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SIMULATION OF BRUSHLESS DC MOTOR SPEED CONTROL IN MATLAB

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Abstract — *Brushless Direct Current (BLDC) motors, also known as permanent magnet motors find wide applications in many industries due to their higher performance, reliability and ease of control. A new generation of microcontrollers and advanced electronics has overcome the challenge of implementing required control factions, making BLDC motor more practical for a wide range of uses. The main objective of this paper is controlling speed of BLDC motor and displays its speed. The speed control of the BLDC motors is very essential. This proposed system provides a very precise and effective speed control system. The user can increase or decrease the speed as per the requirement and the motor will run at that exact speed. In this paper, we focus on the simulink modeling of BLDC using MATLAB/SIMULINK.*

Keywords- *Brushless DC motor speed control in open and closed loop; six step inverter; PI controller; HALL sensor; Simulink model in MATLAB,*

1. INTRODUCTION

Simulink model is discussed with output waveform using a PI algorithm. This application deals only with BLDC motor speed control application using Hall effect position sensors using commutation sequence.

1.1 Basic Of Brushless Dc Motor:-

Brushless Direct Current (BLDC) motors are one of the motor types rapidly gaining popularity. BLDC motors are used in industries such as Appliances, Automotive, Aerospace, Consumer, Medical, Industrial Automation Equipment and Instrumentation. As the name implies, BLDC motors do not use brushes for commutation; instead, they are electronically commutated

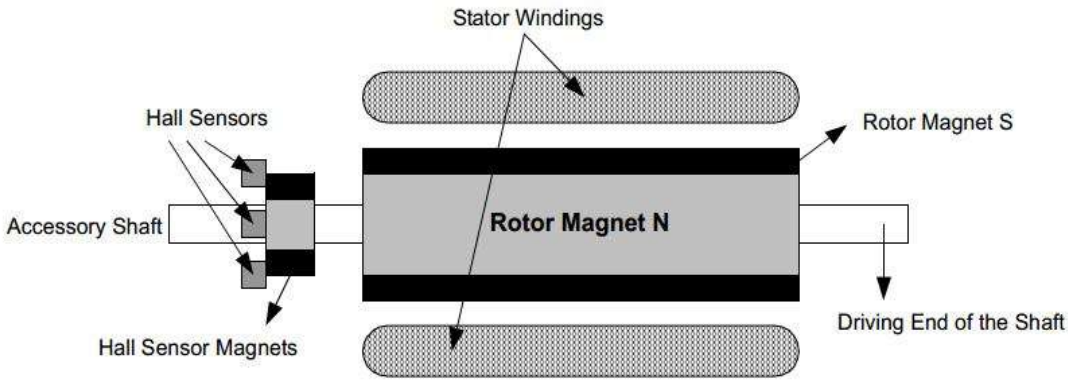
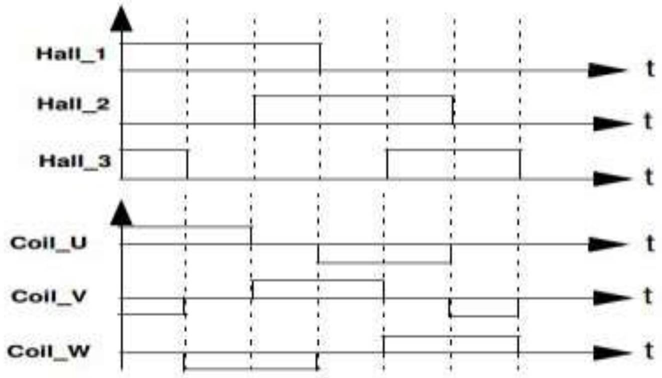


Figure 1: BLDC Motor Transverse Section

1.2 BLDC Motor Hall Sensor:-

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-drying end of the motor. Whenever the rotor magnetic poles pass near the Hall sensors, they give a high or low signal, indicating the N or 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. 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, 6 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.



1.3 Phase Commutations:-

To simplify the explanation of how to operate a three phase BLDC motor, a typical BLDC motor with only three coils is considered. As previously shown, phases commutation depends on the hall sensor values. . When motor coils are correctly supplied, a magnetic field is created and the rotor moves. The most elementary commutation driving method used for BLDC motors is an on-off scheme: a coil is either conducting or not conducting. Only two windings are supplied at the same time and the third winding is floating. Connecting the coils to the power and neutral bus induces the current flow. This is referred to as trapezoidal commutation or block commutation. To command brushless DC motors, a power stage made of 3 half bridges is used.

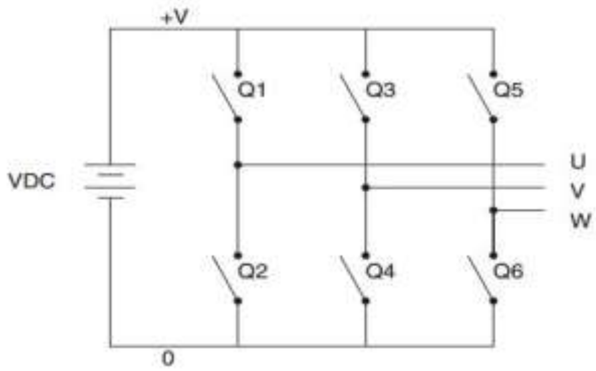


Figure 3 :Bridge schematic

Reading hall sensor values indicates which switch should be closed.

Hall Sensors Value (H3 H2 H1)	Phase	Switches
101	U-V	Q1 ; Q4
001	U-W	Q1 ; Q6
011	V-W	Q3 ; Q6
010	V-U	Q3 ; Q2
110	W-U	Q5 ; Q2
100	W-V	Q5 ; Q4

Table 1: Switches commutation for rotation

1.4 Operation of Brushless DC motor:-

Each commutation sequence has one of the windings energized to positive power (current enters into the winding), the second winding is negative (current exits the winding) and the third is in a non-energized condition. Torque is produced because of the interaction between the magnetic field generated by the stator coils and the permanent magnets of the rotor. In order to keep the motor running, the magnetic field produced by the windings should shift position, as the rotor moves to catch up with the stator field. What is known as “Six-Step Commutation” defines the sequence of energizing the windings. In six-step commutation, only two out of the three Brushless DC Motor windings are used at a time. Steps are equivalent to 60 electrical degrees, so six steps make a full, 360 degree rotation. One full 360 degree loop is able to control the current, due to the fact that there is only one current path. Six-step commutation is typically useful in applications requiring high speed and commutation frequencies. A six-step Brushless DC Motor usually has lower torque efficiency than a sine-wave commutated motor.

2. SIMULINK MODEL USING MATLAB/SIMULINK

2.1 SIMULINK MODEL OF Brushless DC Motor Fed by Six-Step Inverter using PI algorithm:-

This simulation shows the use of a Six-Step Switch-on mode for a trapezoidal PMSM motor rated 1kW, 3000 rpm and speed regulated. A three-phase motor rated 1 kW, 500 Vdc, 1500 rpm is fed by a six step voltage inverter. The inverter is a MOSFET bridge of the SimPower Systems ™library. A speed regulator is used to control the DC bus voltage. The inverter gates signals are produced by decoding the Hall effect signals of the motor. The three-phase outputs of the inverter are applied to the PMSM block's stator windings. The load torque applied to the machine's shaft is first set to 0 and steps to its nominal value (11N.m) at t = 0.1 s. Two control loops are used. The inner loop synchronizes the inverter gates signals with the electromotive forces. The outer loop controls the motor's speed by varying the DC bus voltage. Give specification of Motor in the simulink model for BLDC motor which is given below in to the table

No of Pole	4
No of Phase	3
Rated Voltage..................................V	36
Rated Speed..................................RPM	4000
Rated Torque..................................N_M	0.32
Max peak Torque.............................N_M	098
Torque constant..............................N_M/A	0.061
Terminal Resistance.........................Ohm	0.5
Line to Line Inductance....................mH	1.65
B.E.M.F AT NOMINAL SPEED.........V_{RMS}	20.3
Max peak Current............................Amp	15
Length A...mm	94
Rotor Inertia....................................$K_G M^2 x10^{-6}$	17.3
Mass...K_G	1.0

2.2 Simulation:-

Observe the saw tooth shape of the motor currents. That's caused by the DC bus which applies a constant voltage during 120 electrical degrees to the motor inductances. The initial current is high and decreases during the acceleration to the nominal speed. When the nominal torque is applied, the stator current increases to maintain the nominal speed. The saw tooth waveform is also observed in the electromagnetic torque signal Te. However, the motor's inertia prevents this noise from appearing in the motor's speed waveform.

2.3 Block Diagram Of Speed Control:-

In closed loop speed control, the set speed and the actual speed are compared andthe error is fed to the PI controller, which finally outputs the required duty cycle in orderto achieve the required speed operation of the motor.

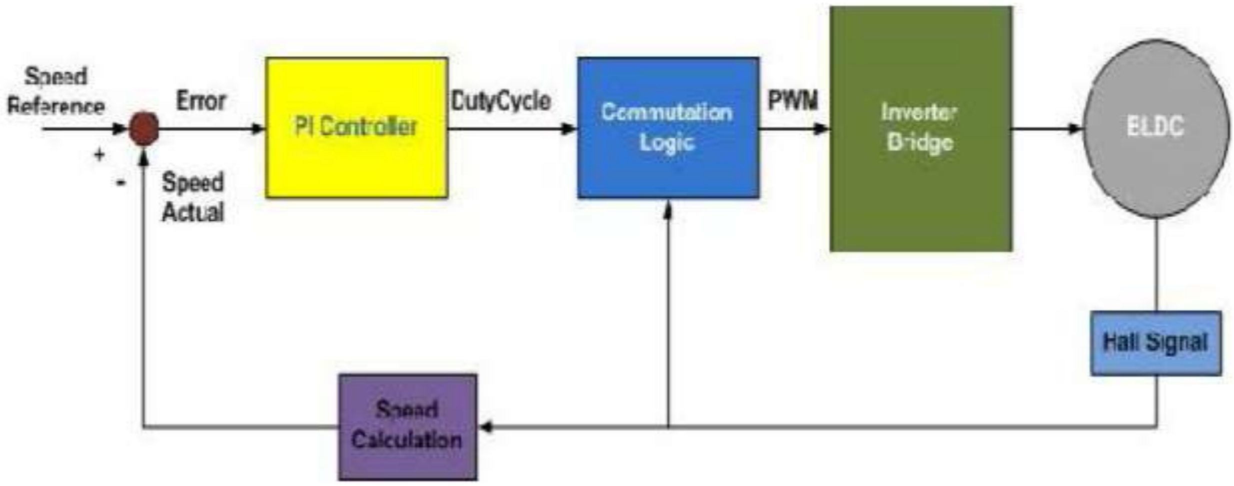


Figure 4: Closed loop speed control block diagram

2.4 Proportional-Integral Controller (PI Controller):-

The regulation of speed is done with the PI controller. The error difference between the actual speed and reference speed is calculated at every PWM cycle and is given as an input to the PI controller.

The dutyCycle output from the PI controller is given in continuous time domain as:

$$dutycycle = k_P * error + k_i \int error * dt$$ Where,

k_P = Proportional Gian

k_i = Integral Gain

$error$ = Difference in Reference speed with Actual speed

$dutycycle$: Controller Duty cycle Output

In discrete time domain the same PI controller is represented by following equations,

$$y_n(k+1) = y_n(k) + k_i * e(k)$$
$$Y_n(k+1) = y_n(k+1) + k_p * e(k)$$

Where,

k_P = Proportional Gian

k_i = Integral Gain

$e(k)$ = Difference in Reference in speed with Actual speed

$Y_n(k+1)$ = Current computed dutycycle

$y_n(k+1)$ = Current integrated error term

$y_n(k)$ = Previously integrated error term

2.5 Simulation Model Description :-

With the help of the designed circuit parameters, the MATLAB simulation is done and results are presented here. Speeds are set at 1500 rpm and load torque disturbance are applied at time t= 5 sec. The speed regulations are obtained at set speed and the simulation results are shown. The wave form of the back emf are shown in fig. it can be seen the phasor voltages are displaced by 120 deg. The stator current waveforms are shown in fig. They are quasi sinusoidal in shape and displaced by 120 deg.

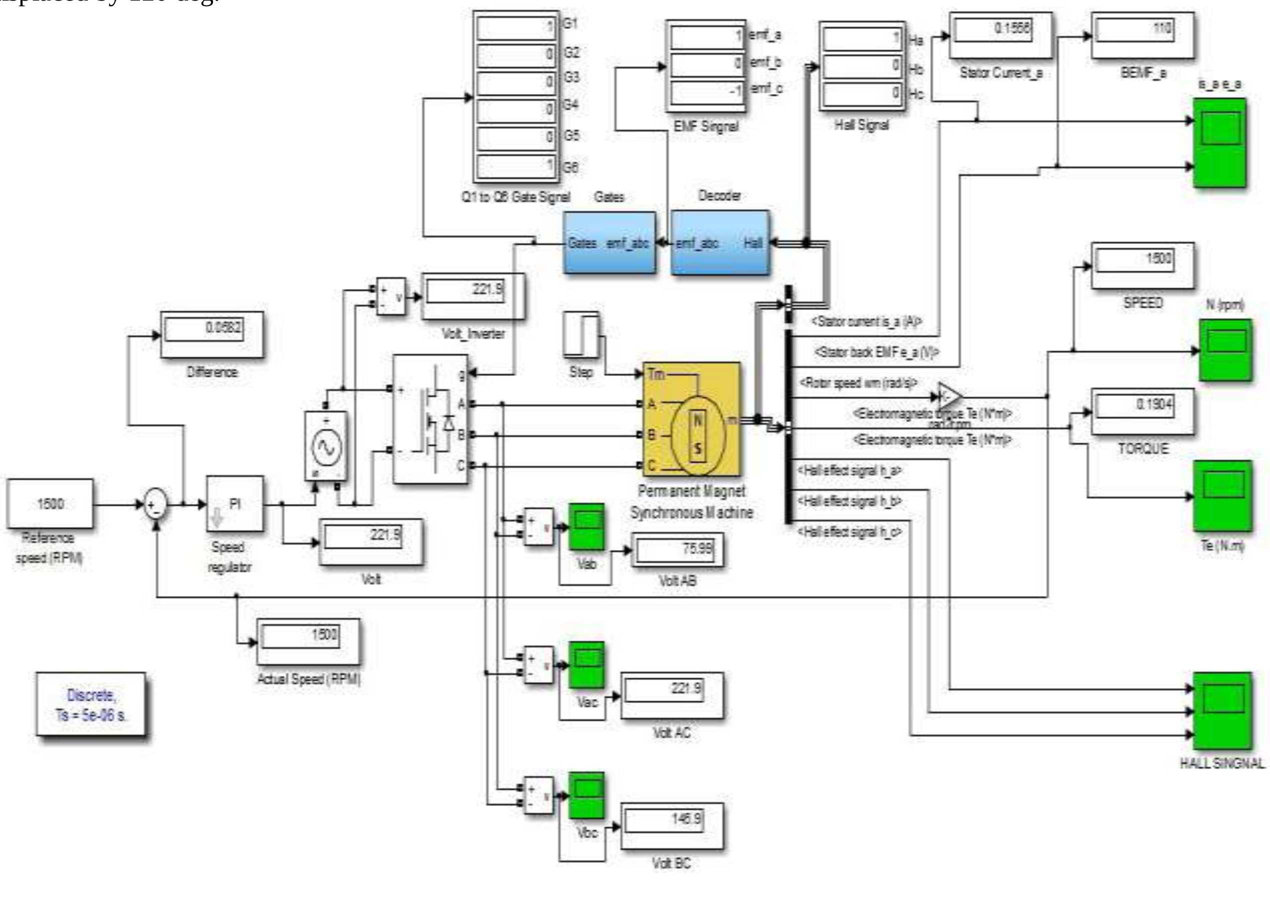


Figure 5: Simulation model in matlab

2.5.1 Under Mask Of Decoder:-

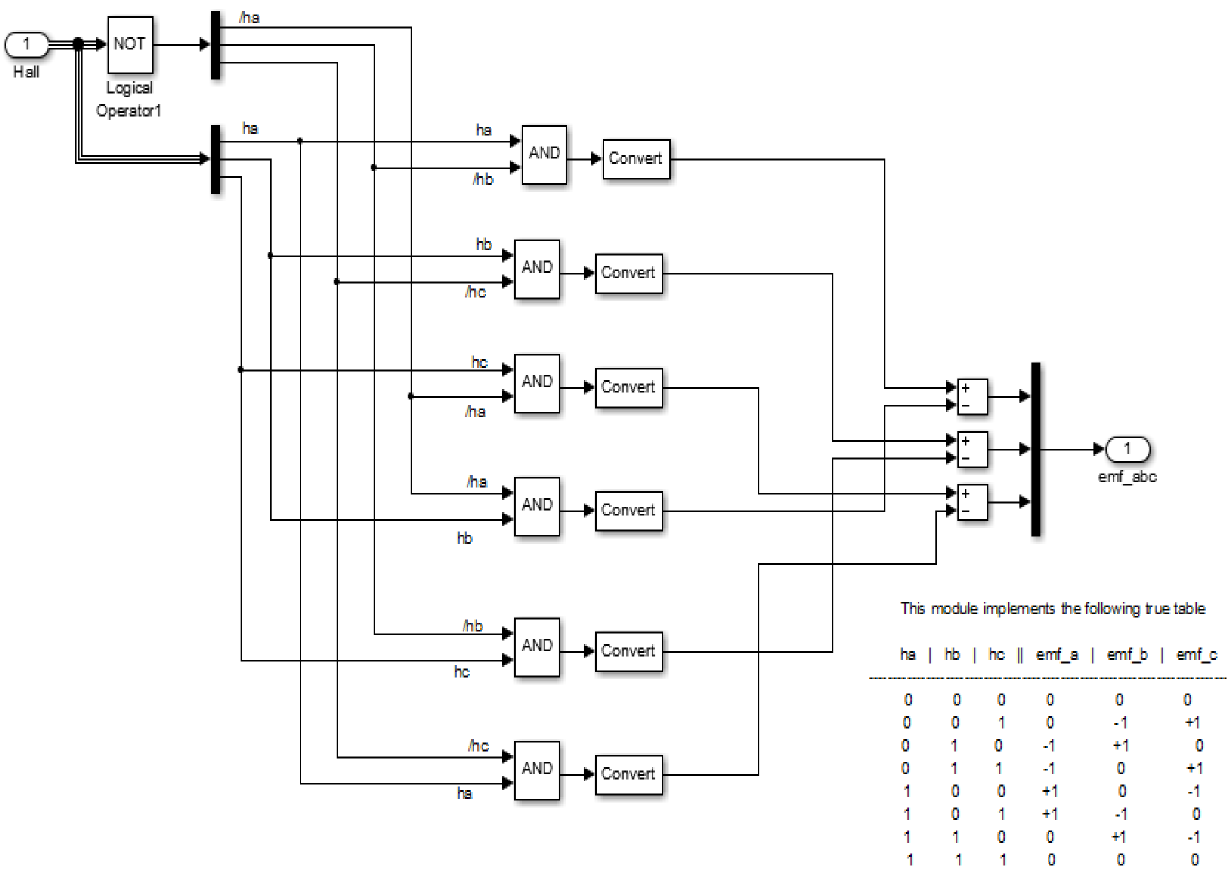


Figure 6: Decoder

3. PERFORMANCE AND ANALYSIS OF SIMULATION RESULT

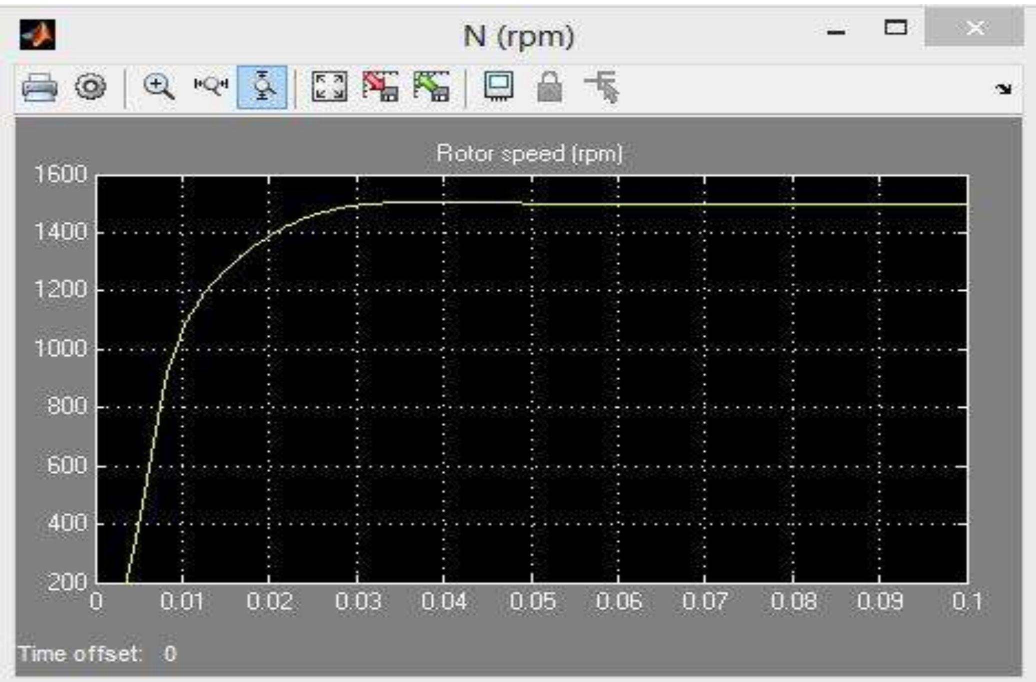


Figure 7: BLDC motor speed in RPM graph

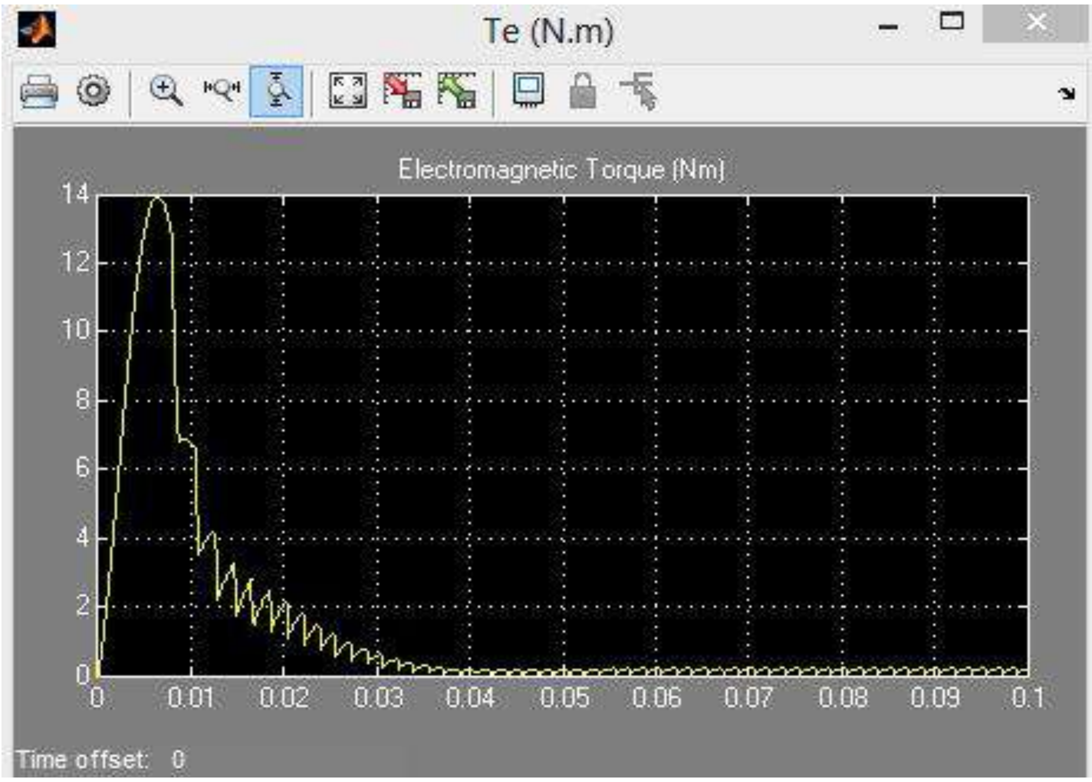


Figure 8: Motor Torque (N.m) graph

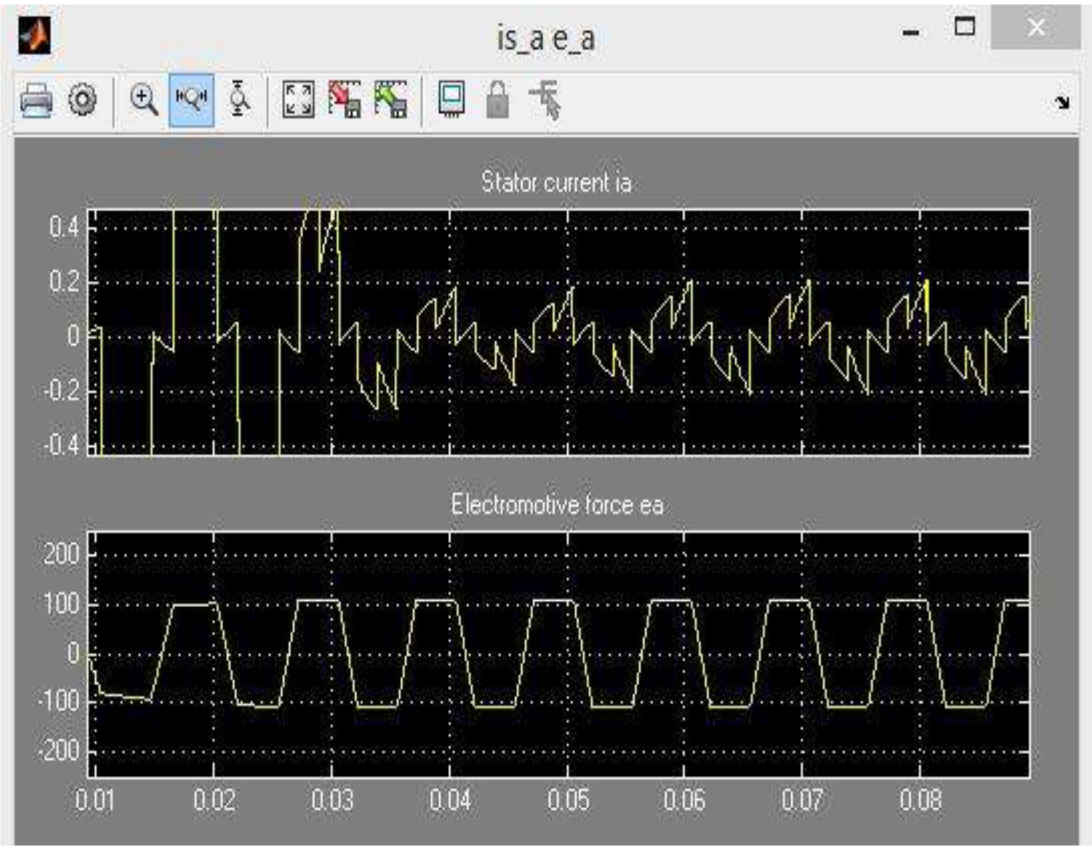


Figure 9 : Motor Stator current and Electronmotive force wave form

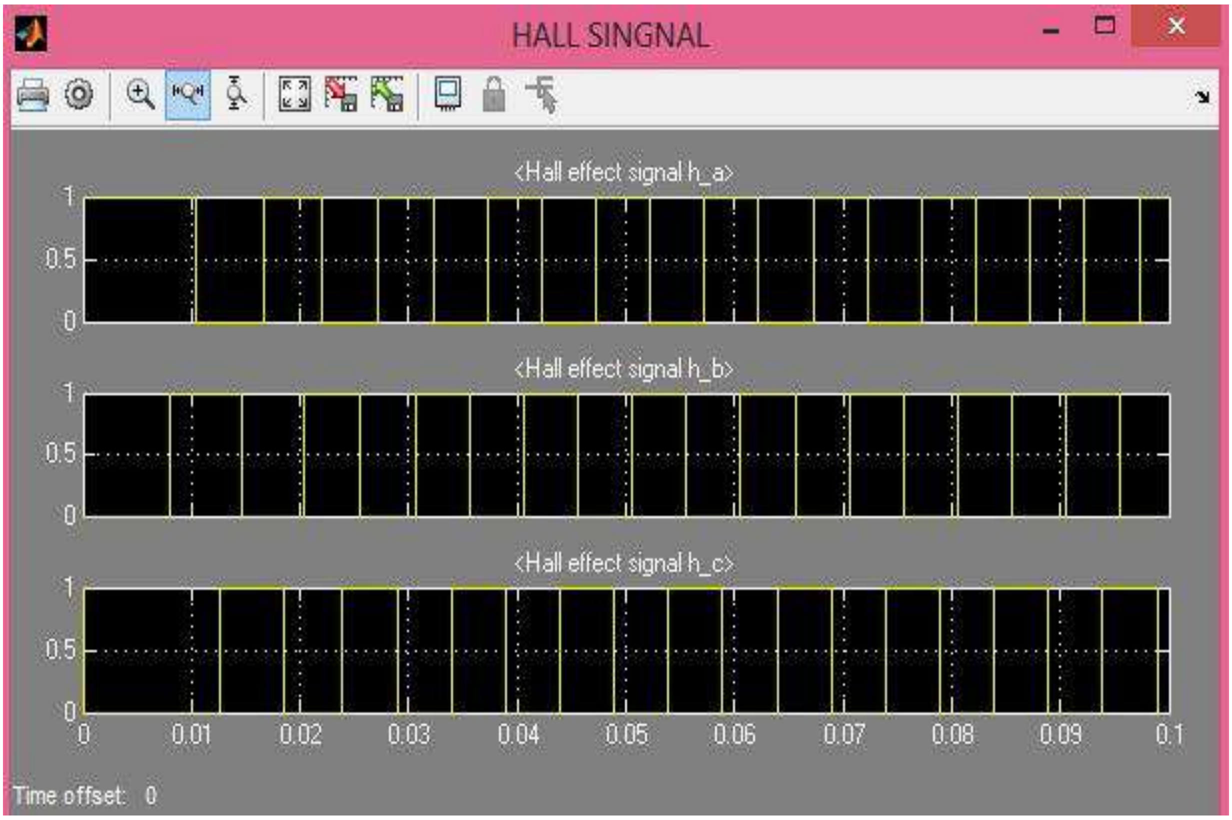


Figure 10: Hall effect signal waveform

4. CONCLUSION

A Matlab/Simulik model of a three phase BLDC motor was developed. The main part of the work was involved in the development of the six step inverter and its interaction with motor. The aim was to make a model that would be accurate, easy to modify and fast running.

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