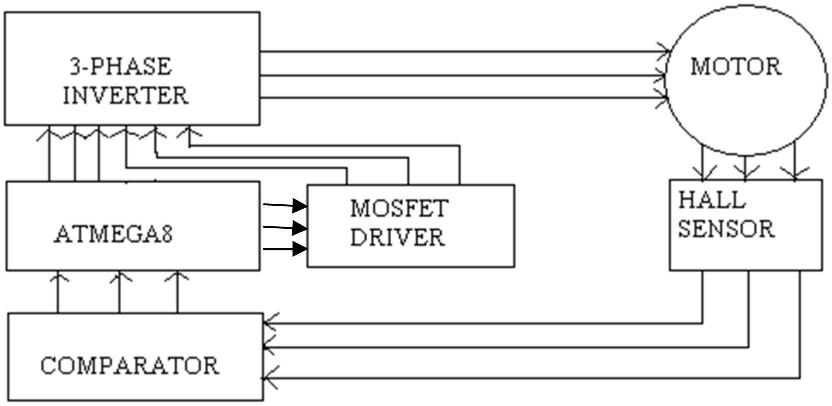


Figure 4.1: Block diagram of the control system

A digital controller can be used to provide the appropriate firing pulses to the inverter based on the position sensor information. A microcontroller ATmega8 can be used since it offers design flexibility that hardwired control components cannot.

Moreover, ATmega8 is readily available. Table-4.1 illustrates a possible relation between hall IC position and drive signals to be fed to the inverter for CW direction of rotation of motor and Table-4.2 is for the CCW direction.

Table 4.1 Clockwise rotation sequence

PINS	PC5	PC4	PC3	PB0	PB1	PB2	PB3	PB4	PB5
Phase	Sensor C	Sensor B	Sensor A	CH	BH	AH	CL	BL	AL
6	1	0	1	0	0	1	0	1	0
4	1	0	0	1	0	0	0	1	0
5	1	1	0	1	0	0	0	0	1
2	0	1	0	0	1	0	0	0	1
1	0	1	1	0	1	0	1	0	0
3	0	0	1	0	0	1	1	0	0

Table 4.2 Anti-Clockwise rotation sequence

PINS	PC5	PC4	PC3	PB0	PB1	PB2	PB3	PB4	PB5
Phase	Sensor C	Sensor B	Sensor A	CH	BH	AH	CL	BL	AL
6	0	0	1	1	0	0	0	0	1
4	0	1	0	0	0	1	0	1	0
5	0	1	1	1	0	0	0	1	0
2	1	0	0	0	1	0	1	0	0
1	1	0	1	0	1	0	0	0	1
3	1	1	0	0	0	1	1	0	0

4.2 DC DRIVE SYSTEM USING ATmega8

The developed PMBLDC drive system consists of power circuit, control hardware and software. Power circuit part have MOSFET based inverter and its driver circuit.

The control circuit consists of the rotor position sensing circuit. Assembly language program has written to provide firing pulses to the inverter.

4.3 HARDWARE CIRCUITRY

The hall sensor output from the PMBLDC machine is given as input to the comparator LM3389. Comparator LM339 give digital input to the ATmega8.The microcontroller generates the firing pulses required to drive the MOSFET. These pulses are fed to direct to the lower MOSFET of the H-bridge (n-type MOSFET are used) and other three N- type MOSFET which will drive the upper part of the H-bridge (p-type MOSFET are installed). Required power supply is taken from the readymade adopter (output voltage is 12V and output current 1.5A)

4.4 MOSFET DRIVER CIRCUIT

Three n-channels MOSFET are used to drive the h-bridge high side MOSFET (p-channel). IRF540 is used for MOSFET driver. 47K resisters pull up all the MOSFETs. MOSFETs are connected to atmega8 through 47K resisters.

A B C

Figure 4.2: MOSFET: - IRF540, IRF520, IRF9540N

4.5 COMPARATOR

These comparators are designed for use in level detection, low–level sensing and memory applications in consumer, automotive, and industrial electronic applications.

- ➢ Single Supply Operation
- ➢ Low Input Bias Current: 25 nA
- ➢ Low Input Offset Current: ±5.0 nA
- ➢ Low Input Offset Voltage
- ➢ Input Common Mode Voltage Range to Gnd
- ➢ TTL and CMOS Compatible
- ➢ Device Operation

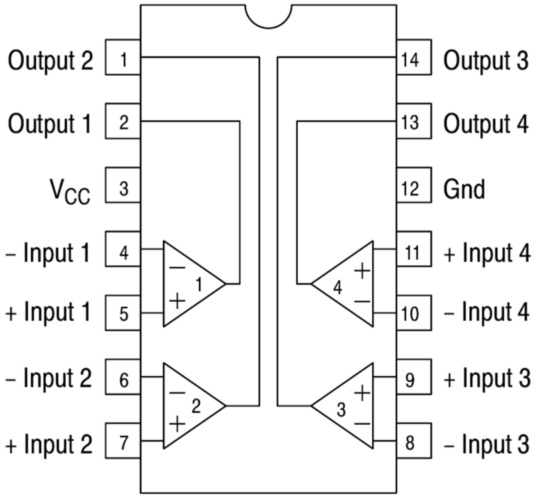


Figure 4.3: Comparator pin diagram

Table 4.3 Pin description of comparator

Function	**Pin no**
OUTPUT PINS	1, 2, 13, 14
INPUT PINS	4, 5, 6, 7, 8, 9, 10, 11
Vcc	3
Ground	12

V_{cc} and ground will be connected through a resistance of 100Ω and output pins should be connected through 10K resister.

4.6 BUTTONS

Four buttons are used named S1, S2, S3, and S4. They have used to start/stop direction change and speed change. Their respective functions are -

1.	S1	start/ stop
2.	S2	direction reversal
3.	S3	speed increase
4.	S4	speed decrease

4.7 PRINTED CIRCUIT BOARD

PCB (printed circuit board) has designed. EAGLE LAYOUT EDITOR (software) is used for this purpose. Free version of the software is available on the internet. First, schematic is drawn using inbuilt component list then after board is designed.

4.8 H-BRIDGE

In h-bridge, six MOSFETs are used. Three are p-type (higher) and three n-type (lower). For the higher part F9540N and for the lower part IRF520 is used. V_{cc} is connected to the higher part of the bridge and a lower part is connected to the ground.

4.9 PMBLDC MOTOR DESCRIPTION

The specifications of the motor is

- Stator voltage - 12V (line to line)
- Speed – 10000 rpm
- Poles - 9
- Hall position sensors - 3 no’s placed 120 degrees apart.

4.10 BILL OF MATERIAL

Table 4.4 Bill of material

S.No	COMPONENTS	VALUE	TYPE	QUANTITY
1	IRF520	-------	---------	3
2	IRF540	----------	----------	3
3	F9540N	-------------	-------------	3
4	RESISTANCE	22K		5
5	RESISTANCE	100ohm	--------	3
6	RESISTANCE	47K		9
7	CAPACITOR	1µF	Ceramic	4
8	CAPACITOR	100µF	Ceramic	3
9	CAPACITOR	22pF	Ceramic	2
10	CAPACITOR	470µF`	Electrolyte	1
11	CAPACITOR	47µF`	Electrolyte	1
12	CRYSTAL	16MHz	--------	1
13	INDUCTOR	10µH	---------	1
14	Atmega8	------------	-------------	1
15	MICRO-CONTROLLER BASE	28 pin	--------------	1
16	RESISTANCE	70 ohm	--------------	2
17	COMPARATOR	LM339	-----------	1
18	SINGLE CORE CABLE	--------	----------	2M
19	15 PIN CONNECTOR		MALE	1
20	15 PIN CONNECTOR		FEMALE	1
21	PUSH BUTTONS		NO	4

22	GENERAL PURPOSE PCB			1

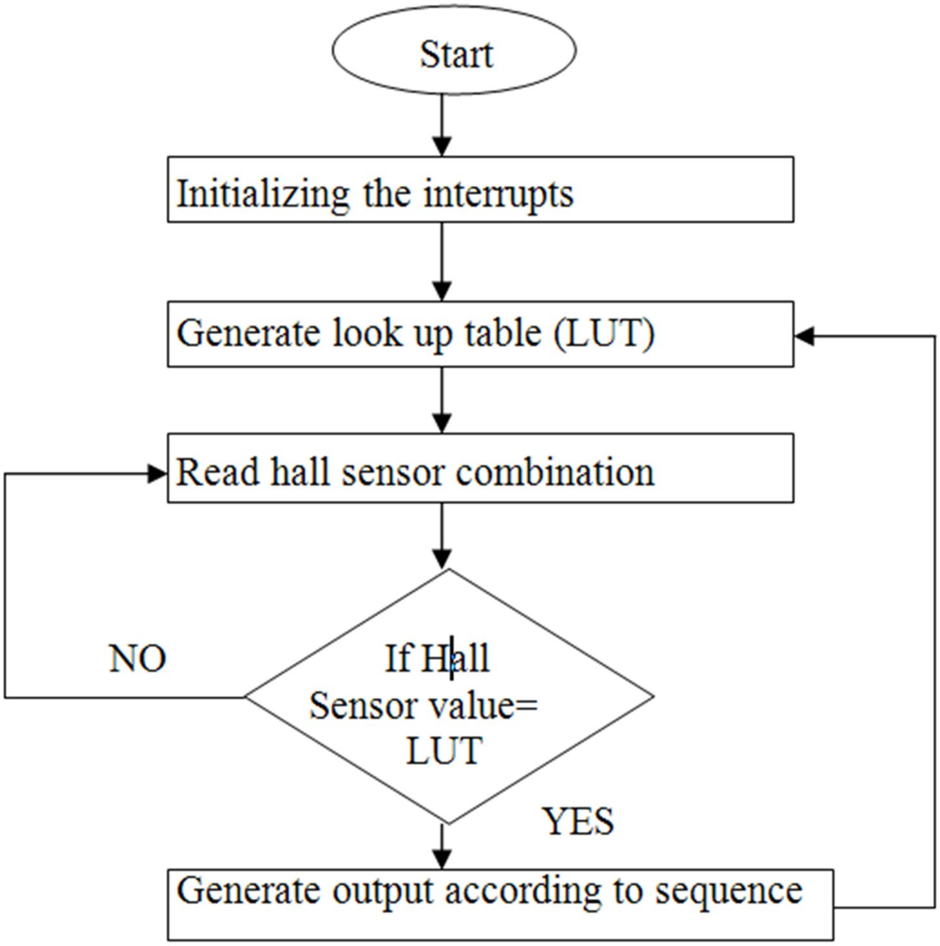
CHAPTER 5

SOFTWARE PROFILE

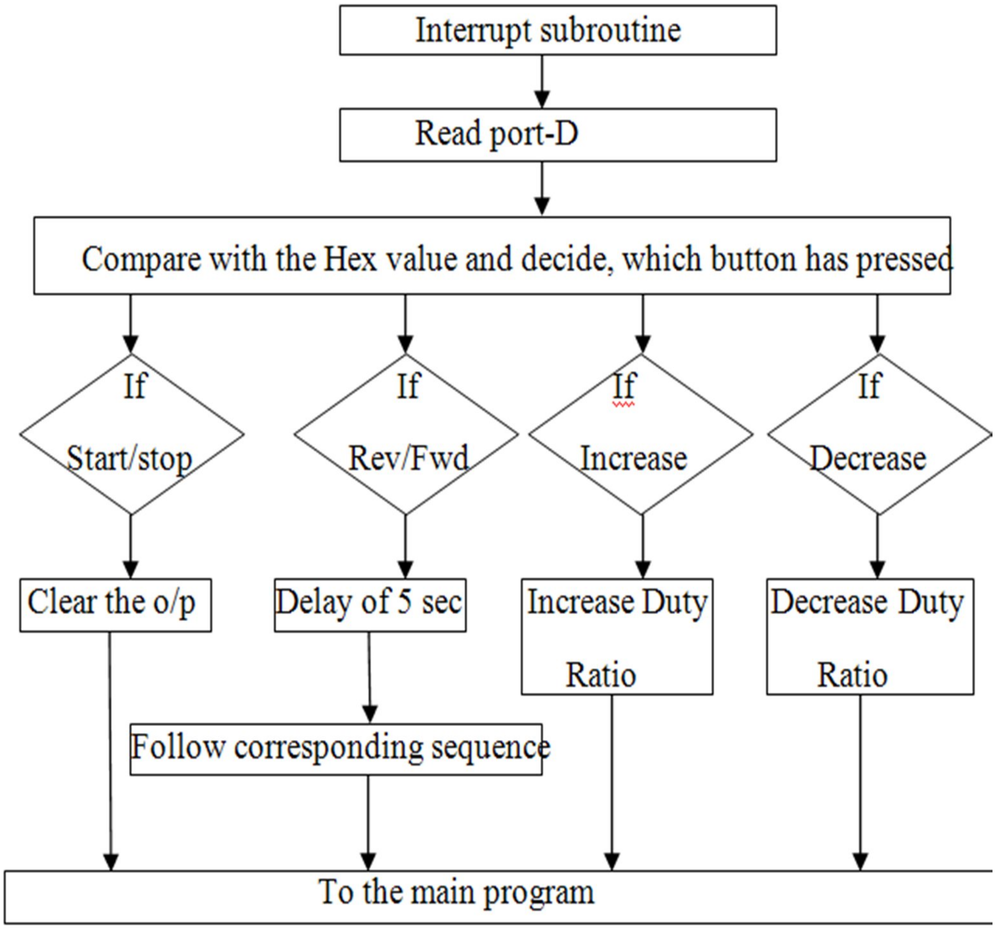
CHAPTER 5

5.1 FLOW CHARTS

5.1a OPERATION OF PMBLDC MOTOR



5.1b SPEED AND DIRECTION CONTROL OF PMBLDC MOTOR



CHAPTER 6
RESULTS AND CONCLUSION

CHAPTER 6

6.1 RESULT

A microcontroller-based controller for PMBLDC machine has constructed using ATmega8.The PWM output from the ATmega8 control the power MOSFETs. The output of the inverter has fed to the PMBLDC motor windings. Waveforms are given below.

6.1.1 Experimental result

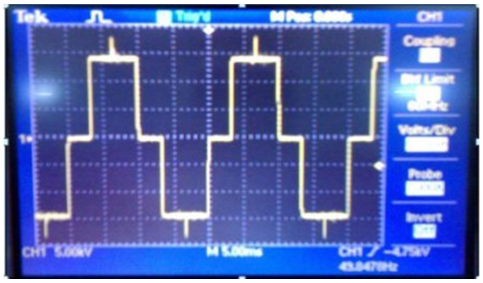


Figure 6.1a: Inverter phase voltage waveform

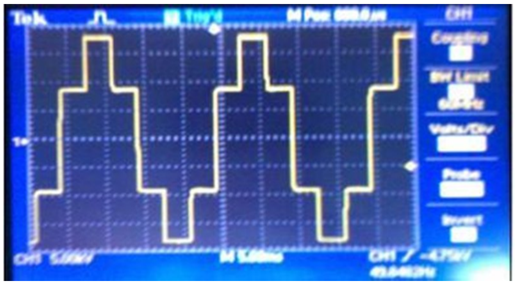


Figure 6.1b: Inverter line voltage waveform

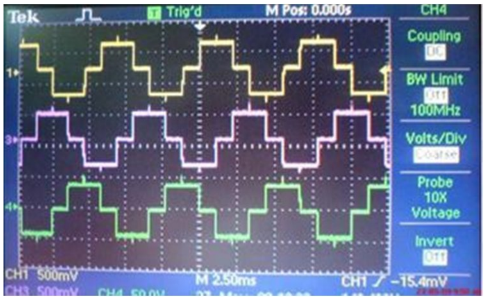


Figure 6.2a

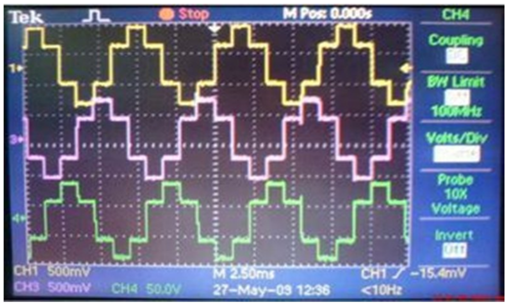


Figure6.2b

Figure 6.2a: Inverter phase voltage waveforms at 120$_0$ mode operation

Figure 6.2b: Inverter line voltage waveforms at 120$_0$ mode operation

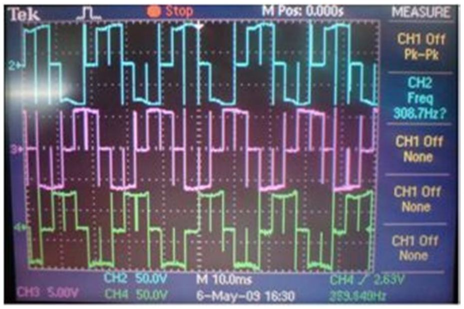


Figure 6.3: Stator voltage waveforms of phase A, B & C

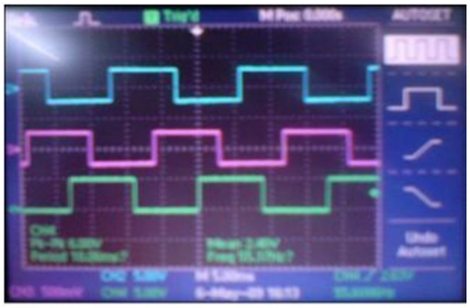


Figure 6.4: Hall sensor signal wave

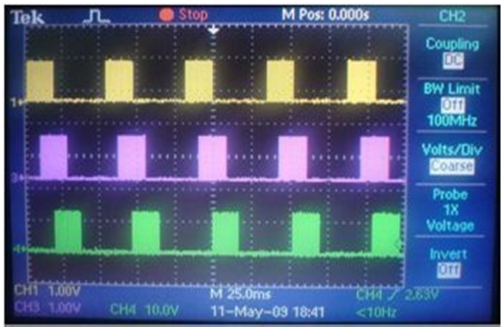


Figure 6.5: PWM Gate signals to the MOSFETs

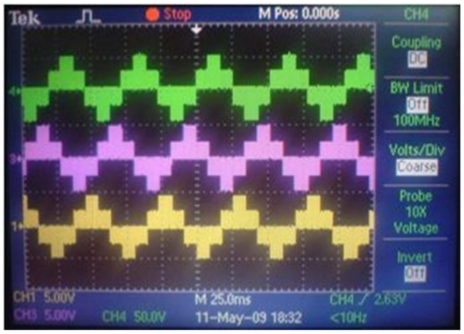


Figure 6.6: Line Voltages of PWM inverter

6.2 Experimental setup:

Figure 6.7: (a) Motor and Comparator

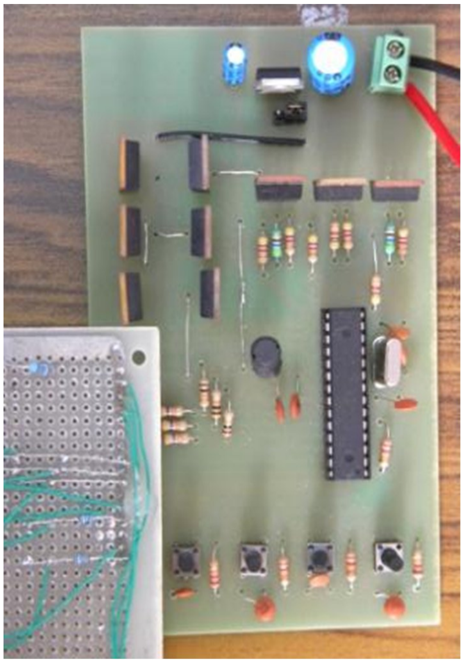


Figure 6.7: (b) Controller, Inverter, Switches

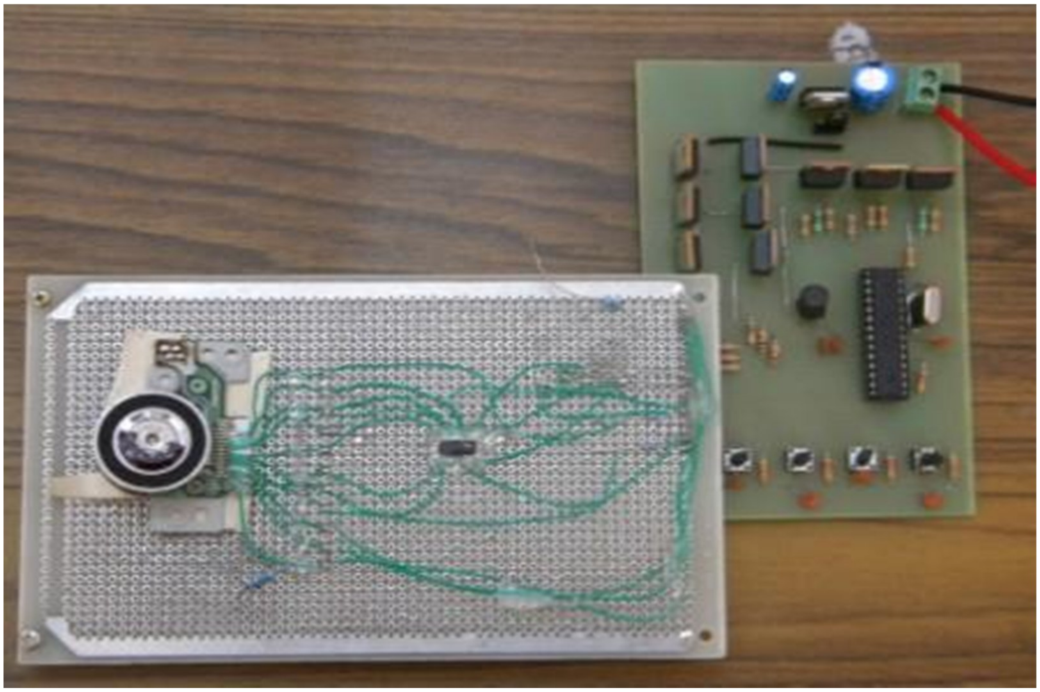


Figure 6.7: (c) View of overall experimental set

6.3 Conclusion:

Thus, the speed and direction control of BLDC motor drives with PWM techniques has done. A further modification in control structure is easily possible by changing the software. The proposed system can be widely used in commercial applications with reduced cost.

6.4 Scope for Future Work

Since hall position sensors are the expensive and fragile components in the drive system, they can be eliminated using sensor less control techniques. No. of speed level can be increased. Double-sided compact PCB can be design, so that, the size can be reduce. Further, DSP TMS320LF2407A can be used for control of PMBLDC drive.

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REFERENCES

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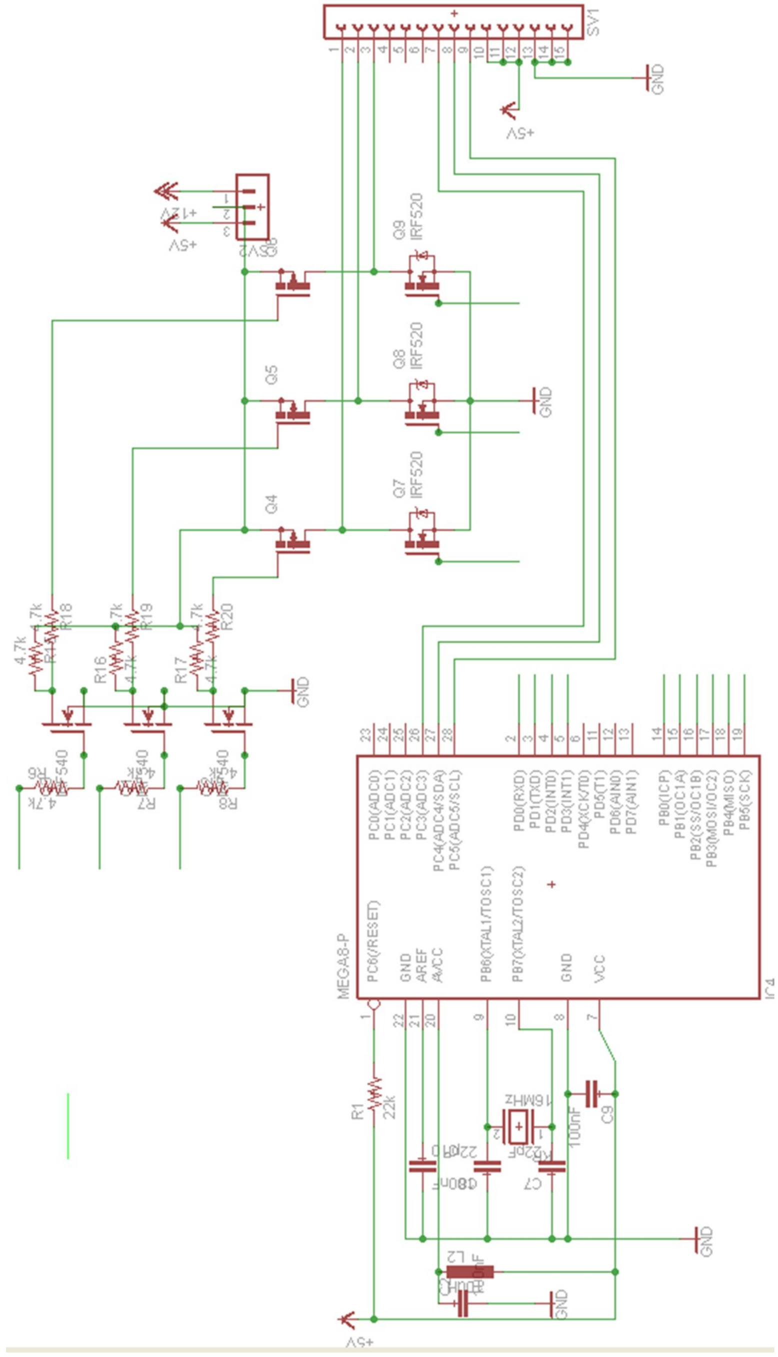
APPENDIX

APPENDIX 1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GND
+5V
SV2
+12V
Q4
Q5
Q6
Q7
Q8
Q9
IRF520
IRF540
R16
R17
R18
R19
R20
R6
R7
R8
4.7k
MEGA8-P
IC4
PC6(/RESET)
GND
AREF
AVCC
PB6(XTAL1/TOSC1)
PB7(XTAL2/TOSC2)
VCC
PC0(ADC0)
PC1(ADC1)
PC2(ADC2)
PC3(ADC3)
PC4(ADC4/SDA)
PC5(ADC5/SCL)
PD0(RXD)
PD1(TXD)
PD2(INT0)
PD3(INT1)
PD4(XCK/T0)
PD5(T1)
PD6(AIN0)
PD7(AIN1)
PB0(ICP)
PB1(OC1A)
PB2(SS/OC1B)
PB3(MOSI/OC2)
PB4(MISO)
PB5(SCK)
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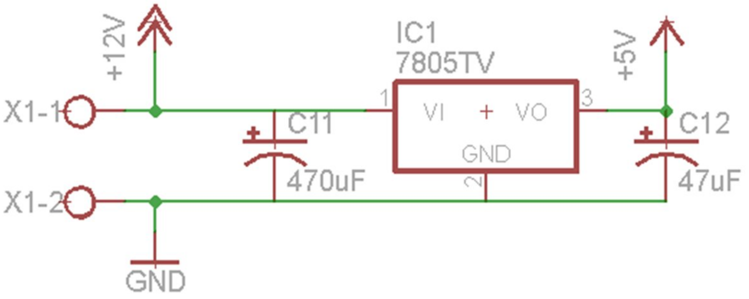
C7
C9
L2
10uH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VI
+
VO
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C12
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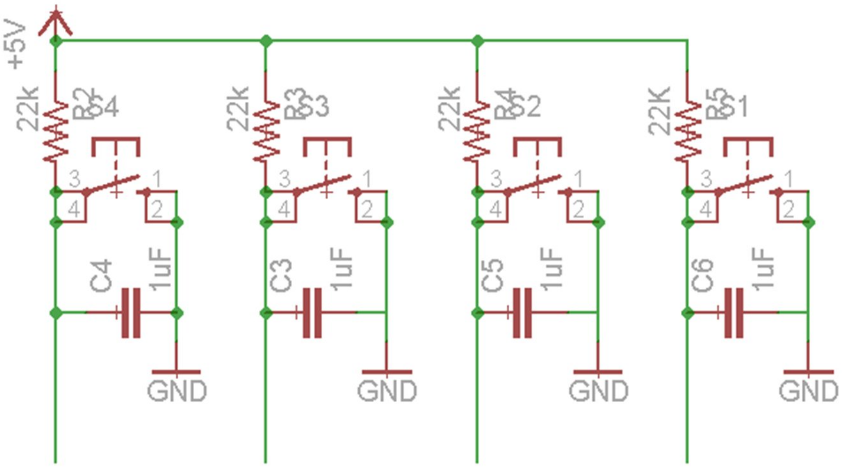
GND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R2
S4
3
1
4
2
C4
1uF
GND
22k
R3
S3
3
1
4
2
C3
1uF
GND
22k
R4
S2
3
1
4
2
C5
1uF
GND
22K
R5
S1
3
1
4
2
C6
1uF
GND

APPENDIX 3

```
;FILE     - BLDC DIRECTION AND SPEED CONTROL USING ATmega8

;AUTHOR  -      GAURAV KUMAR SHARMA

;CONTACT -      diff.genius@gmail.com

;DEVICE AND OPERATING FREQUENCY :

        .include “m8def.inc”


;Crystal frequency =        16MHz, External Crystal

;SYMBOL DEFINITIONS:

        .equu           FWD1        =       $03

        .equ            STOP        =       $04

        .equ            REV1        =       $05

        .def            PwmReg      =       r25

        .def            Temp2       =       r26

;INTERRUPT VECTOR JUMP:

        .org            $000

                          rjmp RESET

        .org            $003

                          rjmp TMR2_COM_ISR

        .org            $004

                          rjmp TMR2_OVF_ISR

        .org            $009

                          rjmp TMR0_OVF_ISR

;RESET ROUTINE:

RESET:

        ldi             Temp, High(RAMEND)

        out             SPH, Temp

        ldi             Temp,Low(RAMEND)
```

```
        out             SPL, Temp
;PORTS INITIALIZATION
        ldi             Temp, $3F
        out             DDRB, Temp
        clr             Temp
        out             PORTB, Temp
        ldi             Temp, $00
        out             DDRC, Temp
        ldi             Temp, $00
        out             DDRD, Temp
; TIMER1
        ldi             Temp, $01
        out             TCCR2, Temp
        ldi             Temp,    100
        out             OCR2, Temp
; TIMER0
        ldi             Temp, $04
        out             TCCR0, Temp
        ldi             Temp, $C1
        out             TIMSK, Temp
; init variables
        Ldi             SystemState, FWD1
        ldi             OutReg, $00
        ldi             PwmReg, $07
        clr              HallStatus
        sei
MAIN:
                        nop
        ; update hall sensor status
        ; if hallstatus changed then
```

```
        ; update output reg based on hallstatus and systemstate
        ; reset pwm timer
MAIN2:
        in              Temp, PINC
        andi            Temp, $38
        cp              Temp, HallStatus
        breq            MAIN
        mov             HallStatus, Temp
        cpi             SystemState, STOP
        breq            STOP_SEQUENCE
        brlo            FWD_SEQUENCE
REV_SEQUENCE:
        cpi             HallStatus, $28
        breq            REV_SEQ_1
        cpi             HallStatus, $20
        breq            REV_SEQ_2
        cpi             HallStatus, $30
        breq            REV_SEQ_3
        cpi             HallStatus, $10
        breq            REV_SEQ_4
        cpi             HallStatus, $18
        breq            REV_SEQ_5
        cpi             HallStatus, $08
        breq            REV_SEQ_6
        rjmp            MAIN
REV_SEQ_1:
        ldi             OutReg, $22
        rjmp            BACK_TO_MAIN
REV_SEQ_2:
        ldi             OutReg, $0A
```

```
        rjmp            BACK_TO_MAIN
REV_SEQ_3:
        ldi             OutReg, $0C
        rjmp            BACK_TO_MAIN
REV_SEQ_4:
        ldi             OutReg, $14
        rjmp            BACK_TO_MAIN
REV_SEQ_5:
        ldi             OutReg, $11
        rjmp            BACK_TO_MAIN
REV_SEQ_6:
        ldi             OutReg, $21
        rjmp            BACK_TO_MAIN
STOP_SEQUENCE:
        ldi             OutReg, $00
        rjmp            BACK_TO_MAIN
FWD_SEQUENCE :
        cpi             HallStatus, $28
        breq            FWD_SEQ_1
        cpi             HallStatus, $20
        breq            FWD_SEQ_2
        cpi             HallStatus, $30
        breq            FWD_SEQ_3
        cpi             HallStatus, $10
        breq            FWD_SEQ_4
        cpi             HallStatus, $18
        breq            FWD_SEQ_5
        cpi             HallStatus, $08
        breq            FWD_SEQ_6
        rjmp            MAIN
```

```
FWD_SEQ_1:
        ldi         OutReg, $14
        rjmp        BACK_TO_MAIN
FWD_SEQ_2:
        ldi         OutReg, $11
        rjmp        BACK_TO_MAIN
FWD_SEQ_3:
        ldi         OutReg, $21
        rjmp        BACK_TO_MAIN
FWD_SEQ_4:
        ldi         OutReg, $22
        rjmp        BACK_TO_MAIN
FWD_SEQ_5:
        ldi         OutReg, $0A
        rjmp        BACK_TO_MAIN
FWD_SEQ_6:
        ldi         OutReg, $0C
        rjmp        BACK_TO_MAIN
; return to main
BACK_TO_MAIN:
        rjmp        MAIN
TMR2_COMP_ISR:
        and         PwmReg, OutReg
        out         PORTB, PwmReg
        ldi         PwmReg, $07
        reti
TMR2_OVF_ISR:
        out         PORTB, OutReg
        reti
TMR0_OVF_ISR:
```

```
        In              Temp1, PIND
        andi            Temp1, $0F
        cpi             Temp1, $0E
        breq            S1_PRESS
        cpi             Temp1, $0D
        breq            S2_PRESS
        cpi             Temp1, $0B
        breq            S3_PRESS
        cpi             Temp1, $07
        breq            S4_PRESS
INVALID_PRESS:
        clr             S1BtnState
        clr             S2BtnState
        clr             S3BtnState
        clr             S4BtnState
        reti
S1_PRESS:       ;Start/Stop Button
        inc             S1BtnState
        cpi             S1BtnState, 3
        brne            END_OF_TMR0_OVF_ISR
        cpi             SystemState, STOP
        brne            STATE_STOP
        ldi             SystemState, FWD1
        reti
STATE_STOP:
        ldi             SystemState, STOP
        reti
S2_PRESS:       ;reverse/forward Button
        inc             S2BtnState
        cpi             S2BtnState, 3
```

```
        brne            END_OF_TMR0_OVF_ISR
        ldi             SystemState, STOP
;delay of few seconds or check if rotor motion is stopped
        ldi             SystemState. REV1
        reti
S3_PRESS:       ;increase Button
        inc             S3BtnState
        cpi             S3BtnState, 3
        brne            END_OF_TMR0_OVF_ISR
        in              Temp1, OCR2
        ldi             Temp2, 30
        add             Temp1, Temp2
        cpi             Temp1, 240
        brsh            END_OF_TMR0_OVF_ISR
        out             OCR2, Temp1
END_OF_TMR0_OVF_ISR:
        Reti
S4_PRESS:
        Inc              S4BtnState
        cpi             S4BtnState, 3
        brne            END_OF_TMR0_OVF_ISR
        brne             END_OF_TMR0_OVF_ISR
        in              Temp1, OCR2
        subi            Temp1,30
        cpi             Temp1, 20
        brlo            END_OF_TMR0_OVF_ISR
        out             OCR2, Temp1
        reti
```