MODELLING & ANALYSIS OF CLOSED LOOP CONTROLLER FOR PMBLDC MOTOR

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ABSTRACT- The Brushless DC motors are widely used in many industrial and traction applications because of their high efficiency, high torque, low maintenance, less noise and low volume. The BLDC motor can act as an alternative for traditional motors like Brushed DC motor, induction motor, switched reluctance motors etc. The performance of BLDC motor is analysed using Matlab with motor on no load. The various performance parameters are analysed by Matlab software. The torque characteristics of BLDC motor is very important factor in designing BLDC motor drive system. After development of simple mathematical model of three phase BLDC motor with trapezoidal waveforms of back emf, the motor is modelled by using MATLAB/SIMULINK. The speed, phase current, back emf waveforms are also obtained using this model. In the presented model speed is regulated by PI controller. In this paper the simulation is carried out for 1200 mode of operation and Trapezoidal back emf waveforms are considered. The results obtained using Matlab software are highly acceptable and this gives very important information for designing BLDC motor drive system.

Keywords: Torque, Batteries, Hysteresis motors, Vehicle dynamics, Force, Acceleration, Motor drives, Brushless DC motor, Electro motive force, 1200 mode of operation, PI controller.

1. Introduction

Brushless DC motor may be described as electronically commuted motor which do not have brushes. These types of motors are highly efficient in producing large amount of torque over a vast speed range. Commutation with electronics has large scope of capabilities and flexibility. BLDC motors are available in many different power ratings, from very small motors as used in hard disk drives to larger motors used in electric vehicles.In this age, as the power requirement increases exponentially, there is a higher need for the equipment to be more efficient and maintenance free. This is solved by the use of BLDC motors. The brushes of the mechanical commutator eventually wear out and need to be replaced. There are other undesirable effects such as sparks, noise, etc. A BLDC motor lacks the brushes and physical commutator. This means there are fewer parts that can break or wear out and need to be replaced. Thus they tend to be more reliable, last longer and be more efficient. The BLDC motors can also operate at speeds above 10,000 rpm in both loaded and unloaded conditions.

To achieve speed control of a BLDC motor by PWM (pulse width modulation) technique used to control six Mosfet/IGBT switches which gives the supply to the stator windings of the motor. The rotor position of the motor is detected by Hall sensors according to which these PWM pulses are generated from a Processor. Furthermore a gate driver circuit was also designed and implemented to drive the inverter.This stdy will control the speed of BLDC motor using PWM technique for which we need to know how to generate those pulses using a processor using assembly or embedded C. Motor specification and hall sensor details also need to be analysed to decide the Mosfet/IGBT rating and the rating for the driver circuit.

Programming for the six step commutation is done using the hall sensor outputs. Initially the hall sensors signal is being sent to the processor to decide which phases are to be excited next to keep the motor running. The processor generates the PWM pulses to the respective drivers which will further switce the respective Mosfet/IGBT switches. The microcontroller will be used to implement closed loop control of BLDC. This project will also be simulated in Simulink using state space model. The Speed control of brushless DC motor circuitry will consist of two main circuits – The Inverter and the Gate Driver Circuit. The pulses given through the processor, based on the hall-effect sensor values, will allow us to control the speed if the motor, which can be used in various applications ranging from home to aerospace engineering.

2. Related Works

Electric vehicle (EV) has been an active research area since last few decades due to galloping increase in environmental pollution and global warming. A lot of government initiatives is being carried out for widespread adoption of EVs. There have been lots of work done by researchers in motor control strategies for EV applications [1-3], nevertheless it has hardly included the electric vehicle load dynamics. This may cause the control system to fail under actual test conditions on road as it includes lots of non-linear dynamics and parametric variations. EV controller designed by overlooking the specifications of vehicle such as torque, speed, acceleration and deceleration profiles, mass of the vehicle, battery characteristics and the road load conditions, etc. would not be a good design and can affect the life cycle and cost of the vehicle. Hence, it is quite essential to model the dynamics of each component and simulate by integrating them in order to achieve the optimum performance before doing an on-road vehicle test.

Various softwares are available to model the powertrain such as ADVISOR, PSIM, PSAT etc., that use steady state, quasi-steady and dynamic vehicle models based on the depth of model details [4]. In [5], an attempt has been made to develop a generic EV model for dynamic simulation and performance prediction using functional models. The motor drive has been modelled as torque-speed lookup table so that any motor can be chosen as long as the input-output relation of the model is not affected. In [6], modelling and simulation of electric vehicle power train in SEQUEL are discussed where the torque (force) given by the motor is not exactly matching and is higher than the required torque (force) command. However, in that case, the motor is unnecessarily producing more than the required torque. This paper discusses the basic method of modelling every subsystem of the EV and simulates a typical BLDC motor based three wheeler EV driven on Indian road conditions.

3. Methodology

The state space model derived is implemented by mathematical modeling of the motor in Simulink which is shown in figure 1.

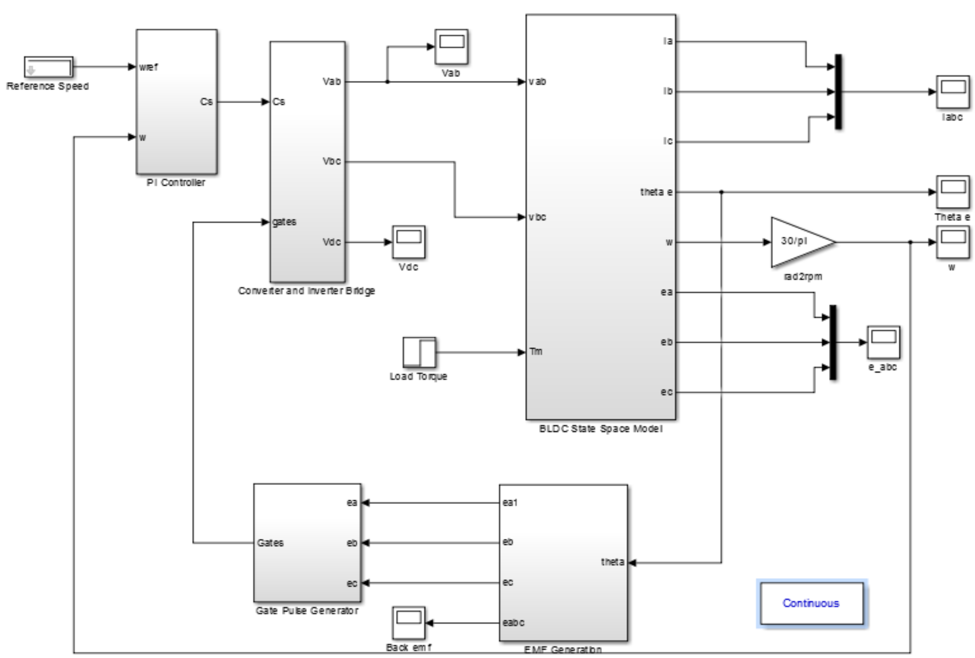


Figure 1: Simulink model

The above model has 6 main sub-systems which are described in subsequent sub-chapters. Initially, the motor is at rest but as the model is mathematical the EMF will start generating itself using the necessary equations. The motor position is detected and as a result the gate pulses are generated to drive the gates which in turn drives the BLDC motor. Here, instead of giving the PWM in the BLDC for speed control an error controlled voltage sources is used i.e. whenever the error is zero the voltage source is reduced to zero. This is similar to the PWM method where the average voltage is varied by varying the on time of the pulse given to the Mosfet. Instead of feeding a PWM to the MOSFET, an error signal is generated and fed to the Voltage source.

Thus the speed of the BLDC motor is controlled. A provision to give an external load torque is also included in this model. The closed loop control of the motor will make the speed of the motor to remain at the reference speed. The simulation allows the user to view the Back Emf of the motor, Current output of the motor, the speed in RPM, and the increasing value of theta so as to know the actual position of the motor at any given instant.

Reference Speed

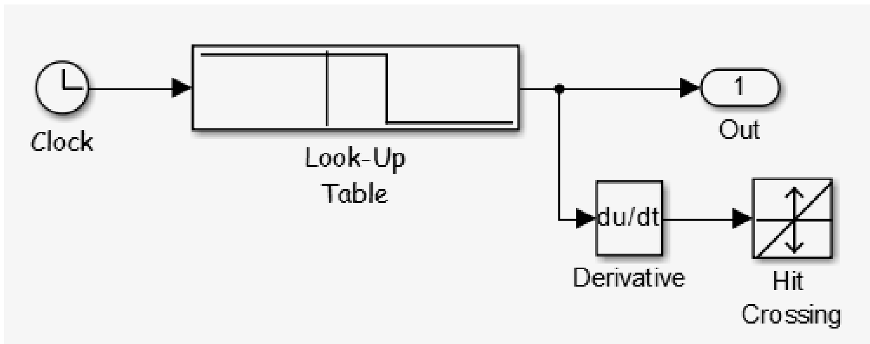


Figure 2: Reference speed sub-block

This block generates a speed signal which changes at specified times. In this particular model the speed is kept at 2000 rpm for the time period 0 to 0.5 seconds and at 0.5 second instant, the speed is reduced to 1000 rpm.

PI Controller

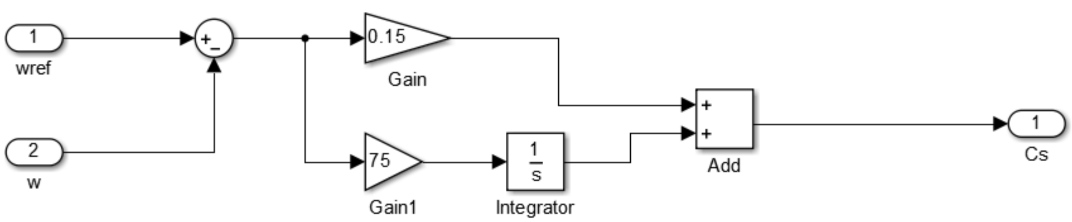


Figure 3: PI controller sub- block

The PI controlled produces the Error Signal ‘Cs’ which is taken from the error between Wactual and Wreference. The generated error signal is then used to control the Voltage control source. The trial and error method of loop tuning is employed in this project for the design of PI speed controller. This method is crude but could help in getting an overview of what the PI parameters could be like and their effects on the whole system model. In this tuning method: First set the Ki and Kp values to zero. Increase the Kp until the output of the loop oscillates. Then increase Ki until oscillation stops.

Converter and Inverter Bridge

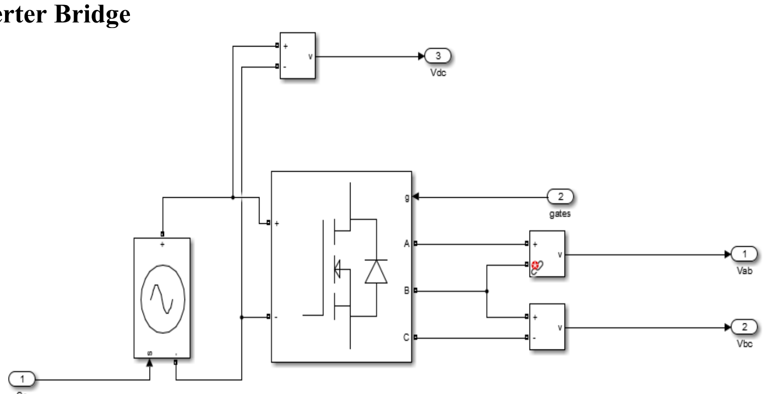


Figure 4: Converter Inverter Bridge sub-block

The error signal generated from the PI block is fed into the controlled AC voltage source. The given AC Voltage source is fed to Universal Bridge which consists of a rectifier and controlled 3 phase inverter circuit. The Voltages are then converted into line values and then sent to the output of the block for further calculations. The line voltages are used as it will simplify the state space model and hence reduce the computational time. The gate pulses are generated in the external EMF generator which generates just the reference EMF and hence according to the EMF the pulses are generated and fed to the 3 phase inverter which is there in the universal bridge.

BLDC state space model

The BLDC Block itself consists of three blocks for implementing the Equation 2. The current generator will generate the current of two phases and the current of the third phase is calculated by the Kirchhoff's current rule. After finding out the current, the currents are used with Emfs and load torque provided externally to calculate the value of theta (Position of rotor) and then Wm, the speed of the rotor. In the speed generator block, the value of theta and Wm is then used to generate the Emfs value of the motor through the Emf generation block.

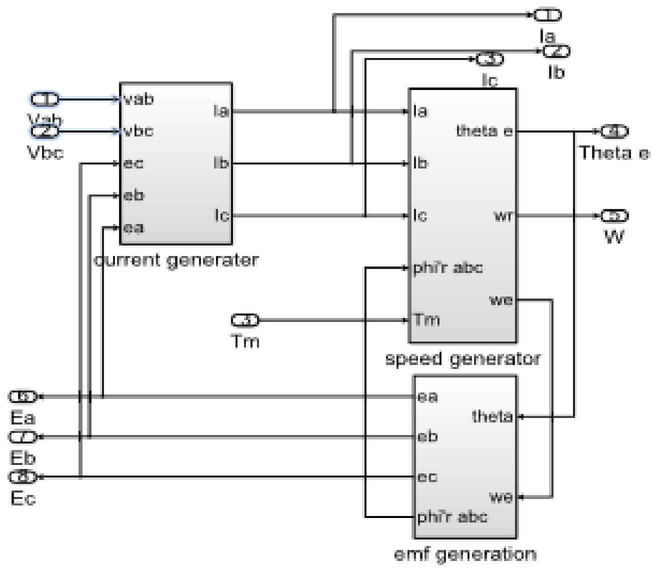


Figure 5: State space model sub block

As the Model is a mathematical model and state space equation are used to derive the model. The real time simulation of the model is not possible through Simulink. This is the reason the motor does not act as a real motor as the real motor is much more complex compared to this model and there are many more parameters not included in this model which are actually present in the BLDC motor.

Current Generator

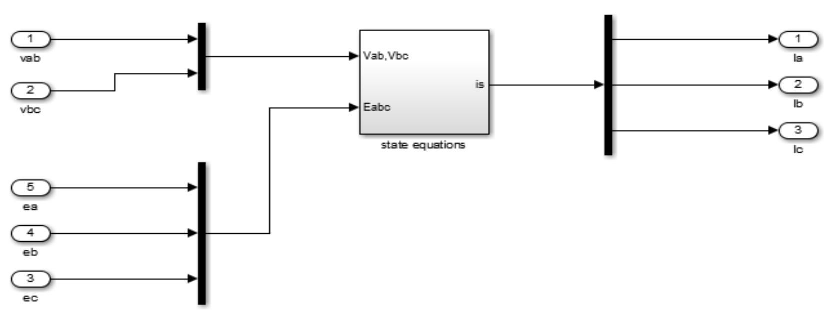


Figure 6: Current Generator sub-block

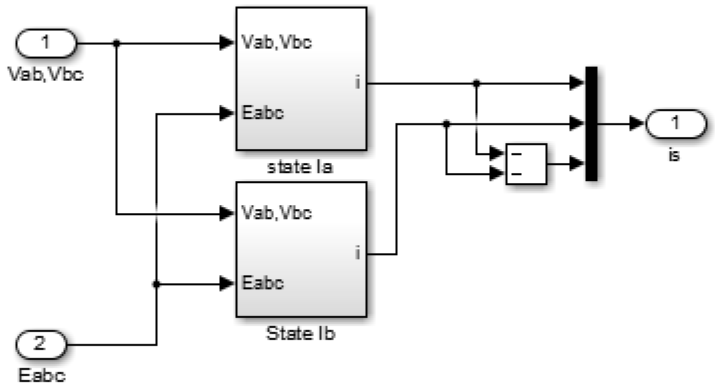


Figure 7: State Equations

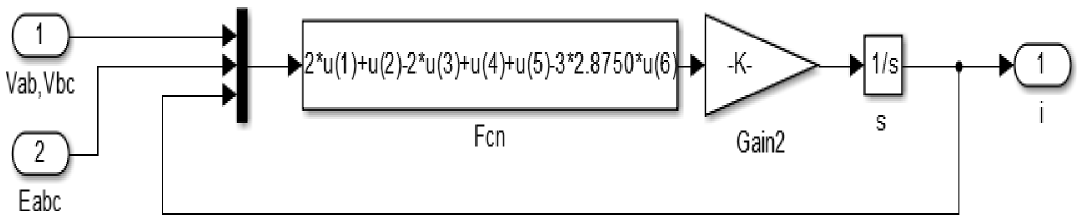


Figure 8: Current generator for Ia

The following current generators for Ia and Ib are mathematically calculated from the state space equations given in equation 2. The state equations of both the currents are blocked separately with functions.

F(Ia) = 2*u (1) +u (2)-2*u (3) +u (4) +u (5)-3*2.8750*u (1)

F(Ib) = -u (1) +u (2) +u (3)-2*u (4) +u (5)-3*2.8750*u (2)

Where u (1) = Vab, u (2) = Vbc, u (3) = Ea, u (4) = Eb, u (5) = Ec, u (6) = Ia/Ib. Then the value integrated to give the value of the currents are then added negatively and as per the Kirchhoff's current rule Ic= -Ia-Ib. is taken out.

Speed generator

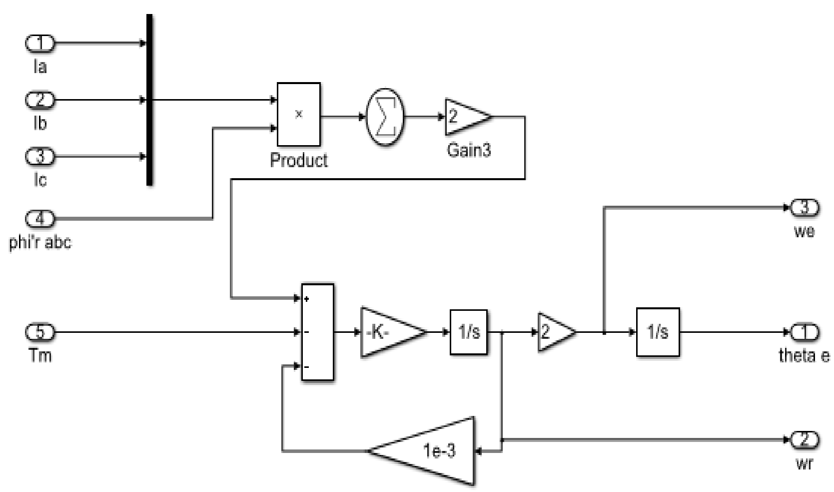


Figure 9: Speed generator sub-block

The current and the EMFs are used with external mechanical load is used to find out the We and then it is converted into Wm by multiplying it with P/2. The W(Speed) is calculated using the equation 2. The Te is calculated using the equation 1.

Emf Generation

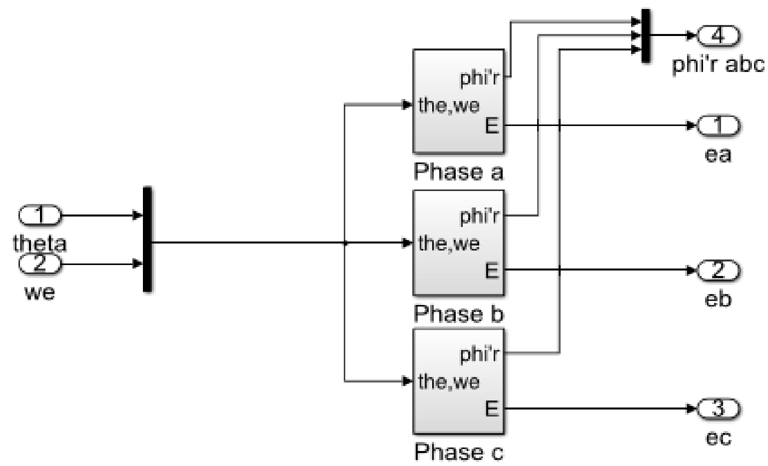


Figure 10: emf generation sub-block

The Emf is generated from the equations 1, 2 according to the F(θe). The function is to generate the trapezoidal function to produce the Emf of the phases. A cosine function is used, which is phases shifted by 120 degrees for the three phases. In addition, a saturation block is included which will saturate the cos at 0.8 which will give a trapezoidal wave.

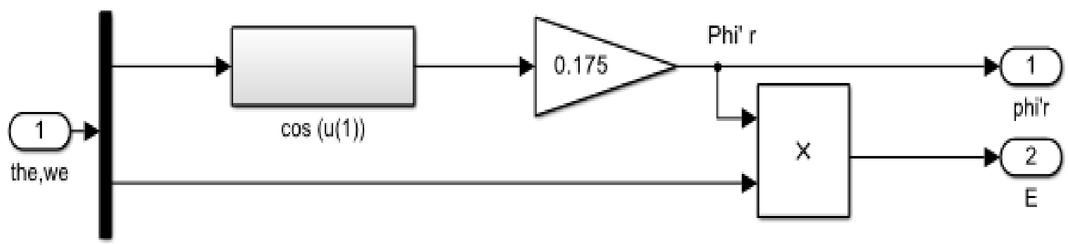


Figure 11: Emf generation for Ea

The figure 9 gives the output for Ea, for Eb the Cos (u (1)) will become Cos(u(1)-2π/3) and Cos (u (1) +2π/3) for Ec. Then the combined Emf values are sent to the speed generator block for speed calculations. So BLDC State space model calculates currents and EMFs of the phases, Theta and Speed in rad/s. This values are then utilized to find out the position of the motor and hence to generate the pulsed as per it.

EMF generation

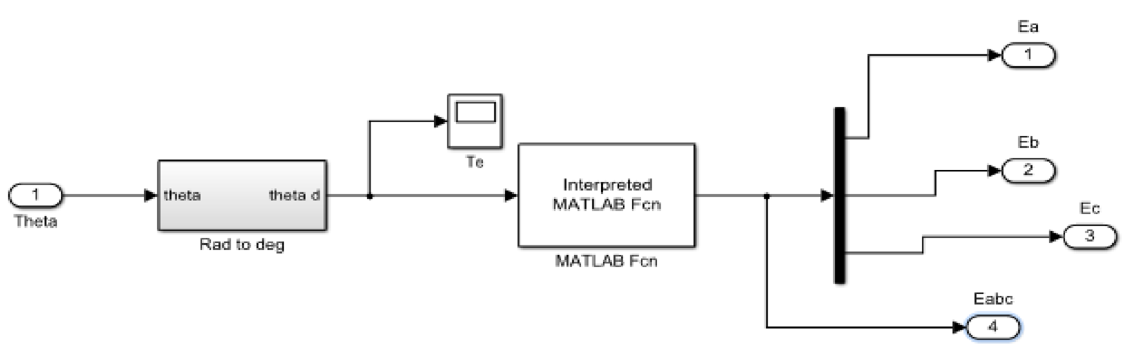


Figure 12: EMF generation for detecting rotor position

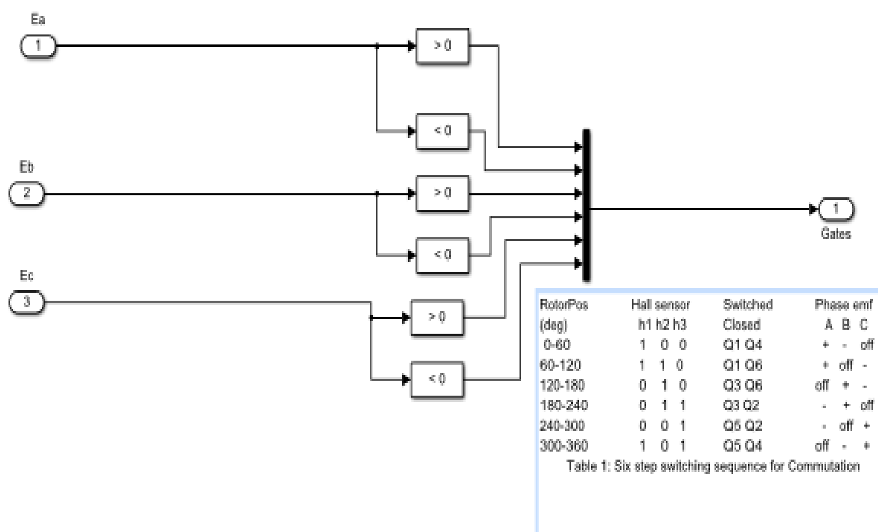
Initially the angle theta is converted to degree using Rad to Deg block. Then the Reference Emfs of the phases is calculated using the Matlab function.

```
function y=emfg(u)

        if (u>-180)&&(u<=-120)
        y=[-1;0;1]; elseif(u>-120)&&(u<=-60)
        y=[0;-1;1]; elseif(u>-60)&&(u<=0)
        y=[1;-1;0]; elseif(u>0)&&(u<=60)
        y=[1;0;-1]; elseif(u>60)&&(u<=120)
        y=[0;1;-1]; elseif(u>120)&&(u<=180)
        y=[-1;1;0]; end
```

This function calculates the Emfs and then gives an output for calculation of gate sequence according to the position of the motor**.**

Gate Pulse Generator



RotorPos (deg)	Hall sensor h1 h2 h3	Switched Closed	Phase emf A B C
0-60	1 0 0	Q1 Q4	+ - off
60-120	1 1 0	Q1 Q6	+ off -
120-180	0 1 0	Q3 Q6	off + -
180-240	0 1 1	Q3 Q2	- + off
240-300	0 0 1	Q5 Q2	- off +
300-360	1 0 1	Q5 Q4	off - +

Table 1: Six step switching sequence for Commutation

Figure 13: Gate pulse generator sub-block

The gate pulses are generated as per the commutation tabled attached with the diagram. It states the commutation sequence for the particular position of the motor.Emf is generated according to the commutation table and it gives the pulses for the three phase inverter in the converter and inverter bridge.

4. Results and Discussion

The figure 14 shows the Speed vs. Time graph for the reference input speed [2000 1000] for the time period [0 0.5]. An external load torque is applied at the instant t=0.2 seconds which counts for the slight dip in speed at that instant. The PI controller, however makes up for this external torque and brings the speed back to 2000 rpm. Figure 14 shows the change in back emf as the speed of the motor changes from 2000 rpm to 1000 rpm at the instant t=0.5 seconds. In figure 15, we can see that the on application of the load torque the back emf experiences a slight reduction but this is almost instantly recovered from. In figure 16, the currents of the three phases are depicted. At t=0.5 seconds the speed of the motor is decreased to 1000 rpm and the subsequent fall in current drawn can be seen. In figure 17, the current drawn by the motor increases when a load torque is applied externally at t=0.2 seconds.

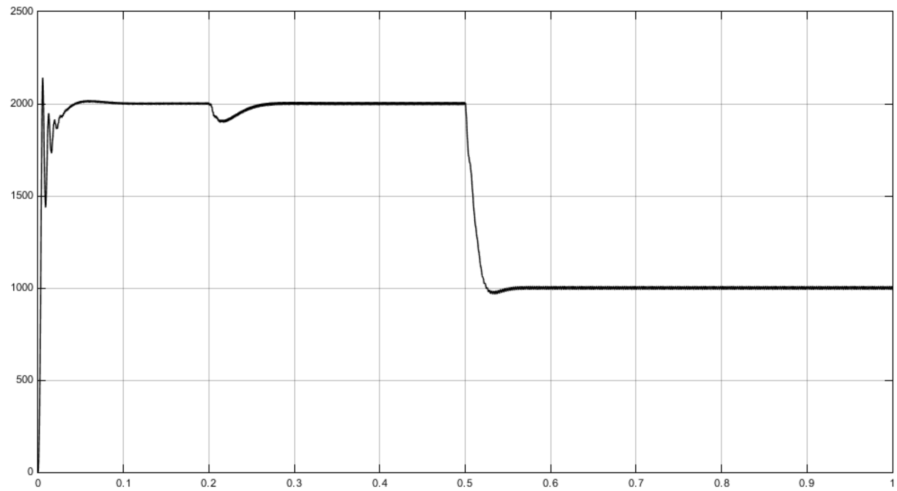


Figure 14: Speed(in rpm) Vs Time(in seconds)

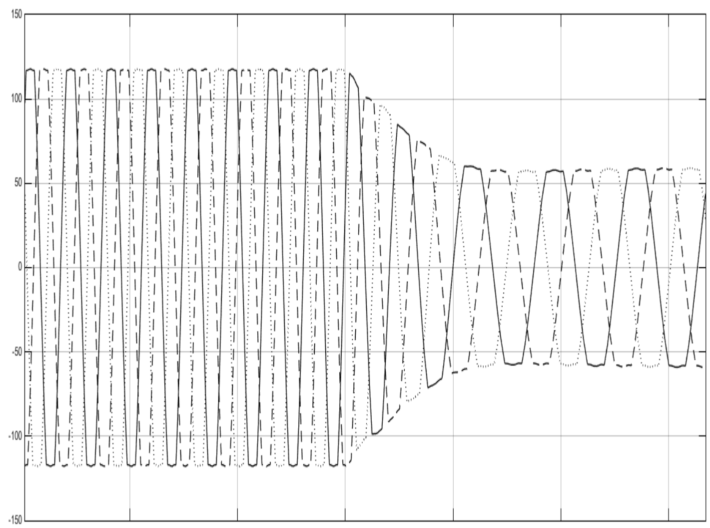


Figure 15: Back emf (in Volts) Vs. Time (in seconds)

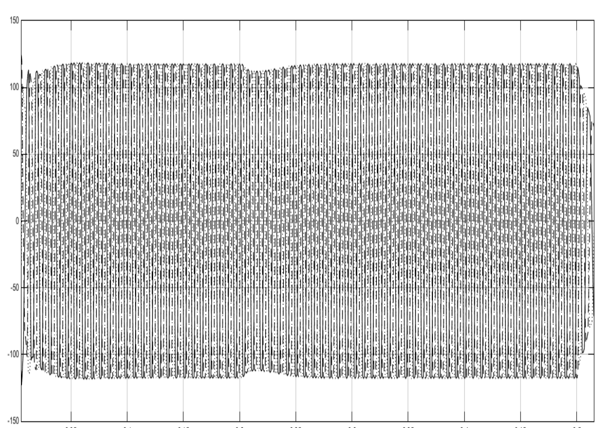


Figure 16: Effect of Load Torque on Back emf

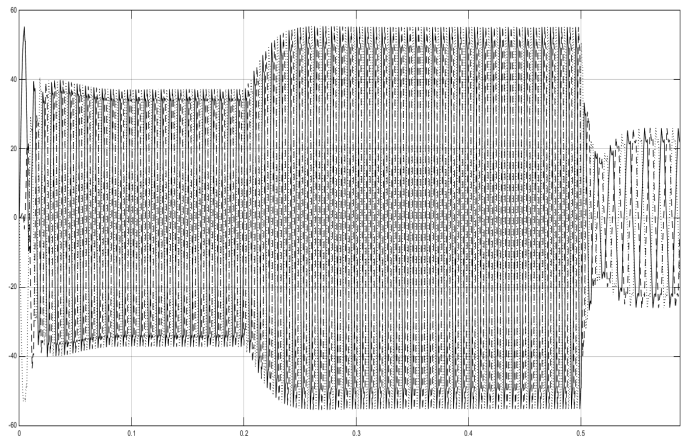


Figure 17: Current (in amps) Vs. Time (in seconds)

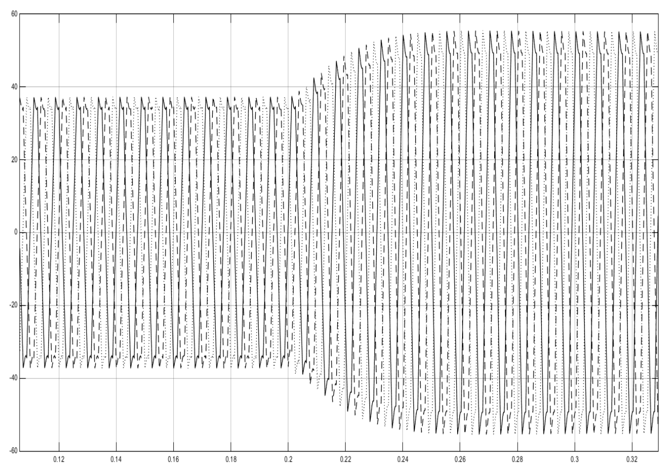


Figure 18: Effect of load torque on current

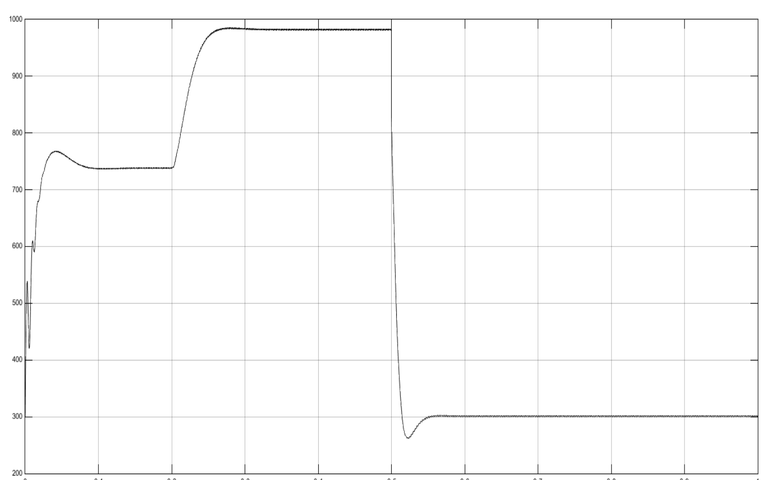


Figure 19: Inverter DC voltage output

The Modelling of the BLDC using the state space model is done and simulated in the Simulink and the related outputs are taken from it. The above simulations are done in Matlab and not simulated on OPEL RT software. So the above results cannot be taken as the real time output of the motor. The Model also considers many assumptions due to which the results are not as expected from the real time motor. The assumptions include.

1. Stator resistance and self-inductance of all phases are equal and constant and mutual inductance is taken zero.
2. Hysteresis and eddy current losses are eliminated.
3. All semiconductor switches are ideal.

Hall sensor output

The Hall sensor module was also tested to see the Hall sensor Voltage outputs depending on which the inverter MOSFET switches are triggered in the required sequence.

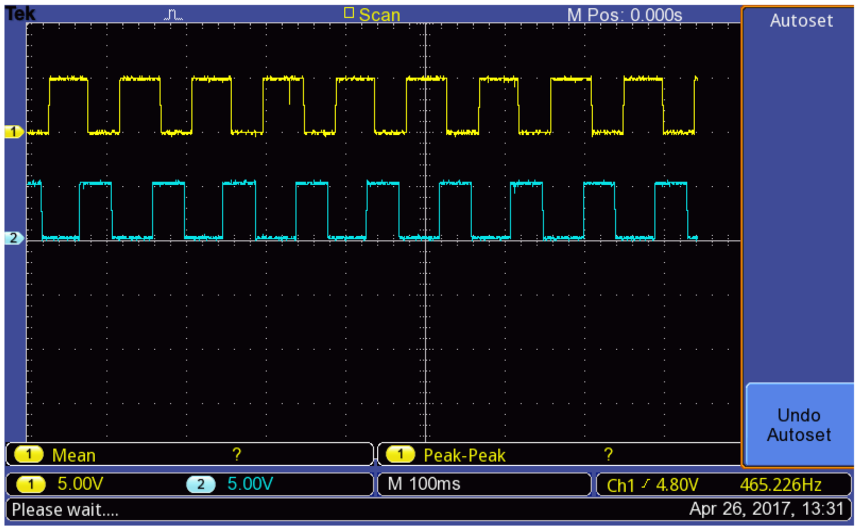


Figure 20: Hall sensor output for phase A and B

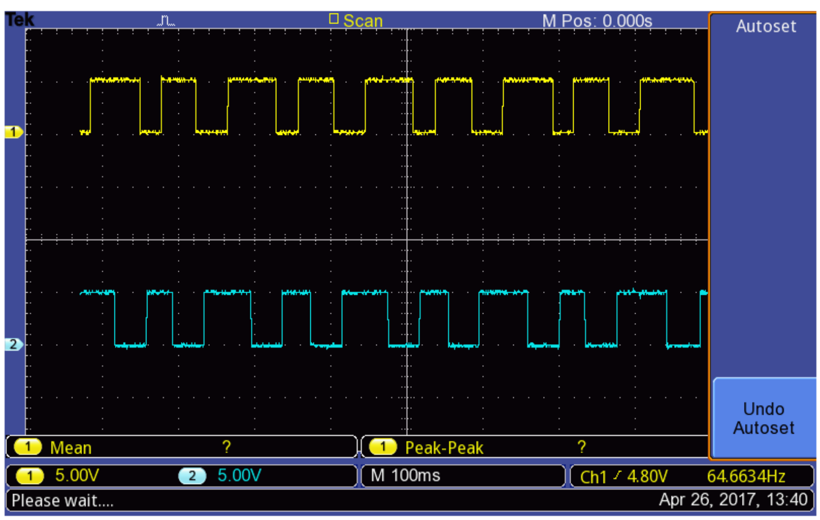


Figure 21: Hall sensor output for phase A and C

5. Conclusion and Future Work

As the name implies, BLDC motor does not use brushes for commutation, instead they are electronically commutated. BLDC motor have advantage over brushed DC motor and induction motor as better speed and torque characteristic, high dynamic response, high efficiency, long operation life and noiseless operation. Future scope of BLDC motor is improvement in speed control using closed loop technique with predictive control. Predictive control is a predictive control algorithm that uses variation trend to regulate. Predictive control has a variety of forms in practical application but no matter what form, all can be summarized as predictive models, rolling optimization, error correcting three basic characteristics. The role of prediction models is predicting the output in the next period of time.

The motor speed can be changed smoothly by the way of adjusting voltage to control the speed. Meanwhile, because the electromagnetic torque of the brushless DC motor is directly proportional to the rotor current, the motor load torque signal feedback is helpful to improve the load capacity of the motor. In order to improve the speed control system quickly and anti-disturbance capacity, the design of the speed control system here takes the structure of double-loop. The other future scope is hybrid integrator back stepping controller, i.e. proposed for robotic manipulators actuated with brushless dc motors in the presence of arbitrary uncertain inertia parameters of the manipulator and the electrical parameters of the actuators. And advancement in it leads to the study of the control of robots actuated by the BLDCM i.e. relatively recent. In a robust feedback linearizing control was proposed. By using integrator back Stepping techniques, robust and adaptive controllers are proposed, respectively. We can also go for Fuzzy logic controller instead of Arduino.

Arduino Uno with the help of hall sensor module has been employed for the speed control of PMBLDC motor drive and analysis of results of the performance of a controller is presented. The modeling and simulation of the complete drive system is described in this thesis. Design and testing of the gate driver circuit has been carried out. Testing of inverter component and PCB fabrication for inverter has been done. The development of the necessary software coding required for the proposed speed control BLDC drive has been carried out.

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