Chapter 1

INTRODUCTION

With the increasing demand for environmentally friendlier and higher fuel economy vehicles, automotive companies are focusing on electric vehicle. These vehicles would also enable meeting the demands for electrical power due to the increasing use of the electronic features to improve vehicle performances, fuel economy emissions, passengers comfort, and safety.

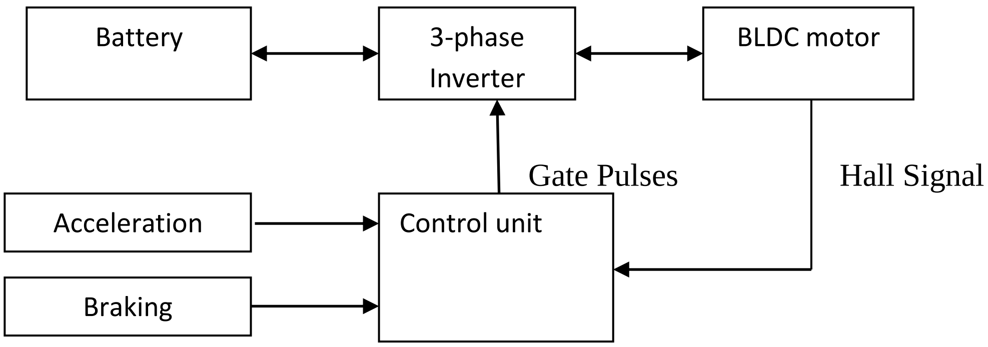


Fig 1.1 Basic Block Diagram of Electric vehicle.

Fig 1.1 shows the basic block of electric vehicle. It can be seen that there are three key components of electric listed below:

1. Battery,
2. Motor and
3. Control unit.

1.1 Batteries

As far as electric scooters are concerned, they need a lot more power to run than a cell phone because they are converting their energy to real, physical, kinetic energy rather than supplying the low-voltage electronic circuit board in a cell phone. This means that you need some serious power to run an electric bike, especially when you consider higher speeds and longer distances as important factors when selecting an electric bike.

Electric bike are mainly powered by three types of batteries that are listed below:

1. Nickel Metal Hydride Battery (NiMH),
2. Sealed Lead Acid Battery(SLA)

3. Lithium ion Battery (Li-ion, LFP, LiPo).

1.2 Motor

For an electric bike, brushed or brushless DC motors can be used.

1.2.1 Brushed DC Motor

The brushed dc electric motor generates torque directly from DC power supplied to the motor by using internal commutation stationary magnets (permanent magnets), and rotating electromagnets.

Advantages of a brushed DC motor include low initial cost, high reliability, and simple control of motor speed. Disadvantages are high maintenance involves regularly replacing the carbon brushes and springs which carry the electric current, as well as cleaning or replacing the commutator. These components are necessary for transferring electrical power from outside the motor to the spinning wire windings of the rotor inside the motor.

Brushes are usually made of graphite or carbon, sometimes with added dispered copper to improve conductivity. In use, the soft brush material wears to fit the diameter of the commutator, and continues to wear. A brush holder has a spring to maintain pressure on the brush as it shortens. For brushes intended to carry more than an ampere or two, a flying lead will be molded into the brush and connected to the motor terminals. Very small brushes may rely on sliding contact with a metal brush holder to carry current into the brush, or may rely on a contact spring pressing on the end of the brush. The brushes in very small, short-lived motors, such as are in toys, may be made of a folded strip of metal that contacts the commutator.

1.2.2 Brushless DC Motor

Brushless DC motors (BLDC) have been a much focused area for numerous motor manufacturers as these motors are increasingly the preferred choice in many applications, especially in the field of motor control technology. BLDC motors are superior to brushed DC motors in many ways, such as ability to operate at high speeds, high efficiency, and better heat dissipation.

They are an indispensable part of modern drive technology, most commonly employed for actuating drives, machine tools, electric propulsion, robotics, computer peripherals and also for electrical power generation. With the development of sensorless technology besides digital control, these motors become so effective in terms of total system cost, size and reliability.

1.3 Control Unit

An Electronic Control Unit is any embedded system in automotive electronics that controls one or more of the systems or subsystems in an electric vehicle. The control unit reads the driver input singles, and is responsible to manage the system energy command the torque, and coordinate the motor ,battery pack and the on-board system.

1.4 Types of EVs

Types of electric vehicle are listed below:-

1. EVs (also known as plug-in electric vehicles) derive all or part of their power from electricity supplied by the electric grid. They include AEVs and PHEVs**.**

2. AEV**s** (All-Electric Vehicles) are powered by one or more electric motors. They receive electricity by plugging into the grid and store it in batteries. They consume no petroleum-based fuel and produce no tailpipe emissions. AEVs include Battery Electric Vehicles (BEVs) and Fuel Cell Electric Vehicles (FCEVs)

3. PHEV**s** (Plug-in Hybrid Electric Vehicles) use batteries to power an electric motor, plug into the electric grid to charge, and use a petroleum-based or alternative fuel to power the internal combustion engine. Some types of PHEVs are also called Extended-Range Electric Vehicles (EREVs).

1.5 Significance of IN WHEEL motor in Electric vehicle

New in-wheel motor systems modify the hub of each electric-vehicle (EV) wheel by adding a complete drive train that supplies torque to its associated tire . Also included with these in-wheel motor systems are braking components and the motor-drive electronics. Road tests will demonstrate in-wheel motor system performance and durability, which will ultimately impact EV performance.

At present, it appears that in-wheel motors can provide advantages in several areas. Conventional vehicles implement functions like traction and stability control by slowing down the wheel that's spinning faster than it should. But that approach is rather slow to respond and is limited to applying retarding force. To unlock a skidding tire, it would be preferable to apply some driving torque. With in-wheel motors, you can do that. You can deliver precisely controlled braking or motoring torque on a millisecond timescale and thereby greatly improve traction and stability control, reducing stopping distances and enhancing drivability and safety.

In-wheel motors also allow torque vectoring the application of different torques to different wheels that can markedly improve handling. In a car with an in-wheel motor system, this hardware ability comes essentially free, requiring only the right software. The result can be a vehicle than corners as if on rails.

1.6 In-Wheel Evolution

Actually, the basic in-wheel motor technology dates back to the end of the 19th century, when Ferdinand Porsche (of the present company) in Vienna and Joseph Ledwinka and Fred Newman in Chicago attached an electric motor to each wheel of a horseless carriage to provide power simply, efficiently, and controllably . Their rudimentary design didn't have the sophistication of current in-wheel motor techniques.

Today's in-wheel technology developers, such as Protean Electric, claim they have overcome or are close to overcoming the challenges of using these motors: cost, additional mass, and road shocks. Motor-control software is also a key design challenge. It must make decisions about what torque to demand from each motor at each instant, based on the vehicle's condition and the driver's commands.

Under normal circumstances, running two motors instead of just one is straightforward. But if a fault occurs in one motor, the controller needs to prevent a dangerous asymmetry from developing, which would cause the vehicle to be pulled to one side in an uncontrollable way. Protean's motors fit behind the wheels of a vehicle, so they can be used as part of a drive system that doesn't require a gearbox, differential, or drive shafts. This creates an energy-efficient drive train that potentially saves cost, reduces weight, and frees up space on board the vehicle that was previously dedicated to drive train components.

According to Protean Electric, its in-wheel motors can increase fuel economy by over 30%, depending on the battery size and driving cycle in a hybrid or plug-in hybrid vehicle. It is also capable of enabling torque vectoring by applying individual torque at optimal levels to each wheel to improve vehicle safety and handling.

1.7 In-wheel motors still have two challenges to overcome

1. Reducing unsprung mass because the weight of a motor will be carried in each powered wheel.
2. Protecting against road shocks and heat from braking due to the proximity of the in-wheel motor to the wheels.

Chapter 2

BRUSHLESS DC MOTOR

2.1 What is a Brushless DC motor (BLDC)?

A brushless DC motor (known as BLDC) is a permanent magnet synchronous electric motor which is driven by direct current (DC) electricity and it accomplishes electronically controlled commutation system (commutation is the process of producing rotational torque in the motor by changing phase currents through it at appropriate times) instead of a mechanically commutation system. BLDC motors are also referred as trapezoidal permanent magnet motors.

Unlike conventional brushed type DC motor, wherein the brushes make the mechanical contact with commutator on the rotor so as to form an electric path between a DC electric source and rotor armature windings, BLDC motor employs electrical commutation with permanent magnet rotor and a stator with a sequence of coils. In this motor, permanent magnet (or field poles) rotates and current carrying conductors are fixed.

Fig 2.1 BLDC motor

The armature coils are switched electronically by transistors or silicon controlled rectifiers at the correct rotor position in such a way that armature field is in space quadrature with the rotor field poles. Hence the force acting on the rotor causes it to rotate. Hall sensors or rotary encoders are most commonly used to sense the position of the rotor and are positioned around the stator. The rotor position feedback from the sensor helps to determine when to switch the armature current.

This electronic commutation arrangement eliminates the commutator arrangement and brushes in a DC motor and hence more reliable and less noisy operation is achieved. Due to the absence of brushes BLDC motors are capable to run at high speeds. The efficiency of BLDC motors is typically 85 to 90 percent, whereas as brushed type DC motors are 75 to 80 percent efficient. There are wide varieties of BLDC motors available ranging from small power range to fractional horsepower, integral horsepower and large power ranges.

2.2 Construction and Operating Principle

BLDC motors are a type of synchronous motor. This means the magnetic field generated by the stator and the magnetic field generated by the rotor rotates at the same frequency. BLDC motors do not experience the “slip” that is normally seen in induction motors.

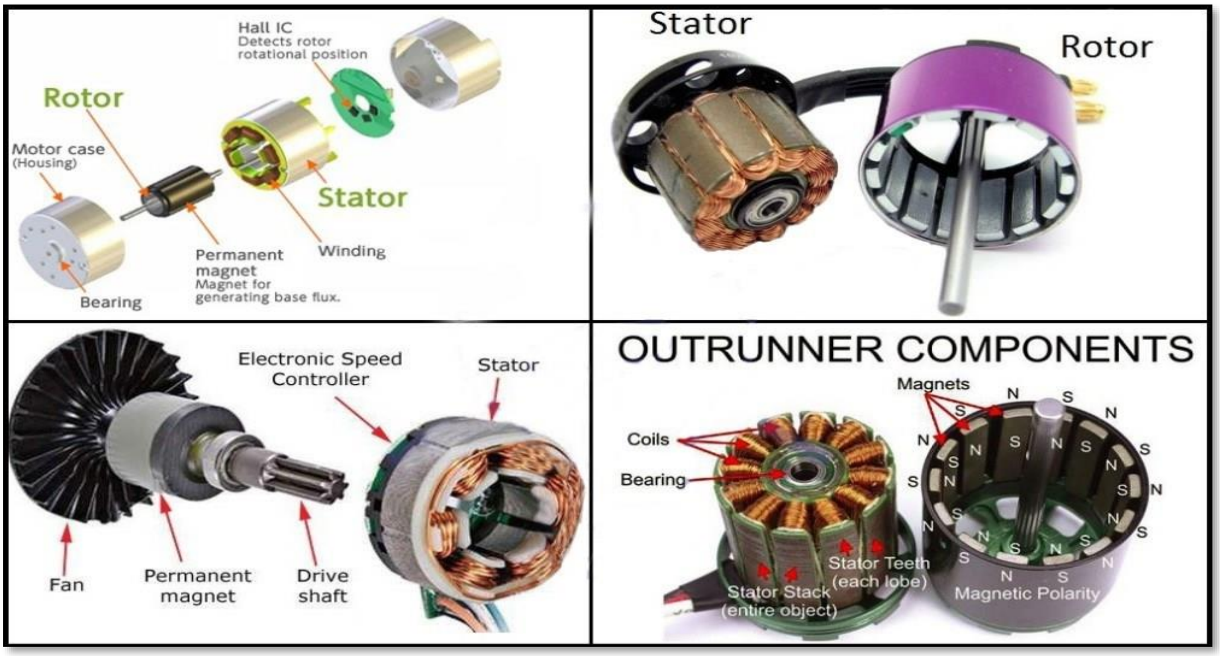


Fig 2.2 construction of BLDC motor

BLDC motors come in single-phase, two-phase and three-phase configurations. Corresponding to its type, the stator has the same number of windings. Out of these, 3-phase motors are the most popular and widely used. This application note focuses on 3-phase motors.

2.3 Stator

The stator of a BLDC motor consists of stacked steel laminations with windings placed in the slots that are axially cut along the inner periphery (as shown in Figure 2.3). Traditionally, the stator resembles that of an induction motor; however, the windings are distributed in a different manner. Most BLDC motors have three stator windings connected in star fashion. Each of these windings is constructed with numerous coils interconnected to form a winding. One or more coils are placed in the slots and they are interconnected to make a winding. Each of these windings is distributed over the stator periphery to form an even numbers of poles.

There are two types of stator windings variants: trapezoidal and sinusoidal motors. This differentiation is made on the basis of the interconnection of coils in the stator windings to give the different types of back Electromotive Force (EMF).

Fig. 2.3: Stator of BLDC Motor

The stator of a BLDC motor consists of stacked steel laminations with windings placed in the slots that are axially cut along the inner periphery (as shown in Figure 2.3). Traditionally, the stator resembles that of an induction motor; however, the windings are distributed in a different manner. Most BLDC motors have three stator windings connected in star fashion. Each of these windings are constructed with numerous coils interconnected to form a winding. One or more coils are placed in the slots and they are interconnected to make a winding. Each of these windings are distributed over the stator periphery to form an even numbers of poles. Basically the permanent magnet synchronous motors are classified based on the back Electromotive Force (EMF) of the motor. They are as follows:

- Permanent Magnet Synchronous Motor (PMSM)
- Brushless DC Motor (BLDCM)

This differentiation is made on the basis of the interconnection of coils in the stator windings to give the different types of back EMF. The motor with sinusoidal back EMF is known as PMSM and the motor with trapezoidal back EMF is known as BLDC motoras shown in Figure 2.4 and Figure 2.5. In addition to the back EMF, The winding is excited by quasi square wave phase current in BLDC Motor while it is excited by sinusoidal phase in PMSM.

This makes the torque output by a sinusoidal motor smoother than that of a trapezoidal motor. However, this comes with an extra cost, as the sinusoidal motors take extra winding interconnections because of the coils distribution on the stator periphery, thereby increasing the copper intake by the stator windings.

Depending upon the control power supply capability, the motor with the correct voltage rating of the stator can be chosen. Forty-eight volts, or less voltage rated motors are used in automotive, robotics, small arm movements and so on. Motors with 100 volts, or higher ratings, are used in appliances, automation and in industrial applications.

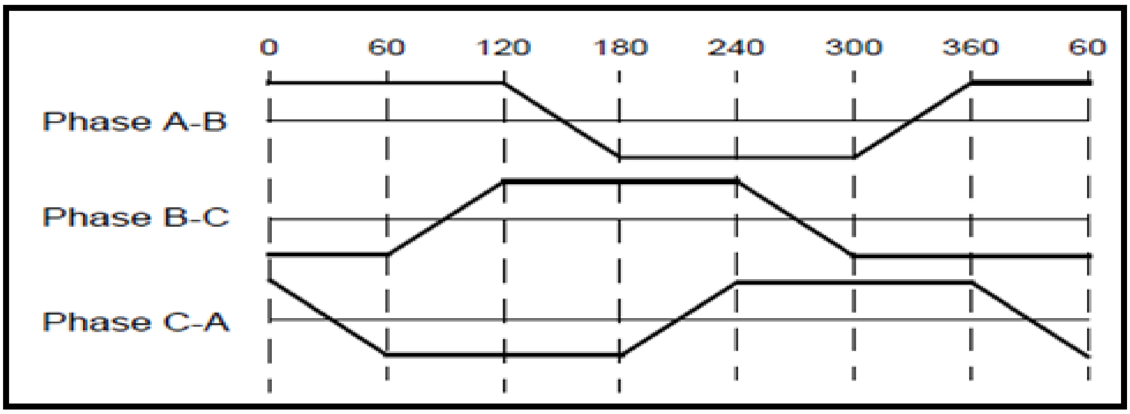


Fig.2.4: Trapezoidal Back EMF

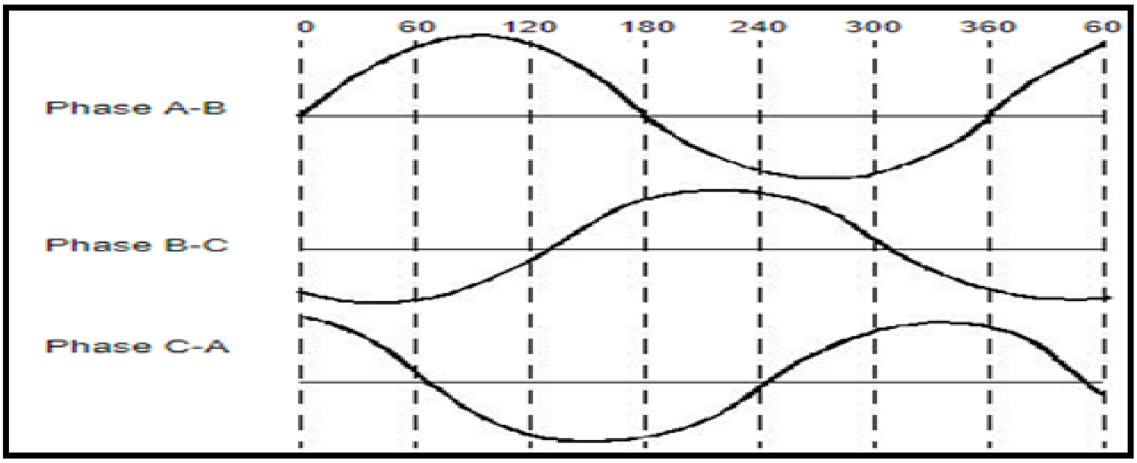
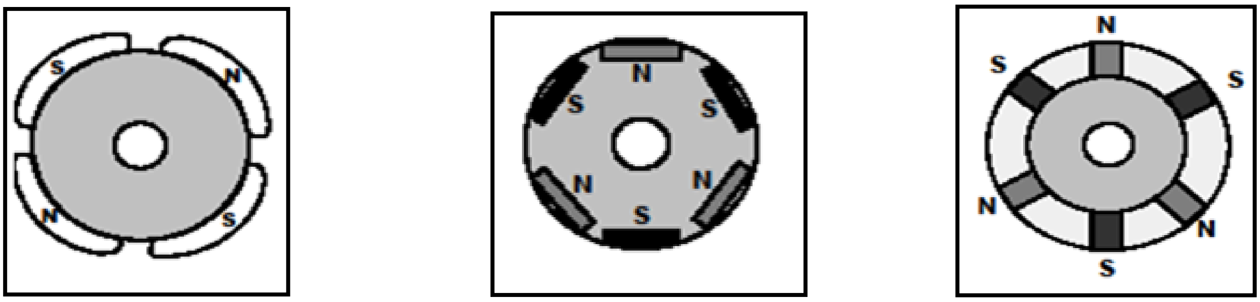


Fig. 2.5: Sinusoidal Back EMF

2.4 Rotor

The rotor is made of permanent magnet and can vary from two to eight pole pairs with alternate North (N) and South (S) poles.

Based on the required magnetic field density in the rotor, the proper magnetic material is chosen to make the rotor. Ferrite magnets are traditionally used to make permanent magnets. As the technology advances, rare earth alloy magnets are gaining popularity. The ferrite magnets are less expensive but they have the disadvantage of low flux density for a given volume. In con- trust, the alloy material has high magnetic density per Volume and enables the rotor to compress further for the same torque. Also, these alloy magnets improve the size-to-weight ratio and give higher torque for the same size motor using ferrite magnets.



Circular Core with With on the periphery | Rectangular magnet embedded in the rotor | Magnets inserted in the core

Fig. 2.6: Rotor Magnet Cross Section

2.4 Hall Sensors

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. It is important to know the rotor position in order to understand which winding will be energized following the energizing sequence. Rotor position is sensed using Hall Effect sensors embedded into the stator.

Most BLDC motors have three Hall sensors embedded into the stator on the non-driving end of the motor. Whenever the rotor magnetic poles pass near the Hall sensors, they give a high or low signal, indicating the Nor S pole is passing near the sensors. Based on the combination of these three Hall sensor signals, the exact sequence of commutation can be determined.

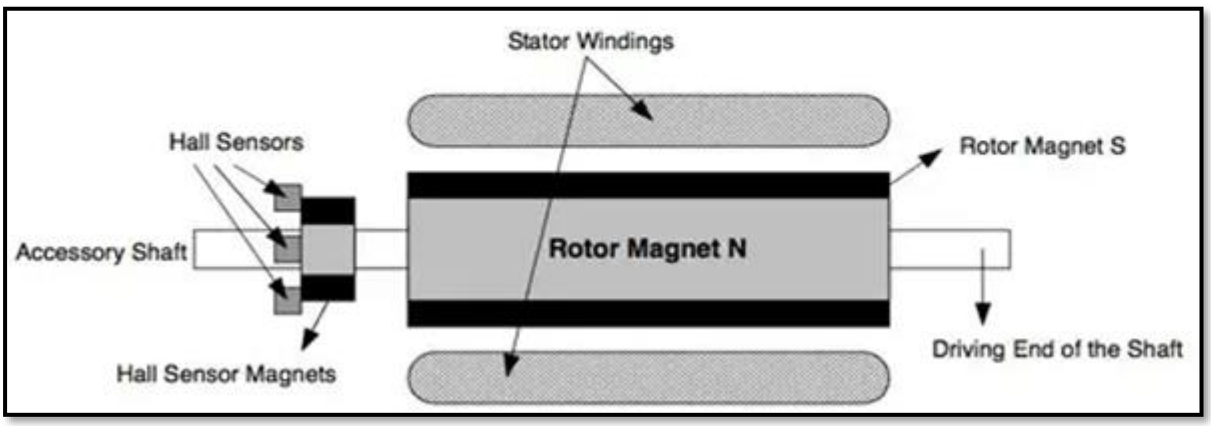


Fig. 2.7: BLDC Motor Transverse Section

Fig 2.7shows a transverse section of a BLDC motor with a rotor that has alternate N and S permanent magnets. Hall sensors are 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.

To simplify the process of mounting the Hall sensors onto the stator, some motors may have the Hall sensor magnets on the rotor, in addition to the main rotor magnets. These are a Scaled down replica version of the rotor.

Therefore, whenever the rotor rotates, the Hall sensor magnets give the same effect as the main magnets. The Hall sensors are normally mounted on a PC board and fixed to the enclosure cap on the non-driving end. This enables users to adjust the complete assembly of Hall sensors, to align with the rotor magnets, in order to achieve the best performance.

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.

2.5 Operation of BLDC Motor

BLDC motor works on the principle similar to that of a conventional DC motor, i.e., the Lorentz force law which states that, “whenever a current carrying conductor placed in a magnetic field it experiences a force”. As a consequence of reaction force, the magnet will experience an equal and opposite force.

In case BLDC motor the current carrying conductor is stationary while the permanent magnet moves.

When the stator coils are electrically switched by a supply source, it becomes electromagnet and starts producing the uniform field in the air gap. Through the source of supply is DC switching makes to generate an AC voltage with Trapezoidal shape. Due to the force of interaction between electromagnet stator and permanent rotor, the rotor continues to rotate.

2.6 Torque/Speed Characteristics

There are two torque parameters used to define a BLDC motor, peak torque (TP) and rated torque (TR). During continuous operations, the motor can be loaded up to the rated torque. As discussed earlier, in a BLDC motor, the torque remains constant for a speed range up to the rated speed. The motor can be run up to the maximum speed, which can be up to 150% of the rated speed, but the torque starts dropping.

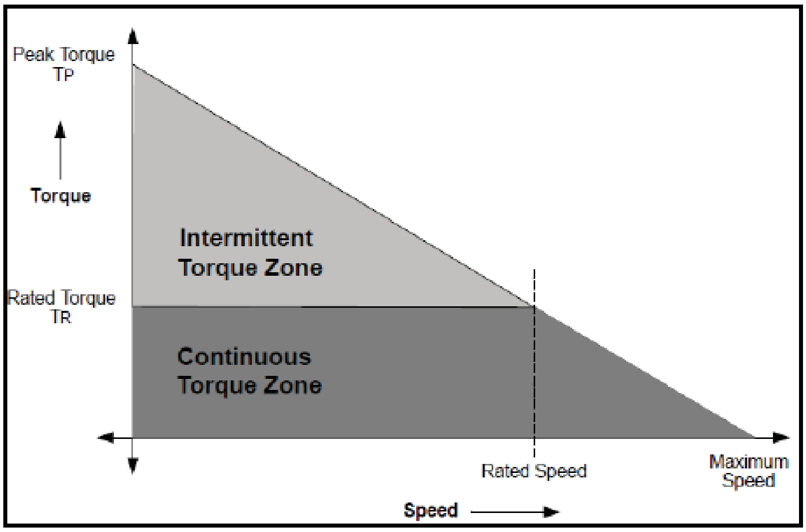


Fig 2.8: Torque/Speed Characteristics

Applications that have frequent starts and stops and frequent reversals of rotation with load on the motor, demand more torque than the rated torque. This requirement comes for a brief period, especially when the motor starts from a standstill and during acceleration. During this period, extra torque is required to over- come the inertia of the load and the rotor itself. The motor can deliver a higher torque, maximum up to peak torque, as long as it follows the speed torque curve.

2.6.1 Continuous Zone

During continues operations, the motor can be loaded up to rated torque. This requirements comes for brief period, especially when the motor starts from stand still during acceleration. During this period, extra torque is overcome the inertia of load & the rotor itself. The continuous limit is usually determined by heat transfer and temperature rise.

2.6.2 Intermittent Zone

The speed is essentially controlled by the voltage, and may be varied by varying the supply voltage. The motor then draws just enough current to drive the torque at this speed. As the load torque is increased, the speed drops, and the drop is directly proportional to the phase resistance and the torque. The voltage is usually controlled by chopping or PWM. This gives rise to a family of torque/speed characteristics in the boundaries of continuous and intermittent operation. The intermittent limit may be determined by the maximum ratings of semiconductor devices in the controller, or by temperature rise.

2.7 Compare BLDC Motor to other Motor

Compared to brush DC motors and induction motors, BLDC motors have many advantages and few disadvantages. Brushless motors require less maintenance, so they have a longer life compared with brushed DC motors. BLDC motors produce more output power per frame size than brushed DC motors and induction motors. Because the rotor is made of permanent magnets, the rotor inertia is less, compared with other types of motors. This improves acceleration and deceleration characteristics, shortening operating cycles. Their linear speed/torque characteristics produce predictable speed regulation. With brushless motors, brush inspection is eliminated, making them ideal for limited access areas and applications where servicing is difficult.

BLDC motors operate much more quietly than brushed DC motors, reducing Electromagnetic Interference (EMI). Low-voltage models are ideal for battery operation, portable equipment or medical applications.

Table 2.1 and Table 2.2 show the comparison of BLDC Motor with Brushed DC Motor and BLDC Motor with Induction Motor. The necessity of the comparison will extract the performance of the PMBLDC Motor.

Table 2.1 Comparison of BLDC Motor with Brushed DC Motor

Feature	**BLDC Motor**	**Brushed DC Motor**
Commutation	Electronic commutation based on Hall position sensors	Brushed commutation
Maintenance	Less required due to the absence of brushes	Periodic maintenance is required
Life	Longer	Shorter
Speed/Torque Characteristics	Flat – Enables operation at all the speed with rated load	Moderately flat – At higher speed, brush friction increases, thus reducing useful torque
Efficiency	High	Moderate
Output Power/ Frame Size	High – Reduced size due to superior thermal characteristics. Because BLDC has the windings on the stator, which is connected to the case, the heat dissipation is better	Moderate/Low – The heat produced by the armature is dissipated in the air gap, thus increasing the temperature in the air gap and limiting specs on the output power/frame size

Rotor Inertia	Low, because it has permanent magnets on the rotor. This improves the dynamic response	Higher rotor inertia which limits the dynamic characteristics
Speed Range	Higher – No mechanical limitation imposed by brushes/commutator	Lower – Mechanical limitations by the brushes
Electric Noise Generation	Low	Arcs in the brushes will generate noise causing EMI
Cost of Building	Higher – Since it has permanent magnets, building costs are higher	Low
Control	Complex and expensive	Simple and inexpensive

The comparison of the proposed method with Induction motor shows the advantage of the proposed model with the conventional field and the Table 2.2 which represents the need of the BLDC motor replacement.

Table 2.2 Comparison of BLDC Motor with Induction Motor

Features	**BLDC Motors**	**Induction Motors**
Speed/Torque Characteristics	Flat – Enables operation at all speeds with rated load	Nonlinear – Lower torque at lower speed
Output Power/ Frame Size	High – Since it has permanent magnets on the rotor, smaller size can be achieved for a given output power	Moderate – Since both stator and rotor have windings, the output power to size is lower than BLDC
Rotor Inertia	Low – Better dynamic characteristics	High – Poor dynamic characteristics
Starting Current	Rated – No special starter circuit required	Approximately up to seven times of rated – Starter circuit rating should be carefully selected
Slip	No slip is experienced between stator and rotor frequencies	The rotor runs at a lower frequency than stator

2.8 Advantages of BLDC motor

- It has no mechanical commutator and associated problems.
- High efficiency due to the use of permanent magnet rotor
- High speed of operation even in loaded and unloaded conditions due to the absence of brushes that limits the speed.
- Smaller motor geometry and lighter in weight than both brushed type DC and induction AC motors.
- Long life as no inspection and maintenance is required for commutator system.
- Higher dynamic response due to low inertia and carrying windings in the stator.
- Less electromagnetic interference.
- Quite operation (or low noise) due to absence of brushes.

2.9 Disadvantages of BLDC motor

- These motors are costly.
- Electronic controller required control this motor is expensive.
- Not much availability of many integrated electronic control solutions, especially for tiny BLDC motors.
- Requires complex drive circuitry.
- Need of additional sensors

2.10 Application of BLDC motor

Brushless DC Motors (BLDC) are used for a wide variety of application requirements such as varying loads, constant loads and positioning applications in the fields of industrial control, automotive, aviation, automation systems, health care equipments, etc. Some specific applications of BLDC motors are

- Computer hard drives and DVD/CD players
- Electric vehicles, hybrid vehicles, and electric bicycles
- Industrial robots, CNC machine tools, and simple belt driven systems
- Washing machines, compressors and dryers
- Fans, pumps and blowers

2.10.1 BLDC motor used in electric vehicles

Conception of E-bike History of electric bikes began in 1890 but on the 31st of December 1895 Ogden Bolton was granted the first patent for the battery powered bicycle. His idea was to place the motor in the rear wheel hub of the bicycle. Even if over the next many years, the constructors have created various types of drives, from belt transmissions to planetary gears, the Bolton's idea is considered the best concept to this day. His motor was the 6-poles DC brush and commutator motor which could take up to 100 A from a 10 V battery. Today, the most widely used drives in the E-bike constructions are the BrushLess Direct Current motors (BLDC) with the high density neodymium permanent magnets and continuous powers up to 6 kW. The robust frame construction combined with the powerful electric motor make that these vehicles can compete with motorcycles and are of great interest today. Electric bikes have become popular all around the world thanks to the electric bike parts manufacturers. They design and produce all kinds of electric bike components that meet requirements of the customers. For example, nowadays one can buy a set for conversion a classic bicycle into an electric one. With the user's manual, the ready-made elements are easy to assemble and to configure. This fast growing market makes the E-bike companies compete with each other offering the more and more efficient drive solutions.

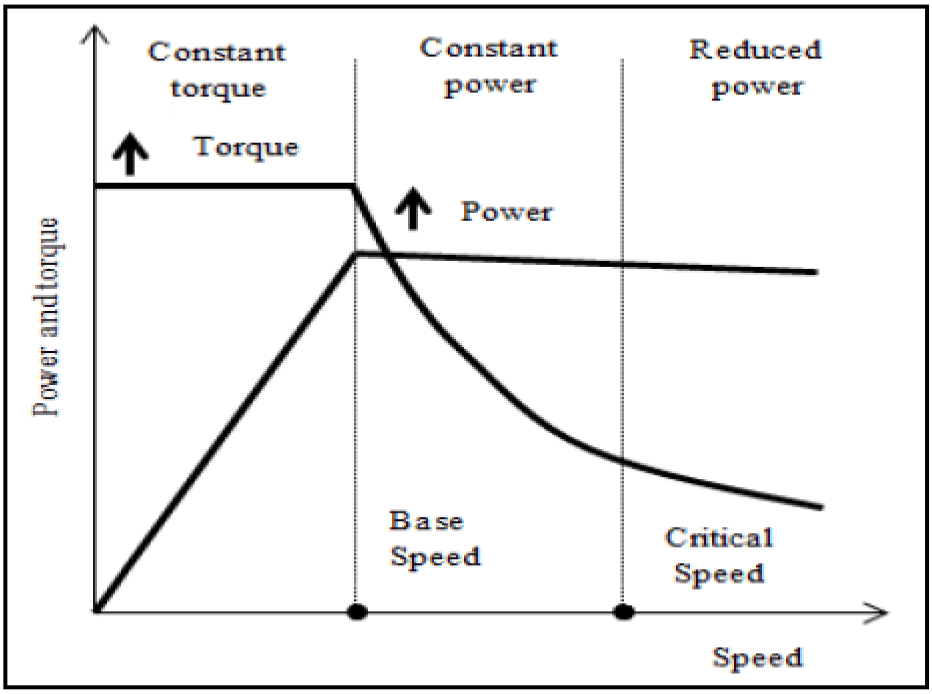


Fig 2.9 Power v/s Speed

Chapter 3

SIMULATION RESULT

Following motor parameters are used in six step operation:

Stator phase resistance: 2.87ohm

Voltage constant: 146.607

Stator phase induction: 8.5e-3 H

Flux linkage: 0.175

Torque constant 1.4

3.1 Six-Step operation of BLDC motor

Consider fig. no2.7 to understand the basic six step operation of BLDC motor. In this three-phase source inverter is connected to a BLDC motor, in motor hall sensor sense the position of stator winding and gives it to control unit, then it decides which switch is to be triggered this method of commutation is known as electronic commutation.

Based on the waveform of Trapezoidal back emf and current given in the fig no. 3.1 we have hall sensor output and switching sequence table

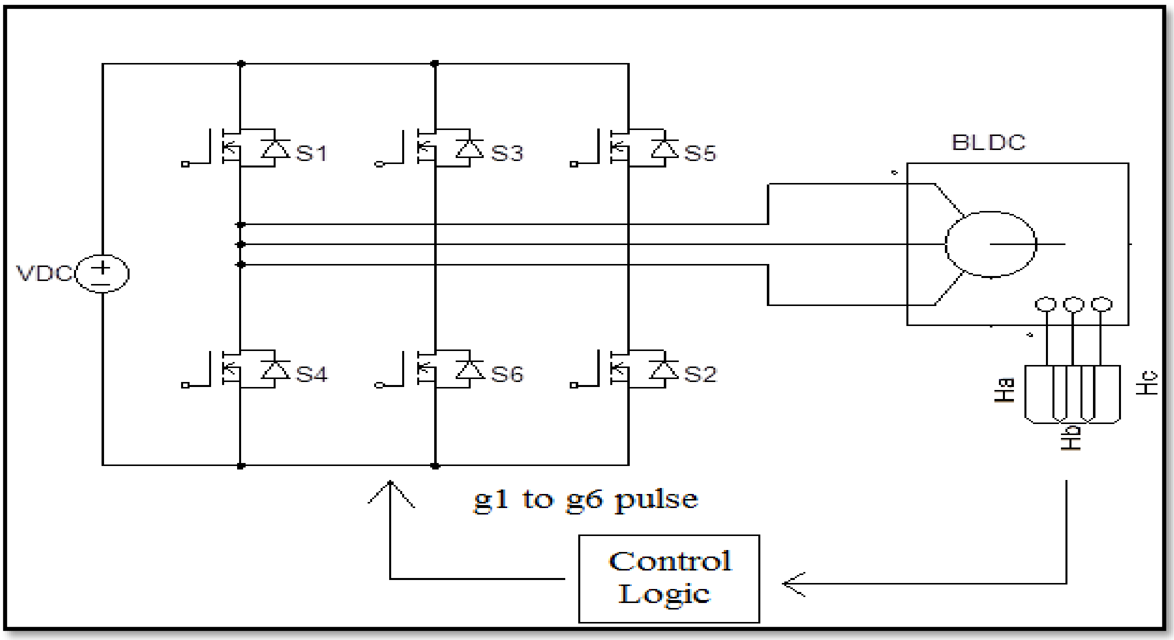


Fig no. 3.1 basic six step operation setup

Table no. 3.2 Commutation Sequence table.

Sr.no.	Ha	Hb	Hc	G_1	G_2	G_3	G_4	G_5	G_6
1	0	0	1	0	0	0	0	1	1
2	1	0	1	1	0	0	0	0	1
3	1	0	0	1	1	0	0	0	0
4	1	1	0	0	1	1	0	0	0
5	0	1	0	0	0	1	1	0	0
6	0	1	1	0	0	0	1	1	0

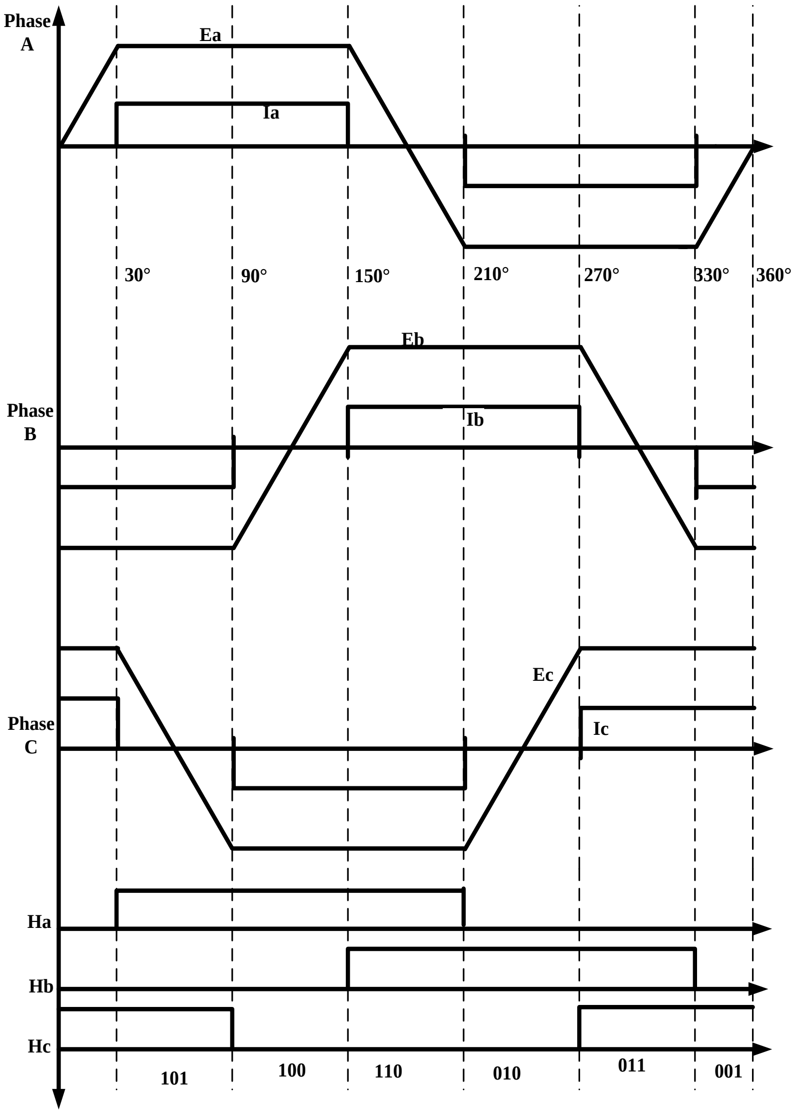


Fig 3.2 waveform of Back emf, Current, and Hall sensors

3.3 Basic Six step Simulation result

We had discussed the basic six step of BLDC motor in section 2.8. Similar we had performed the on Matlab to verify results of back emf, Current, Gate pulse and Hall Sensors. Also we had obtained the speed and torque result.

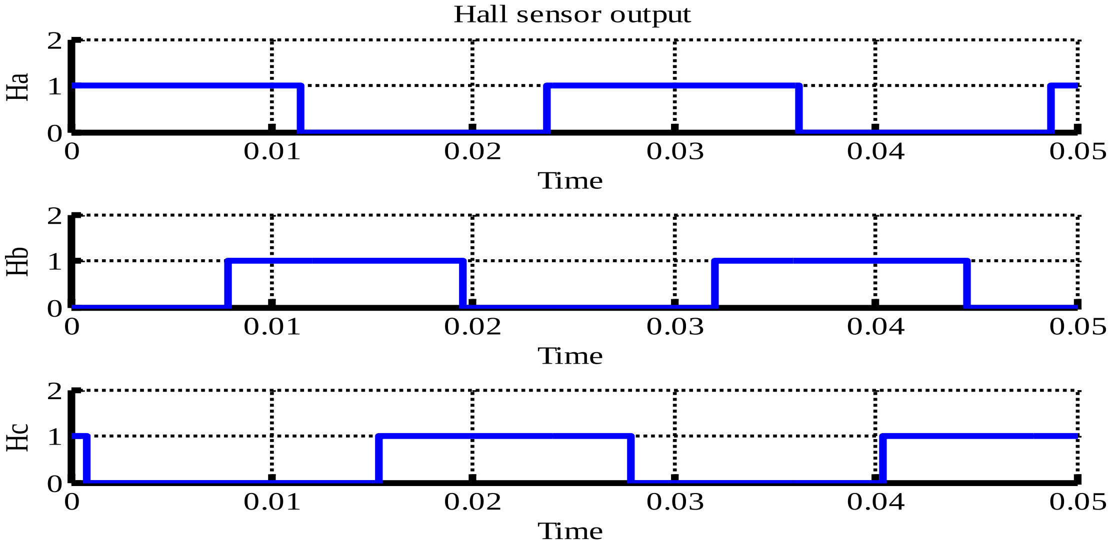


Fig.3.3:Waveform of Hall sensor

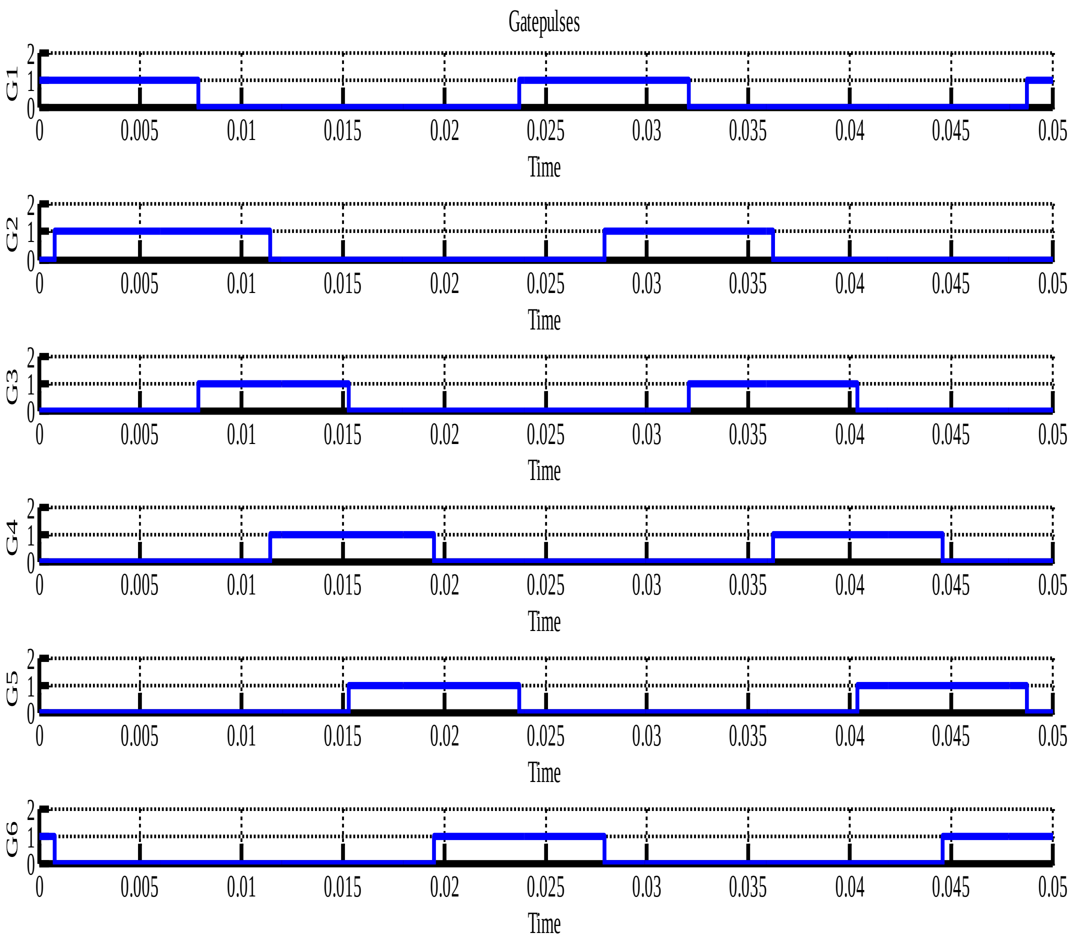


Fig.3.4:Waveform of Gate pulse

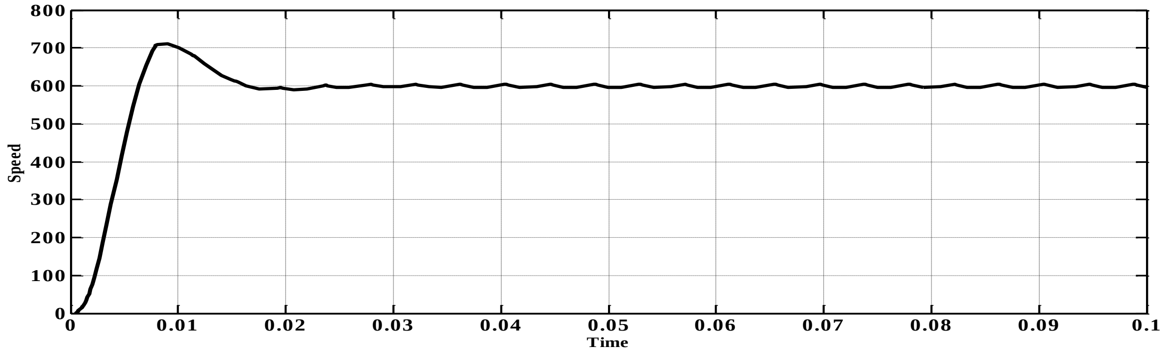


Fig.3.5:Speed V/S Time curve

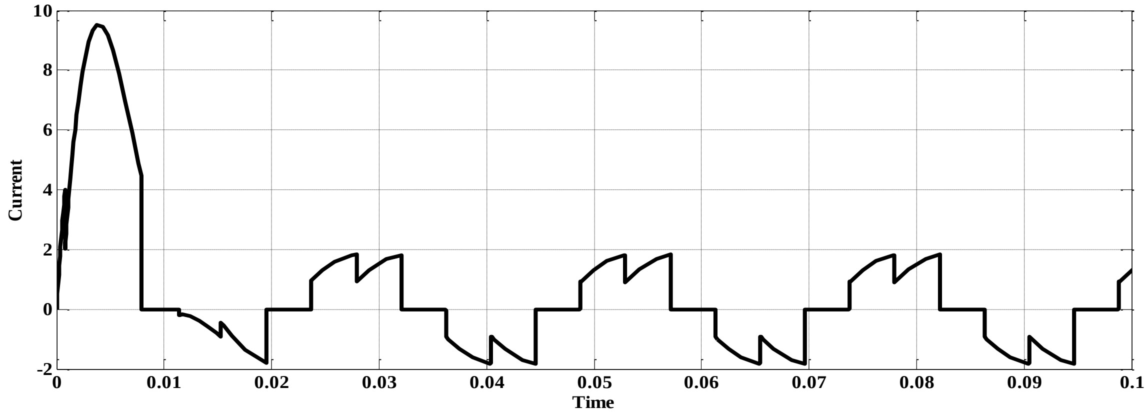


Fig.3.6:Current V/S Time curve

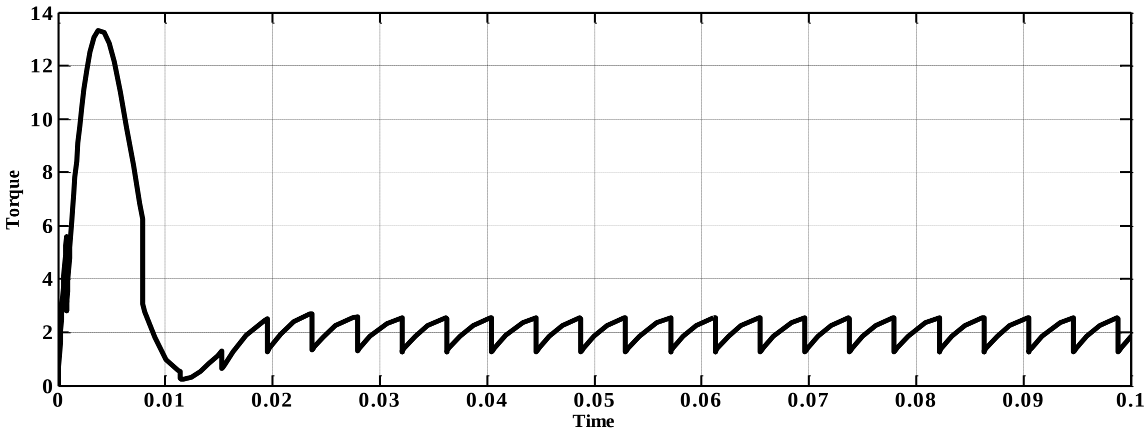


Fig.3.7:Torque V/S Time curve

3.4 PWM technique

3.4.1 Step PWM

For a controlling of motor we had used a PWM technique, in which we had given step input, is compared with a triangular wave and then it is given to upper switches of inverter i.e S_1, S_3, and S_5.

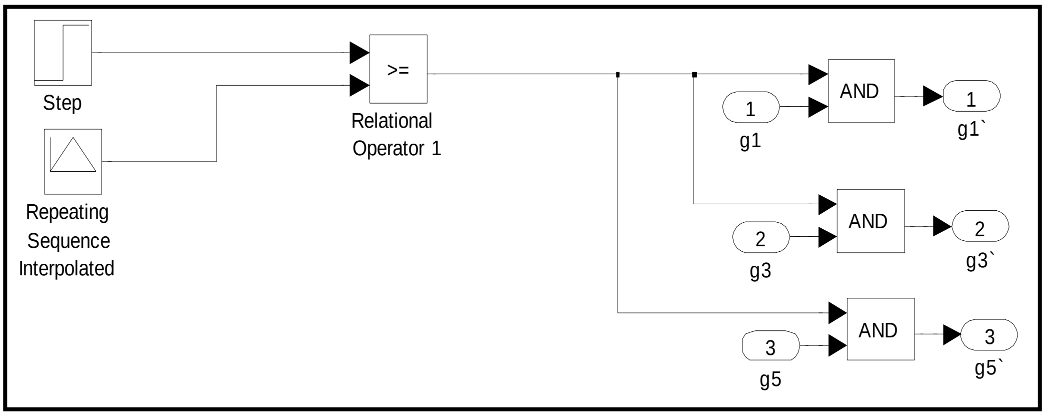


Fig no.3.8 Schematic of PWM ON with step input.

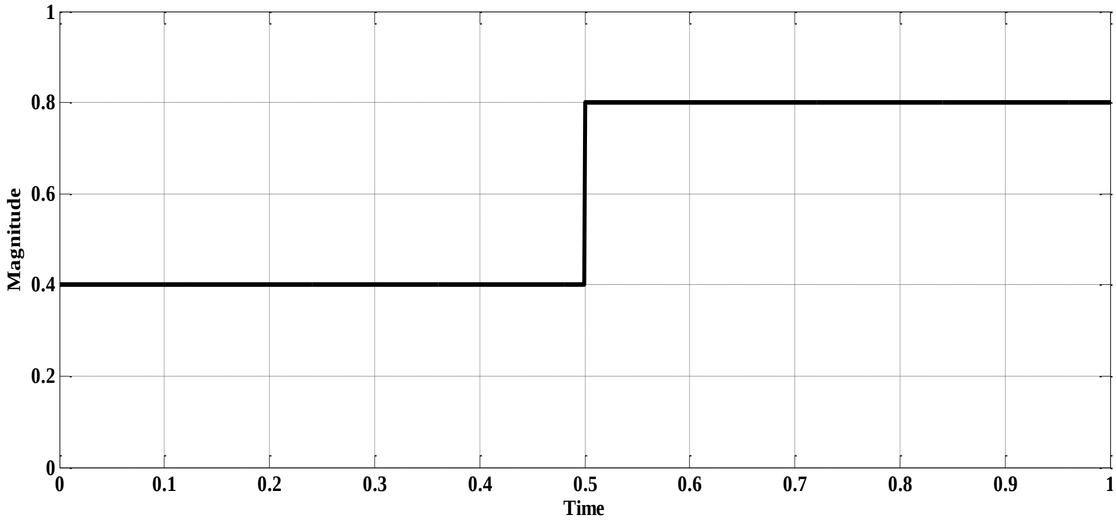


Fig 3.9 Step input

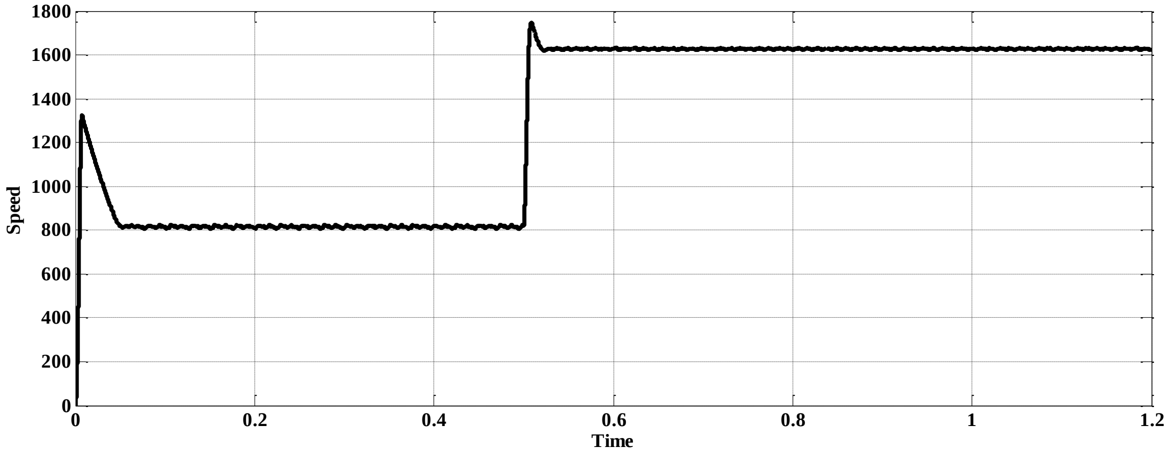


Fig 3.10 Speed v/s Time

In this Step unit at 0.5 time magnitude increases from 0.4 to 0.8. The effect of this reflects on the curve of speed v/s time given in fig 3.10

3.4.2 Forward PWM

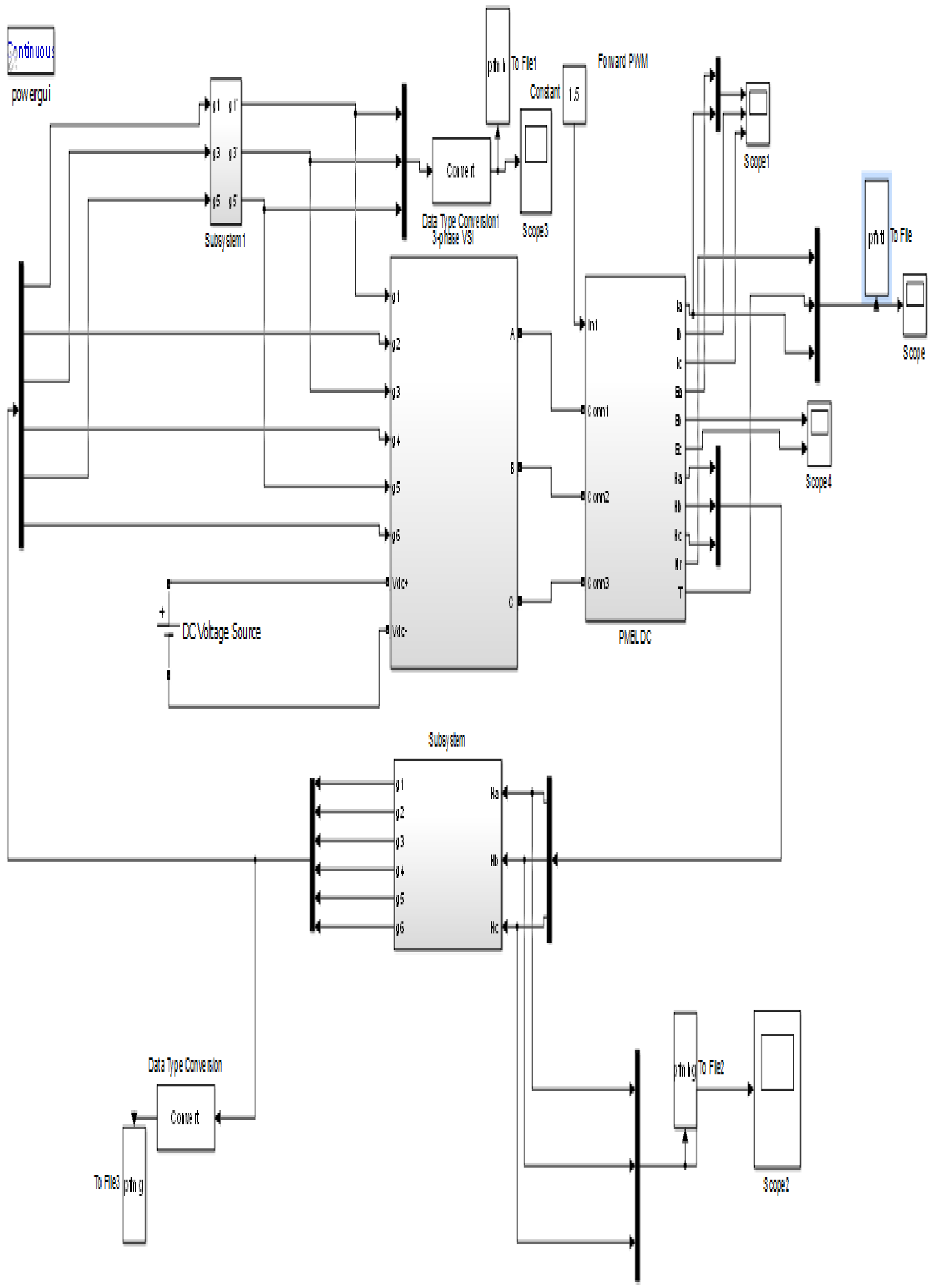


Fig 3.11 Forward PWM Technic

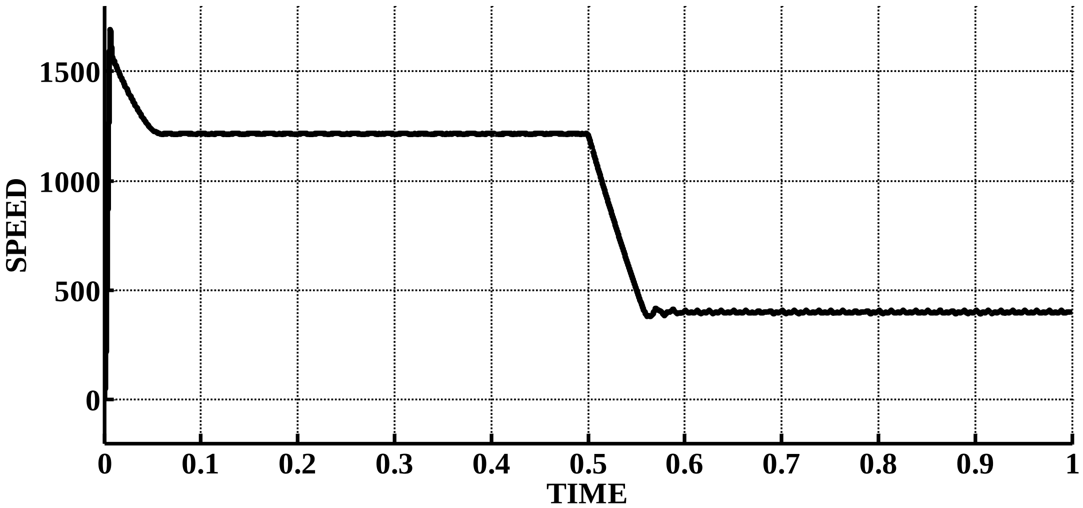


Fig 3.12 speed v/s time

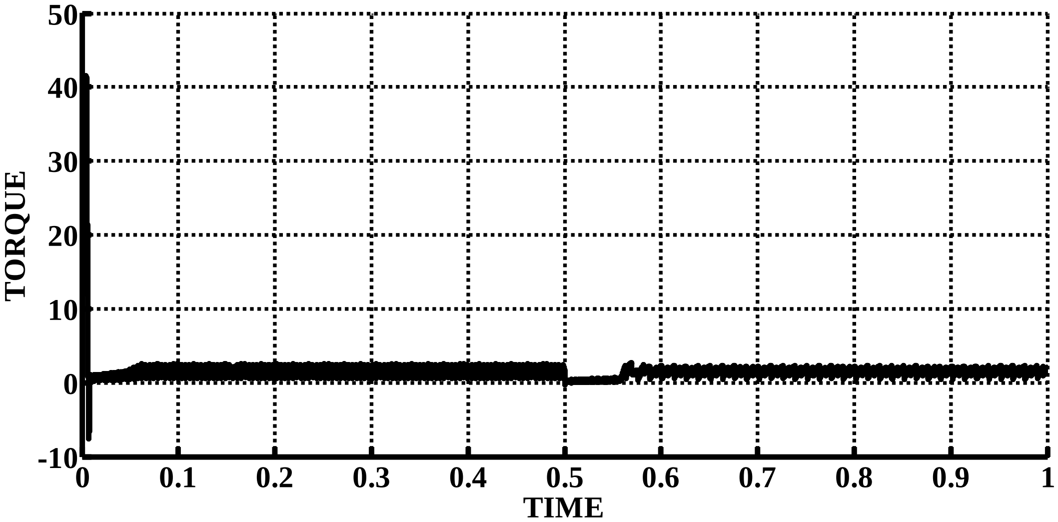


Fig 3.13 torque v/s time

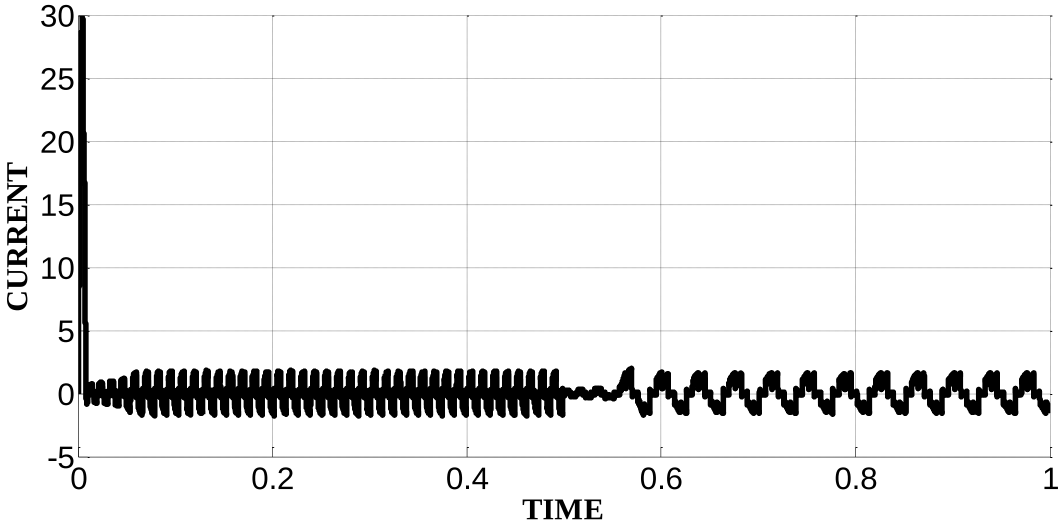


Fig 3.14 current v/s time

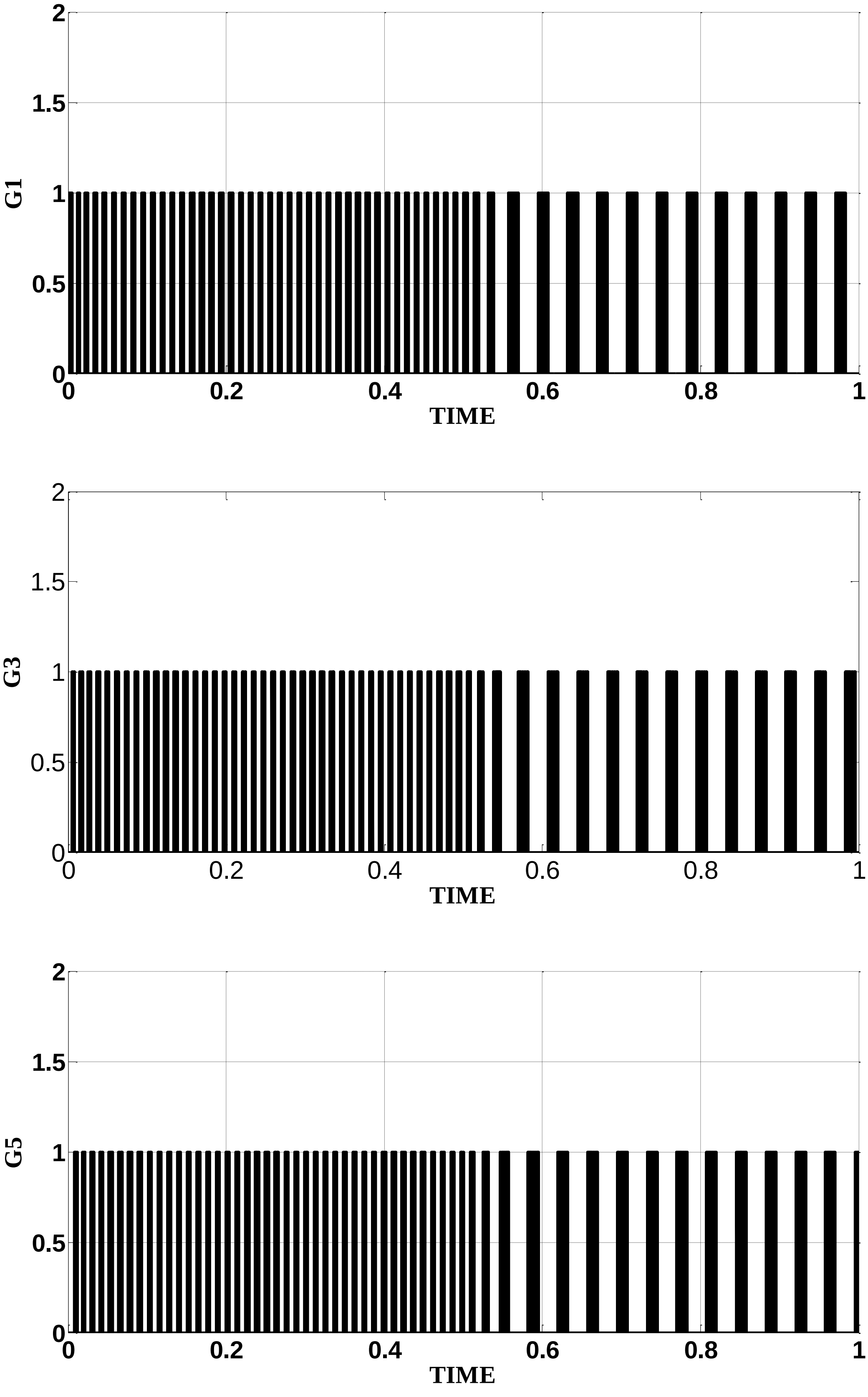


Fig 3.15 Gate pulse signal for forward PWM

3.4.3 Reverse PWM Technic

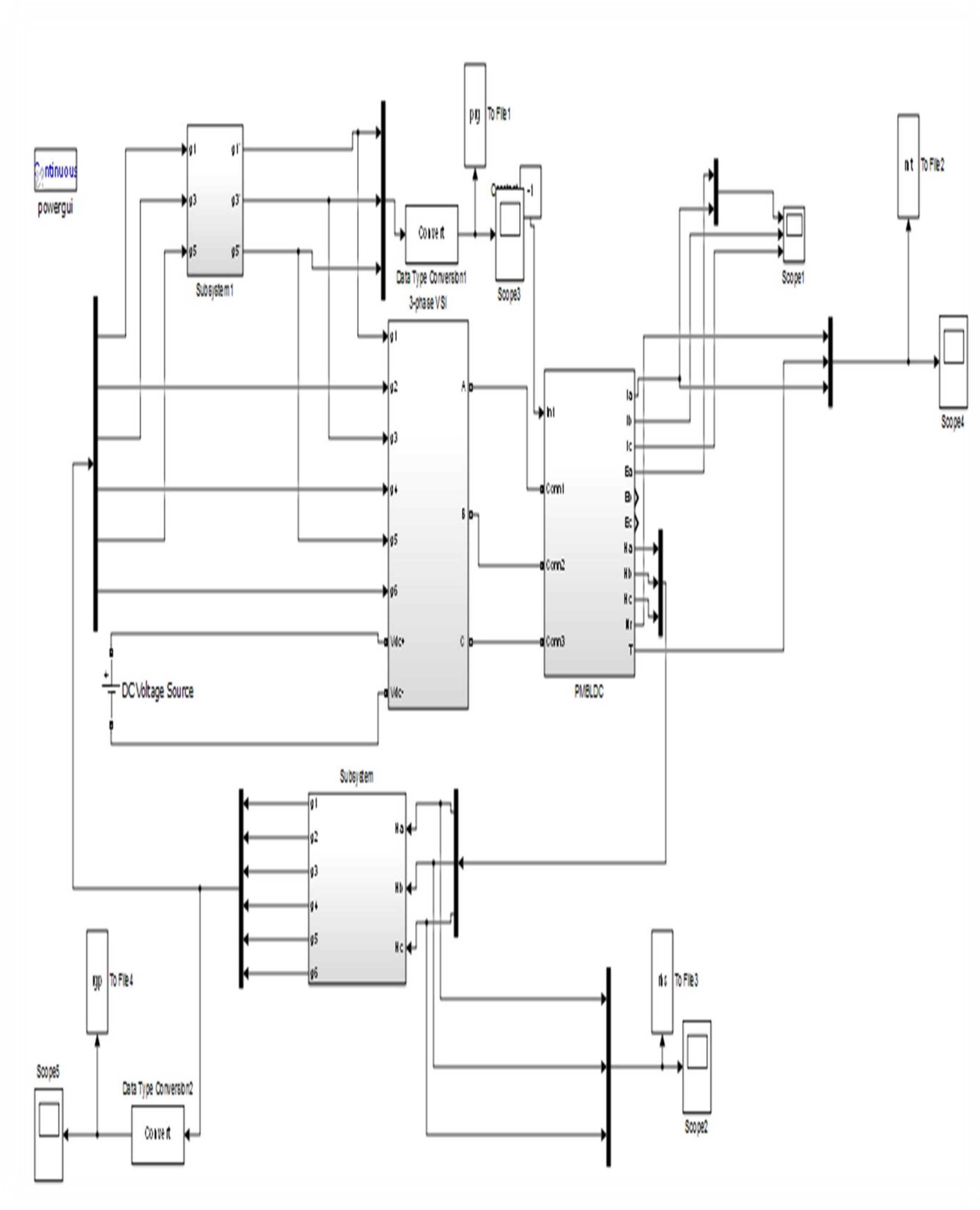


Fig 3.16:Revers PWM technic model

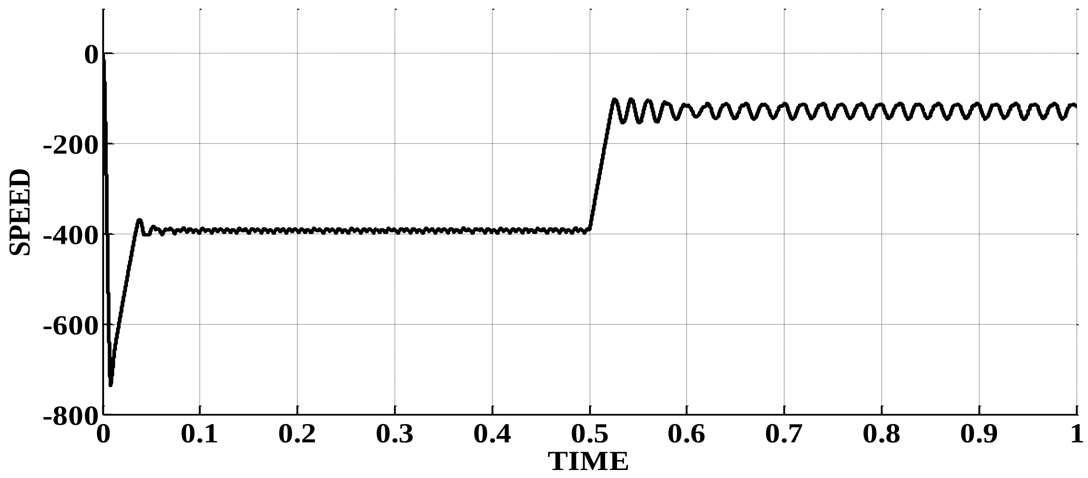


Fig 3.17: speed v/s Time

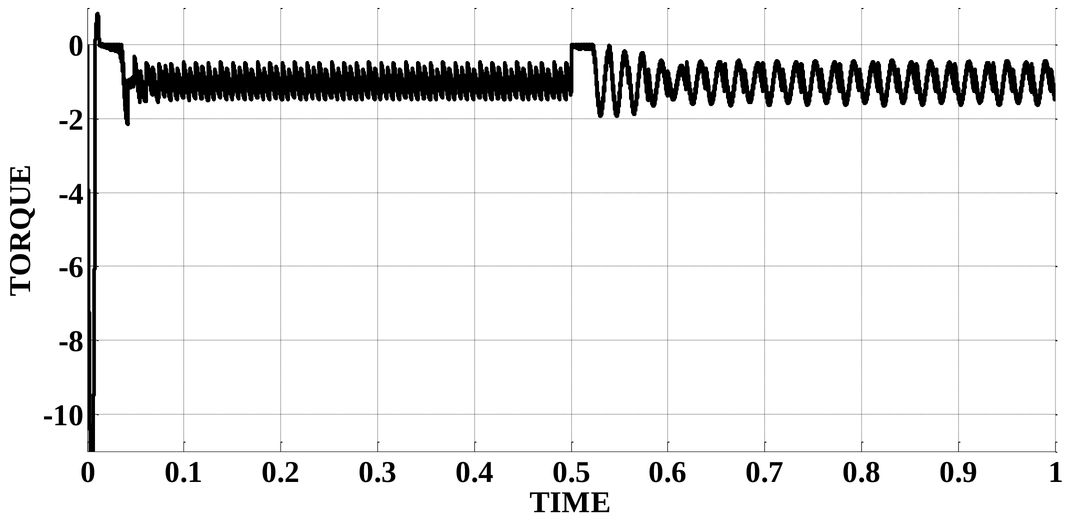


Fig 3.18 Torque v/s time

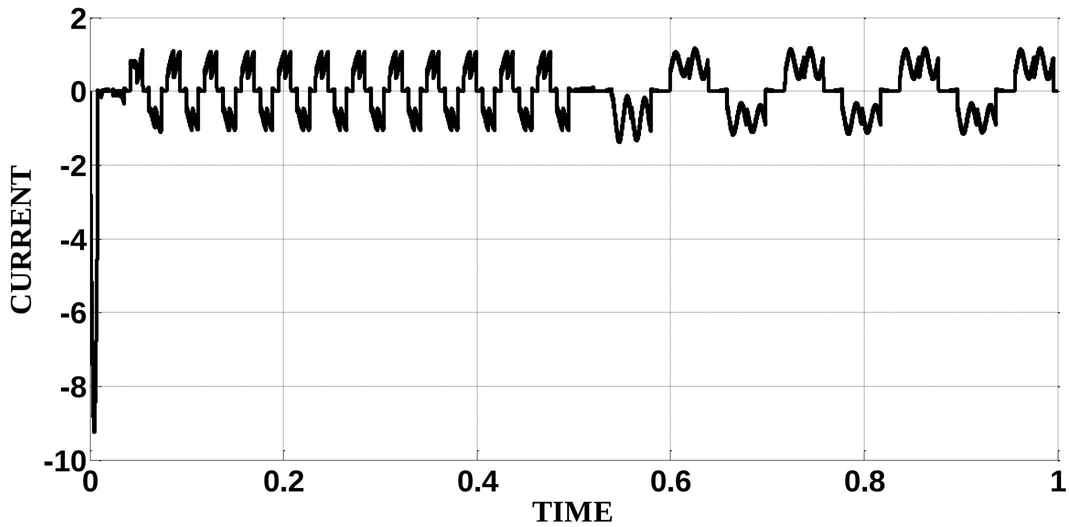


Fig 3.19: Current v/s Time

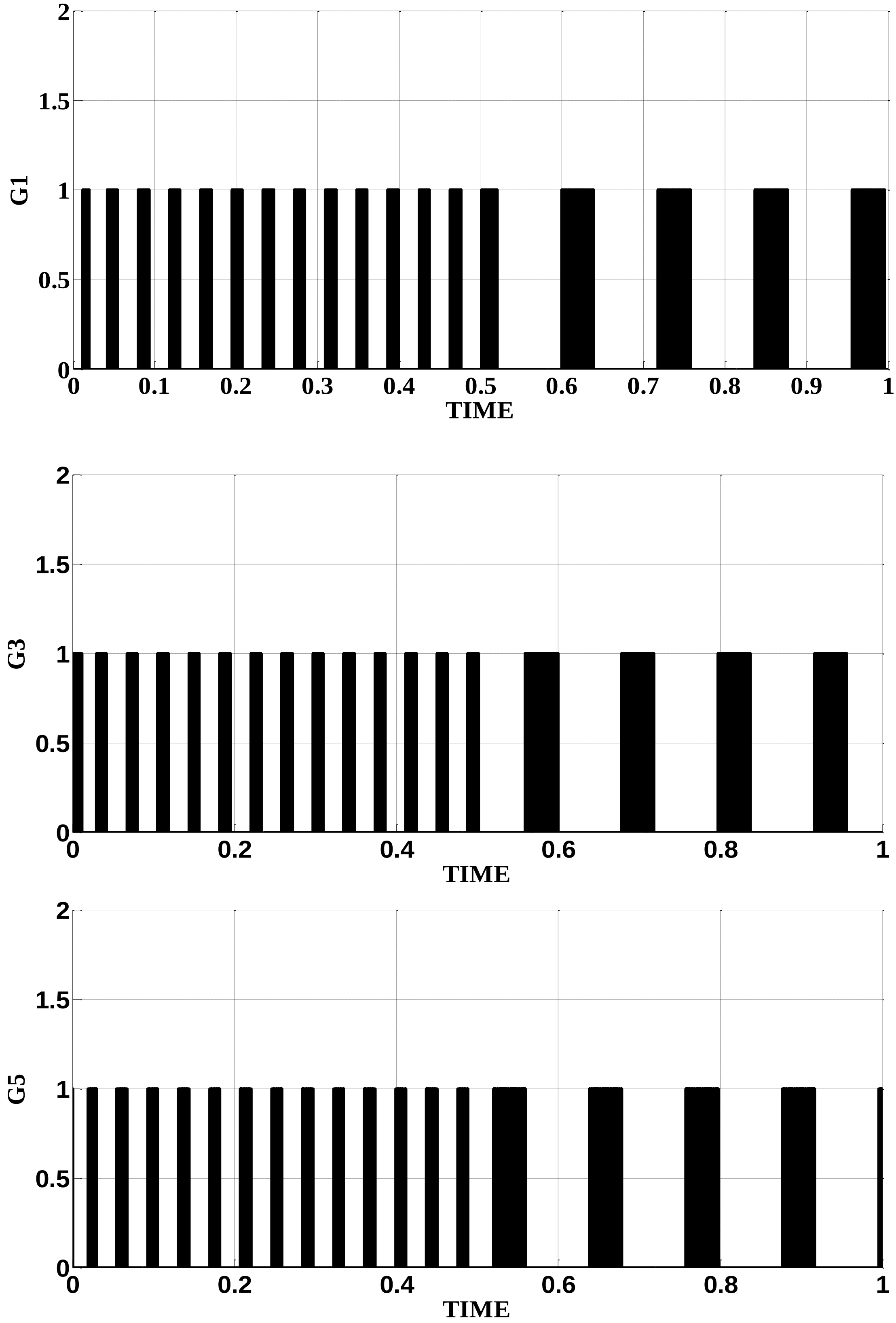


Fig 3.20: Gate pulse for reverse PWM

3.6 Simulation for EV characteristic

Fig no.3.28 shows the variable input given for PWM technique. We can relate this with controlling of bike. We can divide this in 6 periods.

1. Time 0 to 0.2 sec - Acceleration,
2. Time 0.2 to 0.4 sec – Constant speed,
3. At 0.4sec there is sudden step acceleration
4. Time 0.6 to 0.8 sec – step deceleration,
5. Time 0.8 to 1 – constant speed,
6. Time 1 to 1.2 – deceleration.

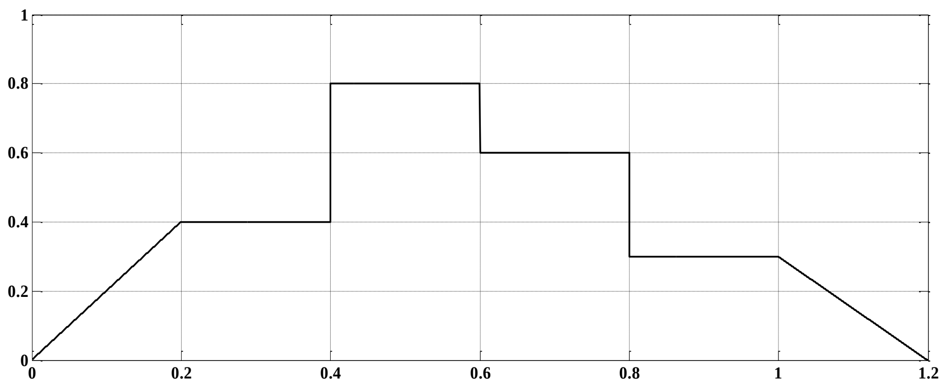


Fig no. 3.28 variable input.

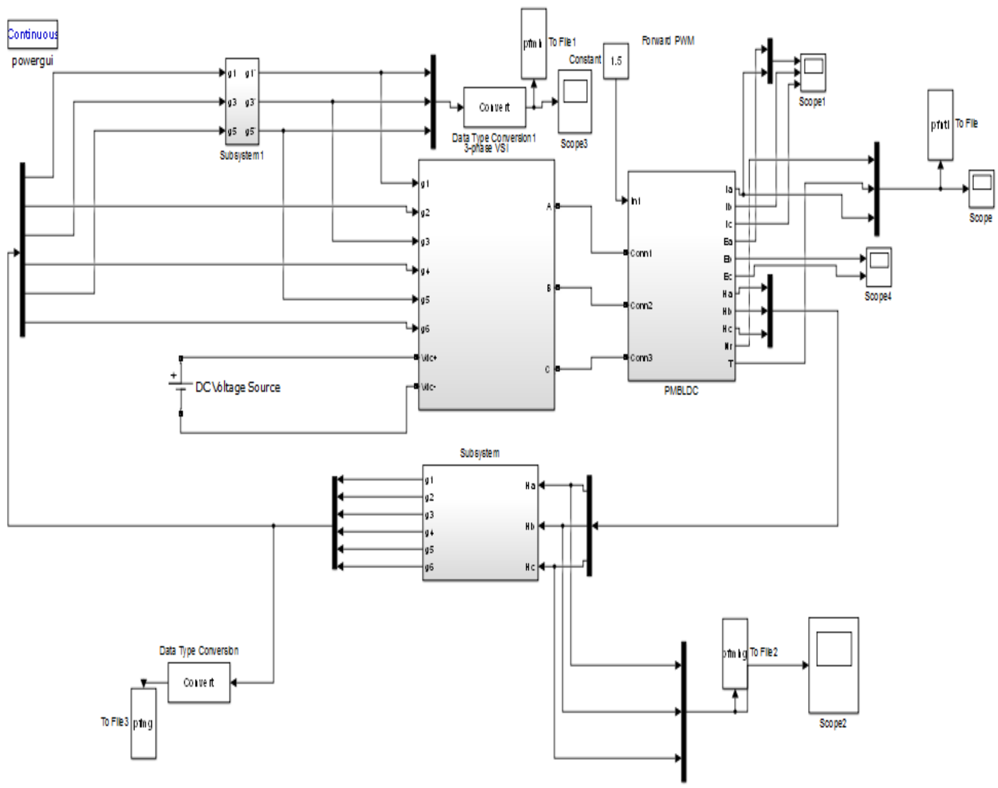


Fig 3.29 EV characteristic model

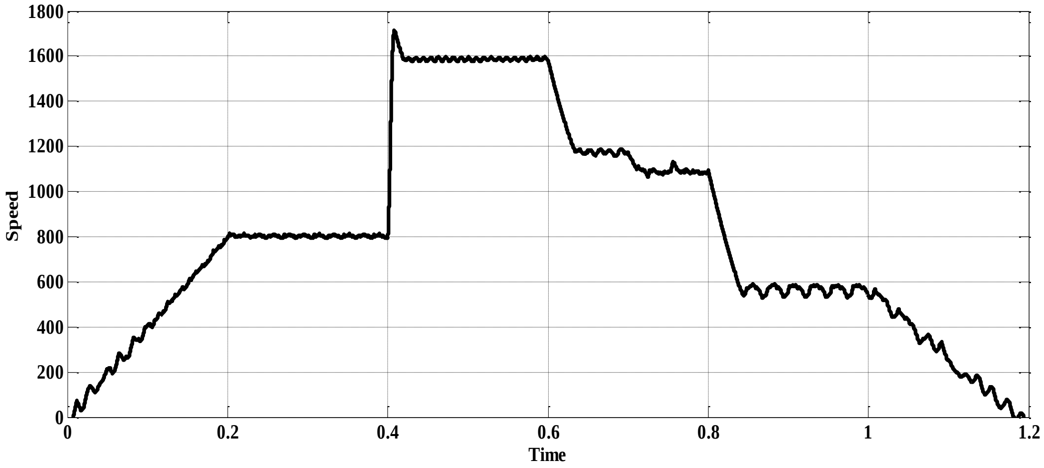


Fig 3.30 Speed v/s Time curve.

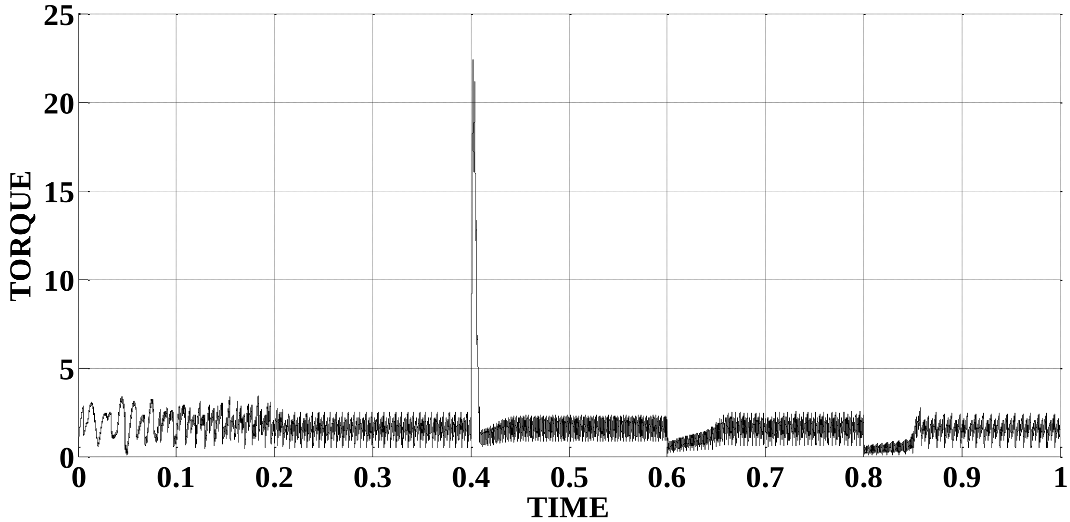


Fig 3.31 Torque v/s Time

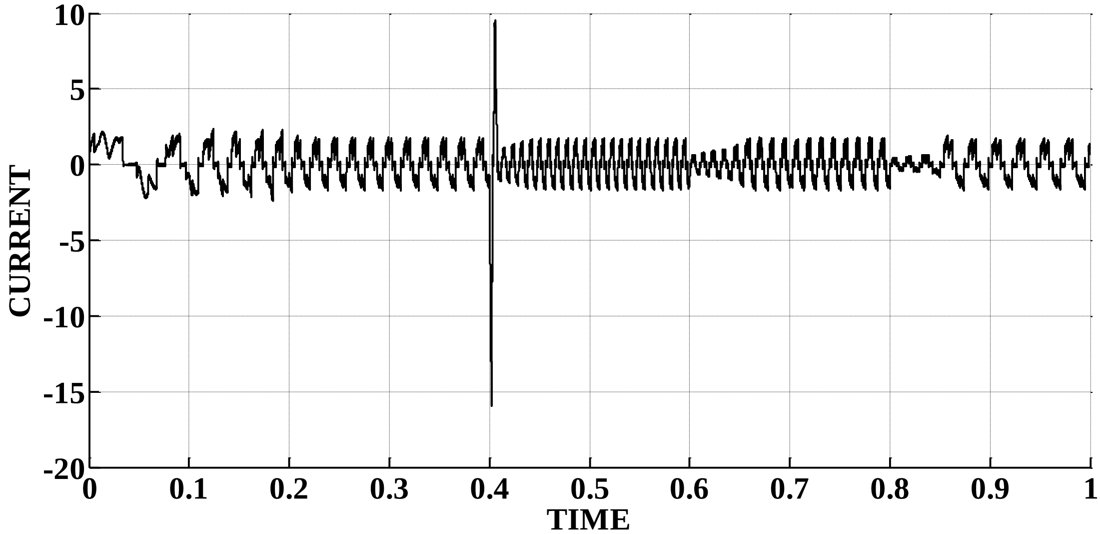


Fig 3.32 Current v/s Time

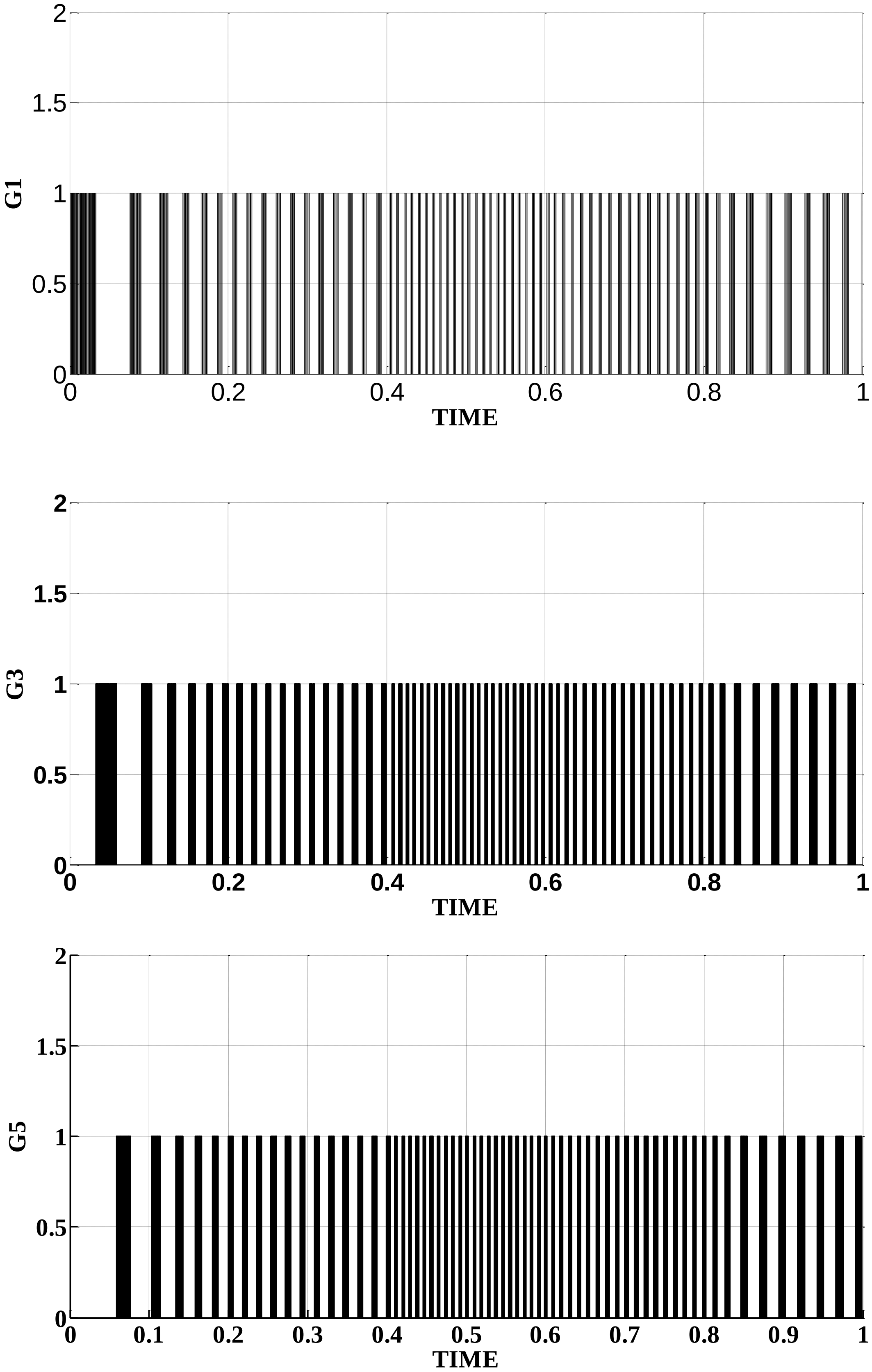


Fig 3.33 Gate pulse v/s time signal for EV characteristic

Chapter 4

HARDWARE IMPLEMENTATION

The BLDC motor operation is verified experimentally for its application in Electric Bike. The parameters of BLDC motor used in experimentation are given in Table 4.1. The experimental setup is shown in Fig. 4.1.

Table 4.1 Motor specification Table

Manufacturer	Indus (electrotherm india.ltd)
Input voltage	48v
Current (Maximum load)	18 amp
Current (No load)	7 amp
Top Speed	55 km/hour
No. of poles	40 pole
Phase shift	120 degree
Power	1 KW
Type of motor	BLDC Hub Motor

The main components of the experimental setup are :

1. Hub type BLDC Motor
2. Rectifier
3. Three phase inverter
4. Throttle
5. Signal conditioning circuit (Hall Sensor circuit)
6. STM M4 32-bit Arm Cortex Controller

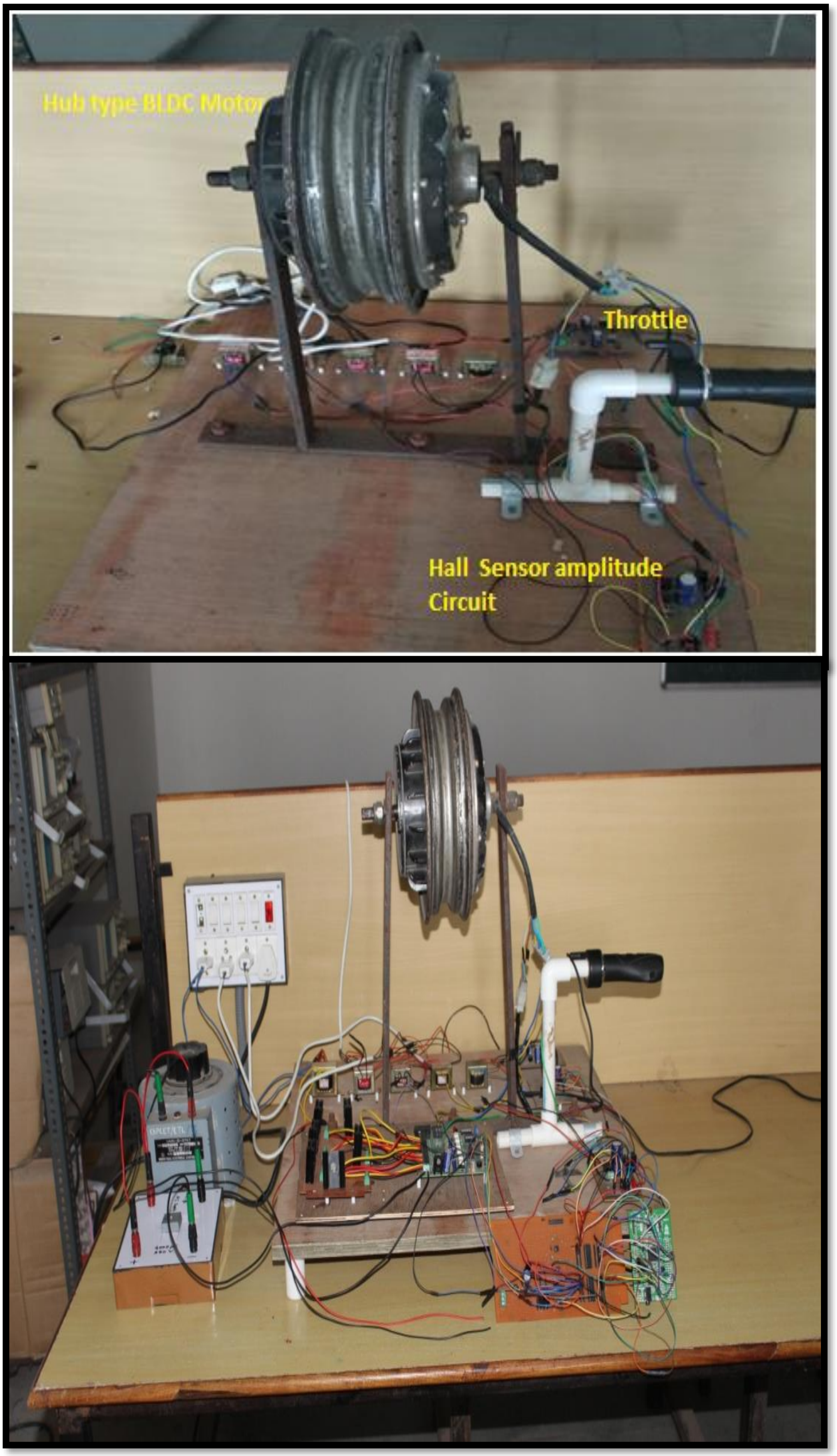


Fig 4.1 Hardware Implementation

4.1 Rectifier Circuit

A rectifier is an electrical device composed of one or more diodes that converts alternating current (AC) to direct current (DC). A diode is like a one-way valve that allows an electrical current to flow in only one direction. This process is called rectification. The main reason of usage of rectifier in this project for bldc motor which runs in the DC supply. In the rectifier circuit there are main four capacitors are use which rated ad 1000 MFD, 250 V. There are also a bridge rectifiers is used which rated as 35 A, 1000 V.

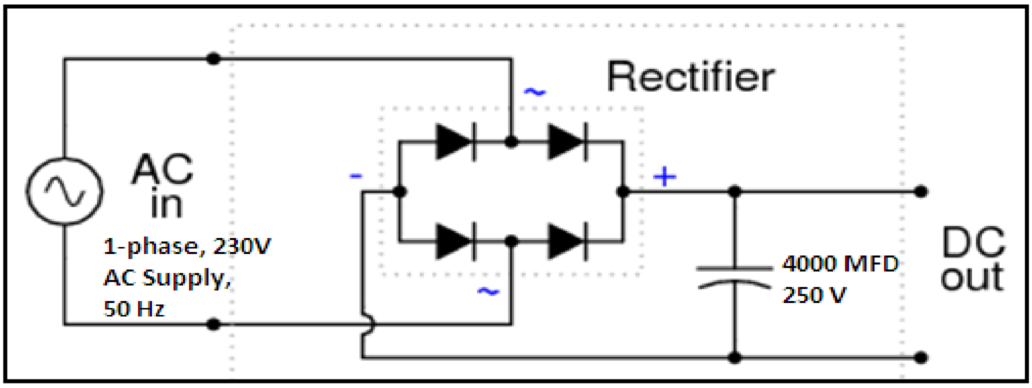


Fig 4.2 Schematic of Rectifier Circuit.

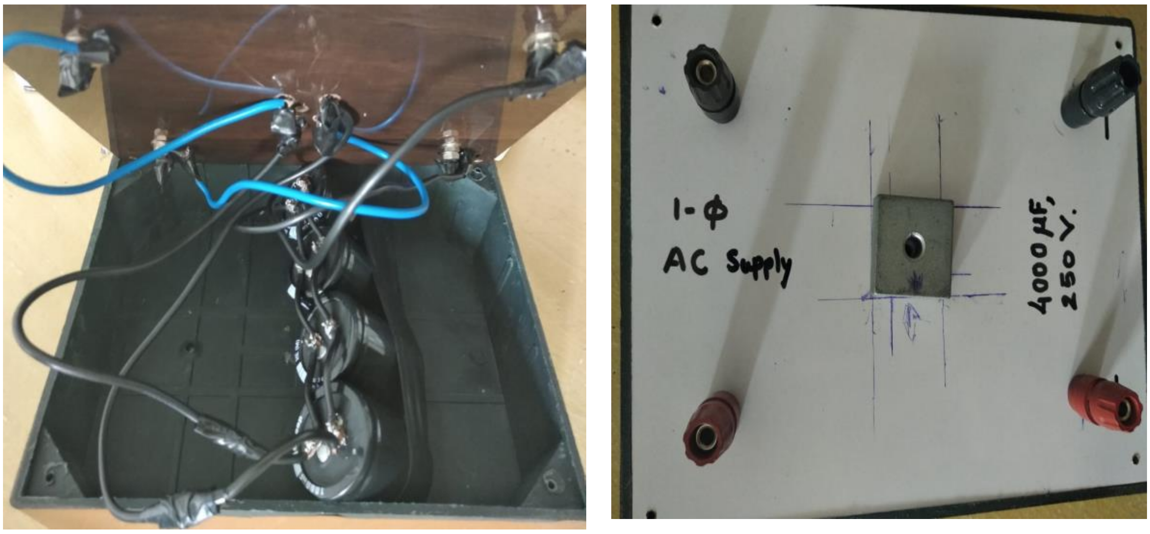


Fig. 4.3: Rectifier Circuit

4.1.1 Rectifier Results

As per AC input different varying output were observed during testing of Rectifier circuit.the results are given in table below:

Table 4.2 Rectifier Result

Sr. No.	AC voltage	DC voltage
1	40	53
2	60	86
3	80	110
4	90	128
5	100	140
6	110	150
7	120	167
8	130	180
9	140	194
10	150	208

4.2 Testing of BLDC Sensor Hall positioning

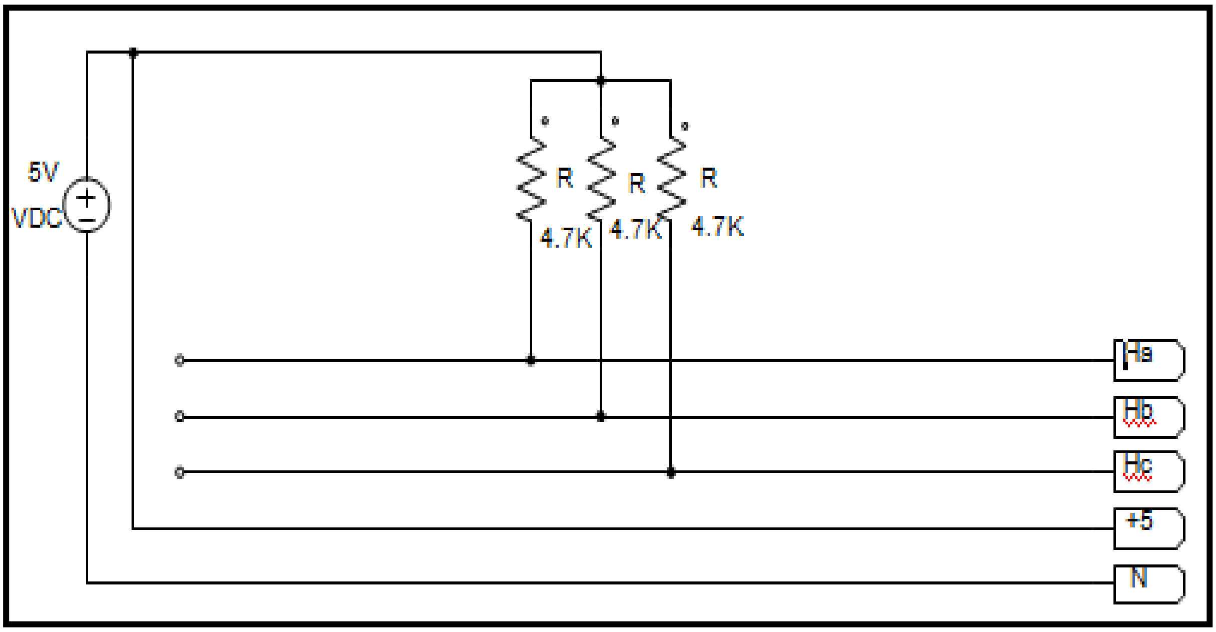


Fig 4.4: hall sensor circuit

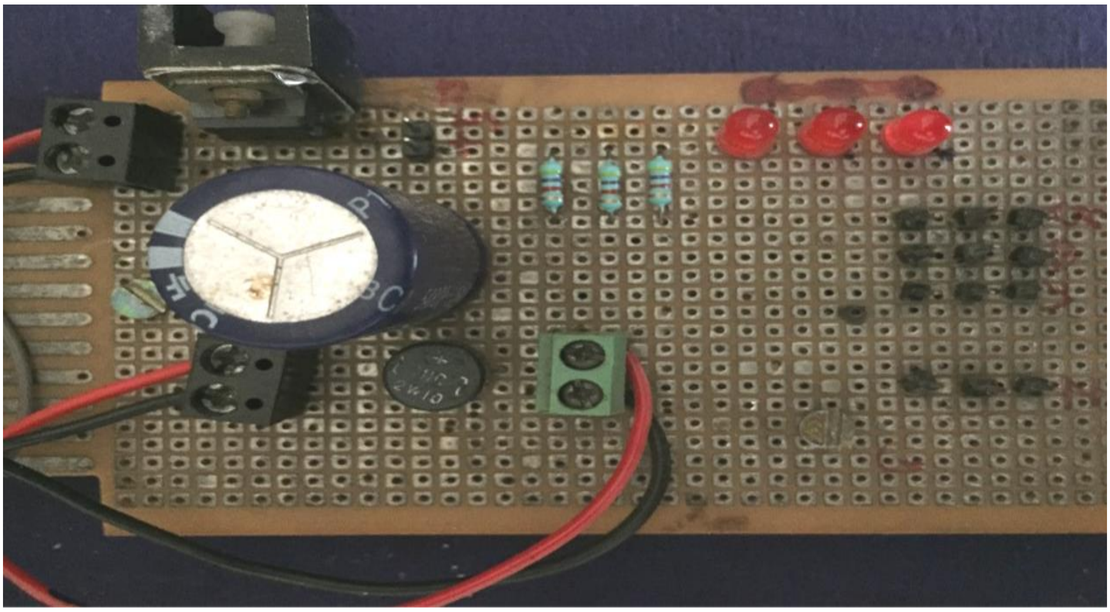


Fig 4.5 Implemented hall sensor circuit

Table 4.3 Sequence verification:

Pole pair	Start	H(Blue)	H(Green)	H(Yellow)
I.	1	1	0	1
	2	1	0	0
	3	1	1	0
	4	0	1	0
	5	0	1	1
	6	0	0	1
II	1	1	0	1
	2	1	0	0
	3	1	1	0
	4	0	1	0
	5	0	1	1

	6	0	0	1
III	1	1	0	1
	2	1	0	0
	3	1	1	0
	4	0	1	0
	5	0	1	1
	6	0	0	1

In testing of motor here by using hall sensor pull-up circuit and multimeters we can find the pole-pairs of motor and we can verify the sequence of hall-sensors. Here by doing this we have found that motor has 40 poles because the sequence of 1 to 6 hall sensors repeats 20 times this means motor has 20 pole pair and 40 poles.

4.3 Pull-up circuit diagram

In electronic logic circuits, a pull-up resistor is a resistor used to ensure a known state for a signal. It is typically used in combination with components such as switches and transistors, which physically interrupt the connection of subsequent components to ground or to V_{CC}.

A pull-up resistor may be used when interfacing logic gates to inputs. For example, an input signal may be pulled by a resistor, then a switch or jumper strap can be used to connect that input to ground. This can be used for configuration information, to select options or for troubleshooting of a device.

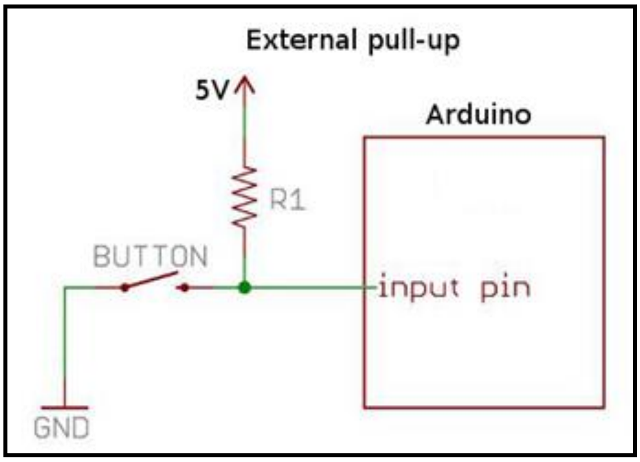


Fig 4.6: circuit diagram for pull up circuit

4.4 Inverter circuit

A power inverter, or inverter, is an electronic device or circuitry that changes direct current (DC) to alternating current. The input voltage, output voltage and frequency, and overall power handling depend on the design of the specific device or circuitry. The inverter does not produce any power; the power is provided by the DC source.

A power inverter can be entirely electronic or may be a combination of mechanical effects (such as a rotary apparatus) and electronic circuitry. Static inverters do not use moving parts in the conversion process.

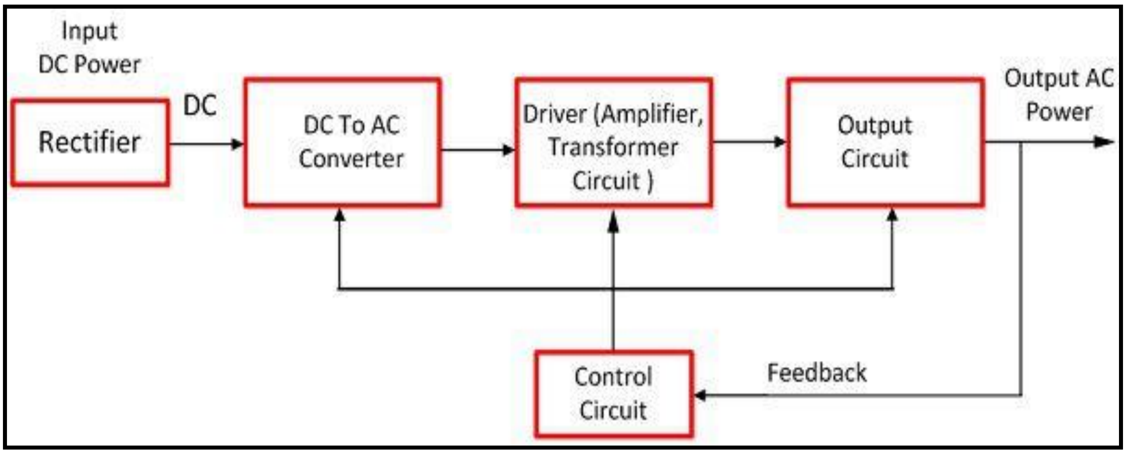


Fig 4.8 circuit diagram of inverter circuit

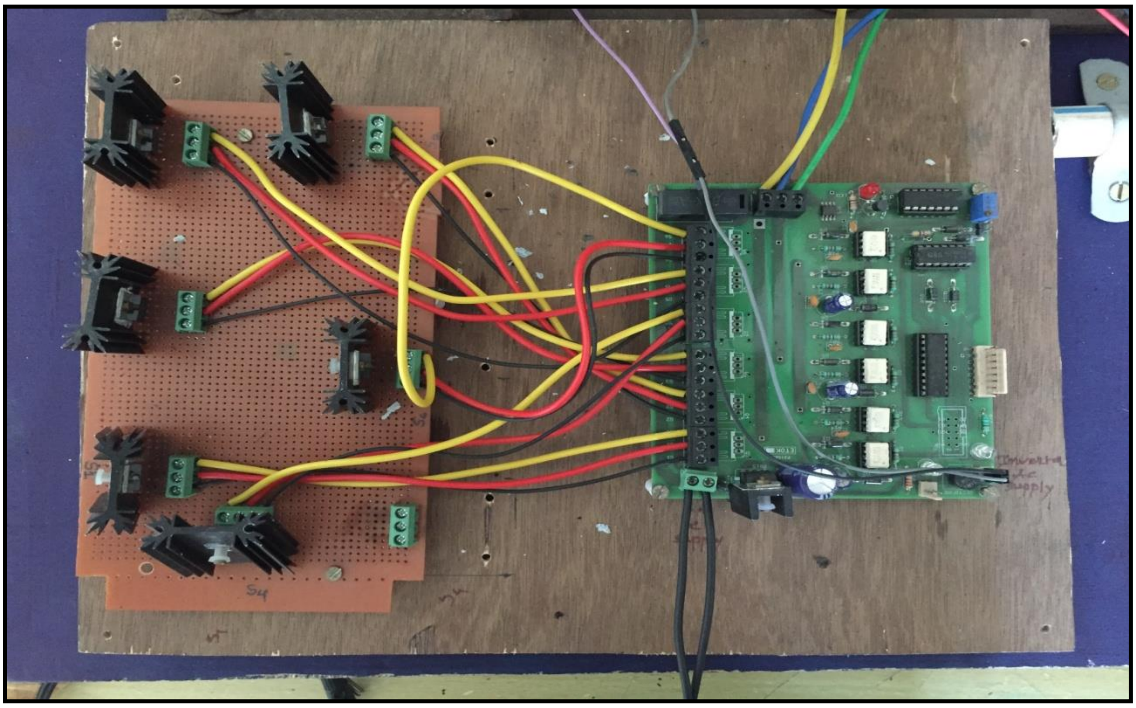


Fig 4.9 Implemented inverter circuit

4.6 STM32M4 Microcontroller:

4.6.1 Info of Controller:

STMicroelectronics STM32 F4 32-bit Cortex™-M4 Microcontrollers (MCUs) offer better performance, DSP capability, more SRAM, and peripheral improvements such as full duplex I²S, less than 1µA RTC, and 2.4MSPS ADCs. These MCUs include a floating point unit and core features such as built-in single-cycle multiply-accumulate (MAC) instructions, optimized SIMD arithmetic, and saturating arithmetic instructions.

The adaptive real-time ART Accelerator combined with STMicroelectronics 90nm technology provides linear performance up to 168MHz, unleashing the full performance of the core. These features expand the number of addressable applications in the industrial, consumer, and healthcare segments. The STM32 F4 series MCUs include devices with 512KB to 1MB of on-chip Flash memory, 192KB of SRAM, and 15 communication interfaces.

4.6.2 Features

- ART Accelerator™ enabling 0 wait state executing from internal Flash
- Up to 2x USB2.0 OTG FS/HS
- SDIO
- USART, SPI, I²C
- 16-bit and 32-bit timers
- Up to 3x 12-bit ADC
- Up to 2x 12-bit DAC
- External memory controller
- 1.7V to 3.6V low voltage

4.4 Buffer circuit:

A buffer is a unity gain amplifier packaged in an integrated circuit. Its function is to provide sufficient drive capability to pass signals or data bits along to a succeeding stage. Voltage buffers increase available current for low impedance inputs while retaining the voltage level.

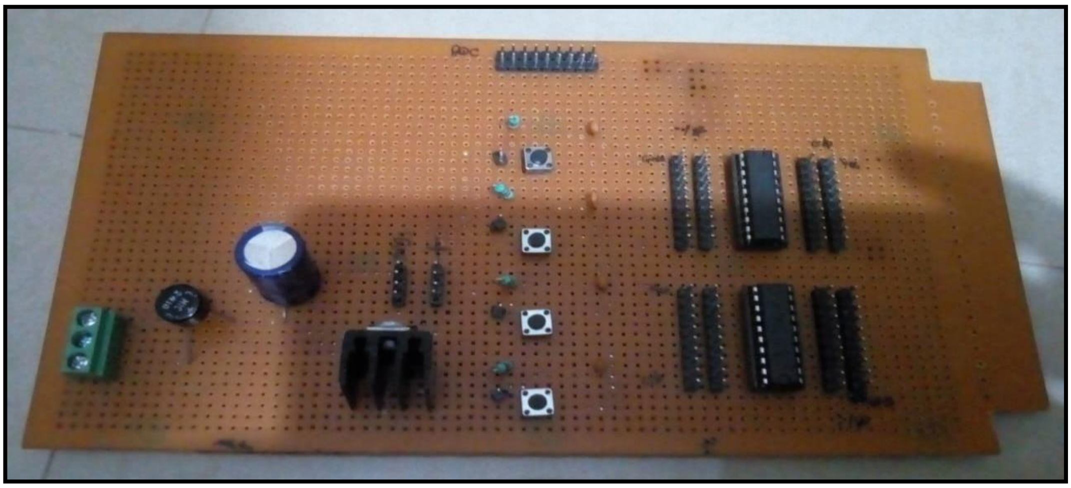


Fig 4.7 Buffer circuit

4.7 Testing of throttle

Fig 4.8 Throttle

As per the position of throttle the output voltage we get at the output is given in the table given below.

4.7.1 Throttle operation results

Table 4.3 Throttle Operation Result

Throttle Position	Supply Voltage	Output Voltage
1	12v	4.32v(Lower Limit)
2	12v	4.47v
3	12v	5.07v
4	12v	5.98v
5	12v	6.85v
6	12v	7.67v
7	12v	8.26v(Upper Limit)

4.8 six step operation of BLDC motor

Sr No.	Vdc	Speed
1	4.80	263
2	7.87	487
3	10.55	568
4	14.00	825
5	19.65	1025
6	24.56	1280
7	27.30	1498

Testing of BLDC motor of Electric vehicles

Sr No.	Throttle output	Speed
1	4.23	5
2	4.47	17
3	5.07	23
4	5.98	30
5	6.85	35
6	7.67	41
7	8.26	45

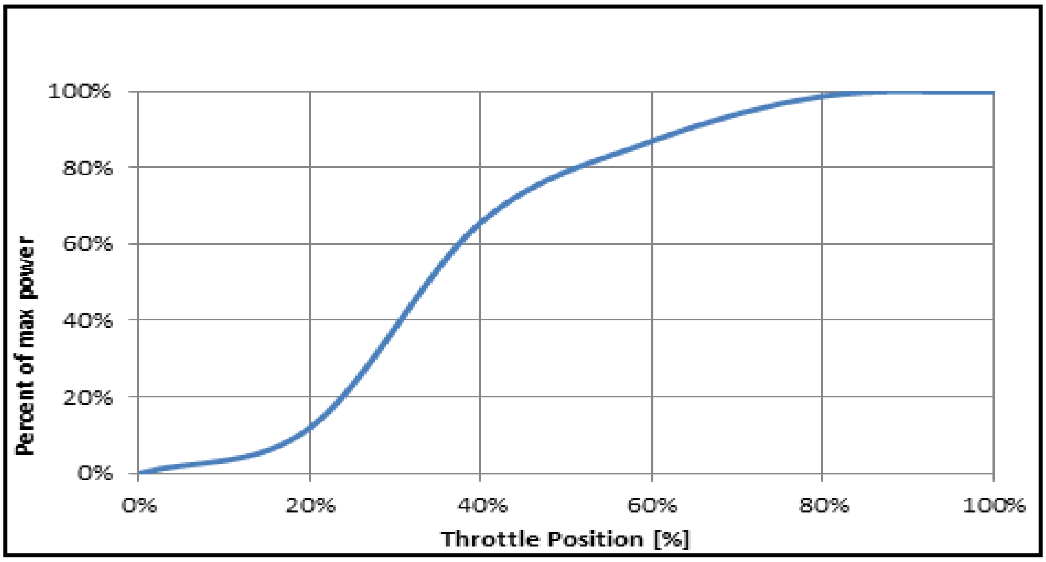


Fig 4.9Characteristics between Throttle Output vs. Speed

Chapter 5

CONCLUSION

Conclusion

By working on this project we conclude that the efficiency of BLDC Motor is greater than the other Motors. BLDC Motor are also used in Electric Vehicles (EVs). So using this we have many Advantage of it. These vehicles would also enable meeting the demands for electrical power due to the increasing use of the electronic features to improve vehicle performances, fuel economy emissions, passengers comfort, and safety. The implemented Project, generates the firing pulses required to drive the IGBTs of three phase fully controlled bridge converter. The generated PWM signals for driving the power inverter bridge for BLDC motor have been successfully tested using STM 32 Controller. The output from the converter is fed to the three phase stator winding of 48V, 250 W, 1500 rpm BLDC motor and the motor is found to run at constant speed. The program is found to be efficient and the results with the designed hardware are promising. The developed control and power circuit functions properly and satisfies the application requirements. Experimental results justify effectively the developed drive designs.

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