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# Modelling of Brushless DC Motor Drive for Electric Vehicle Application

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***Abstract: In Electric vehicle, motor plays a significant role. In wheel, motor improves the efficiency and safety of high-performance Electric vehicle. There are a lot of motors available in market, out of all considering their advantages and disadvantages Brushless DC motor is chosen as an efficient motor for Electric vehicle propulsion. The reason behind to choose BLDC motor is because of its desired torque vs speed characteristics, cost of maintenance is low, efficiency is high and has high power density. In this model simulation of an accurate and precise BLDC drive for Electric vehicle application is done and Simulation results such as speed, Electromechanical torque, and various phase voltages graphs are obtained.***
***Keywords: BLDC motor drive, Electric Vehicle, Hall effect, MATLAB Simulink, Torque vs Speed profile***

## I. INTRODUCTION

For an Electric vehicle, electric motor plays an important role. There are different shapes, size and types are available in market. Contrasting to Combustion engine, Electric motor doesn't pollute the Environment. Electric motor has just three parts, even with such low equipment electric motor remains ahead of Internal Combustion engine. This is one of the main reasons why Electric Vehicles use the Electric motor which are a preposition of planet-saving. Motor simplicity is key characteristic of its dependability which is clearly opposite in case of internal combustion engine as it has thousands of moving parts. Also, Electric motors are more powerful and can be a top source of propulsion. For example, by designing a motor that can produce high torque or of near, a mountain can be moved. Electric motors are highly efficient that can produce 90% output i.e., mechanical torque which almost equals some of the mechanical device's efficiency. The motors used in EVs are classified as commutator & commutator less. Although Commutator motors known as Conventional DC motors have high efficiency and also their characteristics makes them suitable to use as Servomotors. Commutator motors require frequent maintenance due to the presence of Commutator and Brushes. These commutators can be replaced by solid state switches and make them commutator less. In this case motor weight reduces and also these motors are free from frequent maintenance. These motors can be termed as Brushless DC motors. Although the functioning of magnet in both Brushless and DC commutator motor is similar, the additional advantage of BLDC is absence of the brushes which removes the problems that are correlated with the brushes such as brush friction, sparks etc. Since there are no brushes more cross-sectional area is accessible for armature winding and also a greater specific torque is produced by the conduction of heat through the frame. Even frequent maintenance of brushes is not needed. So, by considering these it can be estimated that efficiency of BLDC is more than that of a Commutator motor of similar size and rating.

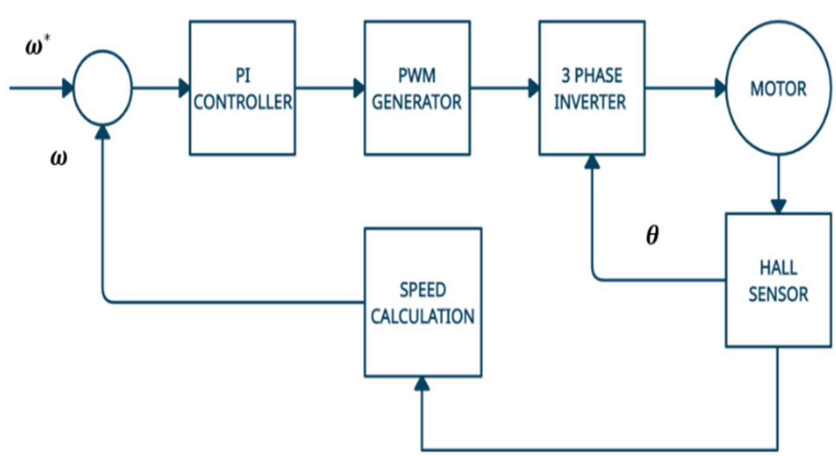


Fig. 1 Block diagram of closed loop system of Brushless DC motor drive

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## II. LITERATURE REVIEW

Although there are different motors available in market, hardly few of them are to be used in EV propulsion application. For selecting a motor for the EV application few factors should be taken into account i.e.; they should have High Efficiency, High instant power, Fast torque response, High power density, Low cost, High acceleration & Robustness. Besides these factors' we should also asses vehicle characteristics driving cycles, Vehicle configuration i.e.; battery capacity, hybrid vehicle or electric vehicle, gear box or direct drive, cost of the motor and at last battery voltage. The BLDC motor drive incorporate a BLDC Motor, a three phase inverter in a closed loop-controlled algorithm. It also incorporates two distinct Mechanical and Electrical parts. Three hall-effect sensors with 120 degrees electric phase difference which detects the motor's rotor position. In the controller, Hall-effect sensors are decoded and supply to the motor is provided by relevant Voltage space vectors. Relative switching pulse is fed to three phase inverter in order to supply input to BLDC motor windings. The speed of the BLDC motor can be controlled with the pulse width modulation that is fed to three phase Inverter in a closed loop system which provides an accurate speed control of the motor. To study the various control schemes of the motor that gives precise values of torque, speed, current and back EMF an accurate model of BLDC motor is required. Although the previous reported research work contributed to BLDC motor modelling, there is not a simple BLDC motor with ideal trapezoidal back EMF appropriate to Electric Vehicle application. In general, to model the motor, mathematical analysis is being used to get the desired torque and speed characteristics w.r.t varying load. Here, in this simulation model we have considered the Permanent synchronous motor which is configured with trapezoidal back emf, Decoder subsystem and signal extraction system.

## III. WORKING OF BLDC MOTOR

The BLDC motor working is similar to that of operation of 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 result of reaction force, the magnet will exert an equal and opposite force. In case of BLDC motor, the permanent magnet moves while current carrying conductor is stationary. Uniform field in the air gap is produced when the stator coils are electrically switched by a supply source. Though the supply is DC, switching makes to generate an AC voltage wave form with trapezoidal shape. Due to force of interaction between electromagnetic stator and permanent magnet rotor, the rotor continuous to rotate. As mentioned earlier electronic controller energises motor winding by turning transistor or solid-state switches to rotate the motor continuously.

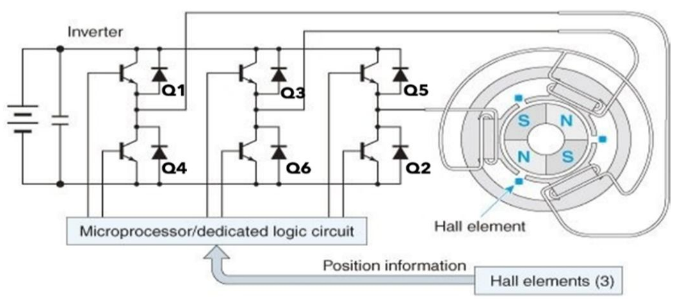


Fig. 2 Working of BLDC motor

To sense the rotor position and feedback the speed Hall sensors are used. Hall sensors sends the signal to the controller. Inverter circuit receive the processed signal from controller.

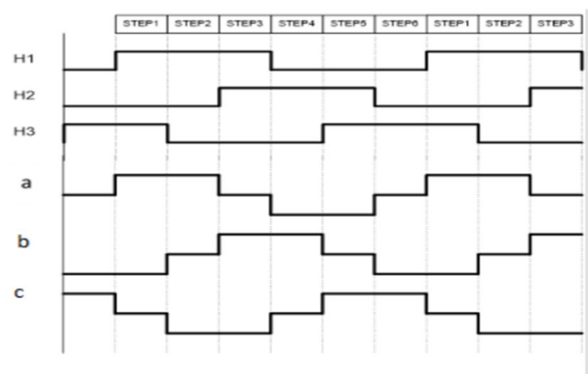


Fig. 3 Hall sensors and phase waveforms

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### *A. Mathematical Formulae*

The trapezoidal back-EMF implies that the mutual inductance between stator and rotor is non-sinusoidal. Thus, a 'abc' phase variable model is more applicable than a d-q axis model. Few assumptions are to be made in order to simplify mathematical equations, they are magnetic circuit saturation is ignored, stator resistance, self and mutual inductance of three phases are equal and constant, hysteresis and eddy current losses are eliminated, inverter semiconductor switches are considered ideal. The simplified mechanical and electrical mathematical equations of BLDC motor can be written as

$$V_a = Ri_a + (L-M)\frac{di_a}{dt} + E_a \quad (1)$$

$$V_b = Ri_b + (L-M)\frac{di_b}{dt} + E_b \quad (2)$$

$$V_c = Ri_c + (L-M)\frac{di_c}{dt} + E_c \quad (3)$$

Where $V_a$, $V_b$, $V_c$ represents phase voltages of a, b, c phases applied from inverter to BLDC motor.

$$E_a = K_e\omega_m F(\theta_m) \quad (4)$$

$$E_b = K_e\omega_m F(\theta_m - \frac{2\pi}{3}) \quad (5)$$

$$E_c = K_e\omega_m F(\theta_m + \frac{2\pi}{3}) \quad (6)$$

Where $E_a$, $E_b$, $E_c$ represents back EMF voltages of phase a, phase b, phase c.

$$T_{ea} = K_t i_a F(\theta_m) \quad (7)$$

$$T_{eb} = K_t i_b F(\theta_m - \frac{2\pi}{3}) \quad (8)$$

$$T_{ec} = K_t i_c F(\theta_m + \frac{2\pi}{3}) \quad (9)$$

Where $T_{ea}$, $T_{eb}$, $T_{ec}$ represents electric torque produced in phase a, phase b, phase c.

$$T_e = T_{ea} + T_{eb} + T_{ec} \quad (10)$$

$$T_e - T_l = J\frac{d^2\theta_m}{dt^2} + \frac{d\theta_m}{dt} \quad (11)$$

$$\theta_e = \frac{P}{2}\theta_m \quad (12)$$

Where $\theta_e$ represents electrical angle in radians, $\theta_m$ represents mechanical angle

$$\omega_m = \frac{d\theta_m}{dt} \quad (13)$$

Where $\omega_m$ represents mechanical speed of motor in radians/second

### *B. Merits and Demerits Of BLDC Motor*

*1) Merits*

*a)* There is no field winding. Therefore, there is no field cu loss.
*b)* Absence of mechanical commutator reduces the length of the motor.
*c)* Size of the motor becomes less.
*d)* It is possible to nave very high speeds.
*e)* It is self-starting motor. Speed can be controlled.
*f)* Motor can be operated in hazardous atmospheric condition.
*g)* Efficiency is better.

*2) Demerits*

*a)* Field cannot be controlled.
*b)* Since available size of permanent magnets is maximum, Power rating is restricted.
*c)* A rotor position sensor is required.
*d)* A power electronic switch circuitry is required.

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## IV. MODELLING OF BRUSHLESS DC MOTOR

The Brushless DC motor is modelled with the help of MATLAB Simulation software. In this model we have considered closed loop operation of BLDC motor so that it can accurately set the speed of the motor. In Simulink software we have used permanent magnet synchronous motor which is configured with Trapezoidal Back-Emf. In generally there are two configurations are available sinusoidal and trapezoidal, by choosing trapezoidal we can able to run the PMSM motor as a Brushless DC motor. In modelling Brushless DC motor drive, we have considered the basic block diagram shown in Figure 1b. When we look into the block diagram, it consists of four major parts i.e.; Hall sensors, 3-phase inverter, PWM generator and a Controller. The controller can be any type, it can be PI, PID, PD.

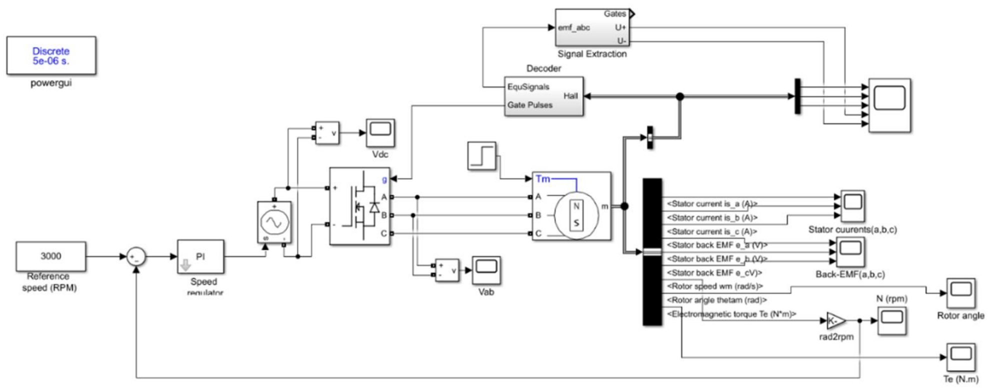


Fig. 4 Simulation model of BLDC drive in MATLAB Simulink

In modelling Brushless DC motor drive as mentioned earlier PMSW is configured with Trapezoidal Back-EMF mode so that it can act as a BLDC motor. Now from the BLDC motor we can able to extract the Hall sensor Data which represents various switching modes. Here in control of BLDC motor Hall sensor data plays a crucial role. After the extraction of Hall sensor data based on the mode received from hall data gate pulses are to be given to universal bridge, here universal bridge acting as a 3-phase inverter. The gate pulse to the bridge is given by Decoder subsystem mentioned in the above simulation diagram

### *A. Subsystem for Generating Gate puLse*

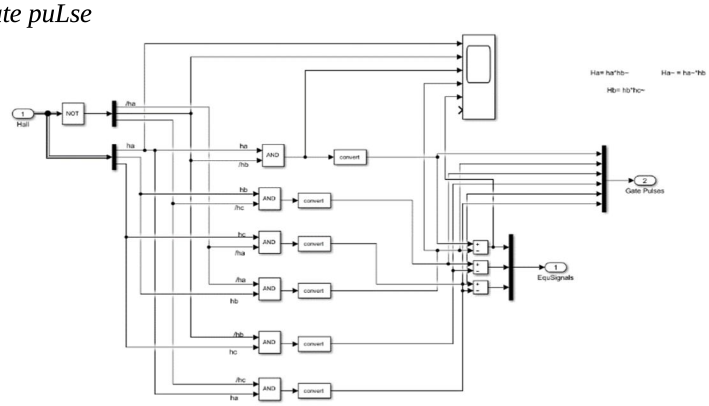

Fig. 5 Subsystem for generating gate pulse

The Hall sensor data is to be used and based of positive and negative pulses we have created a system which incorporates all the three phases as shown in figure. From the subsystem

$H_a$ for positive phase and $H_a\sim$ for negative. Hall sensor data has been configured with the help of Logic gates. Here the logic used can be formulated in equation as follows

$H_a = h_a * h_b\sim$

The above expression is for phase a positive pulse.

Similarly for negative pulse it can be written as

$H_a\sim = h_a\sim * h_b$

The above two equations are mentioned only for single phase a, by considering the same pattern we can also write the equations for phase b and phase c.

### *B. Signal Extraction Subsystem*

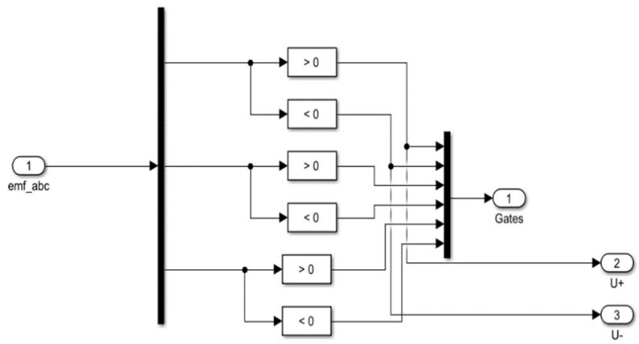


Fig. 6 System to extract inverter phase output

A truth table can be drawn from the above subsystem created. The above-mentioned subsystem model implements the following truth table

Table I
Truth table of Signal extraction Block

| emf_a | emf_b | emf_c | Q1 | Q2 | Q3 | Q4 | Q5 | Q6 |
|---|---|---|---|---|---|---|---|---|
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 0 | -1 | +1 | 0 | 0 | 0 | 1 | 1 | 0 |
| -1 | +1 | 0 | 0 | 1 | 1 | 0 | 0 | 0 |
| -1 | 0 | 1 | 0 | 1 | 0 | 0 | 1 | 0 |
| 1 | 0 | -1 | 1 | 0 | 0 | 0 | 0 | 1 |
| 1 | -1 | 0 | 1 | 0 | 0 | 1 | 0 | 0 |
| 0 | 1 | -1 | 0 | 0 | 1 | 0 | 0 | 1 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

## V. SIMULATION RESULTS

The Brushless DC motor drive has been created in application with Electric Vehicle, by considering its merits. Here, as we are intended to implement the model for EV application the results are obtained for various loads. We have considered three cases as no-load, load with 10 N-m torque and load with 25 N-m torque. These three cases are considered in order to obtain speed, torque characteristics and we also obtained Hall sensor data and stator currents and voltages.

As mentioned earlier here we will be considering various loads conditions as no-load condition, load with *10 N−m* and load with *25 N−m*.

### *A. No-Load Condition*

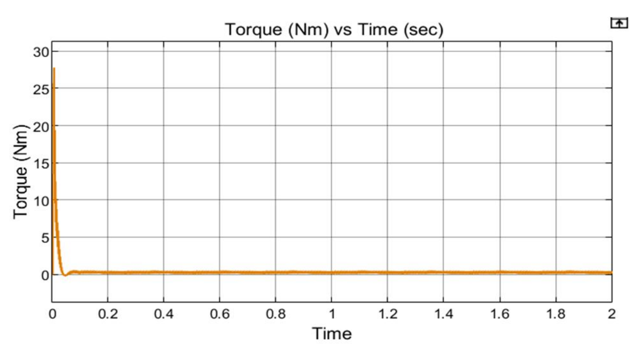


Fig.7 Torque of BLDC drive at NO-LOAD condition

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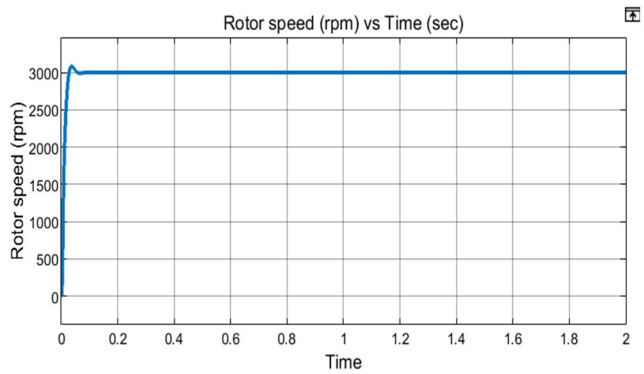


Fig.8 Speed curve in rpm at NO-LOAD condition

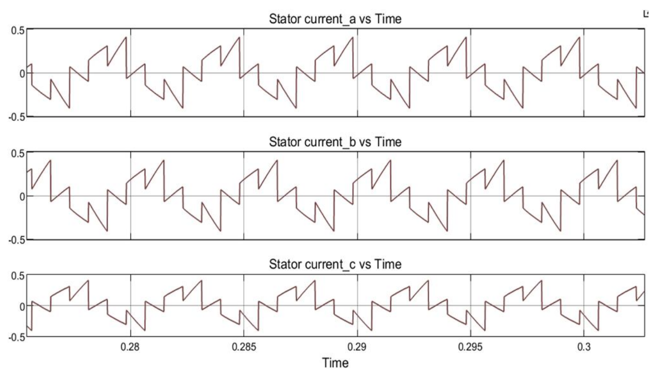


Fig.9 Stator currents of phase a, phase b, phase c

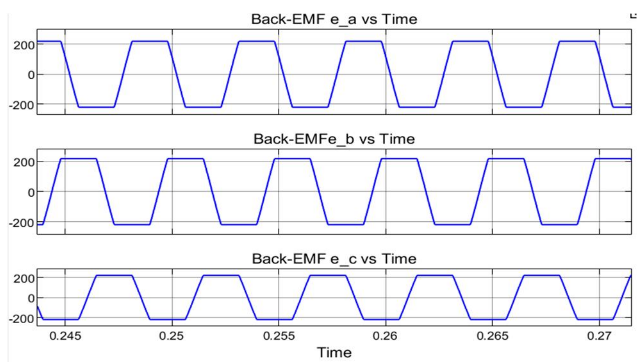


Fig.10 Stator EMF of phase a, b, c under no load condition

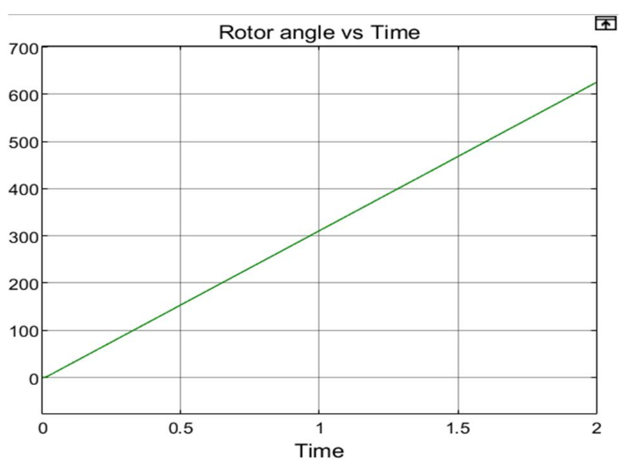


Fig.12 Rotor angle in radians at NO-LOAD condition

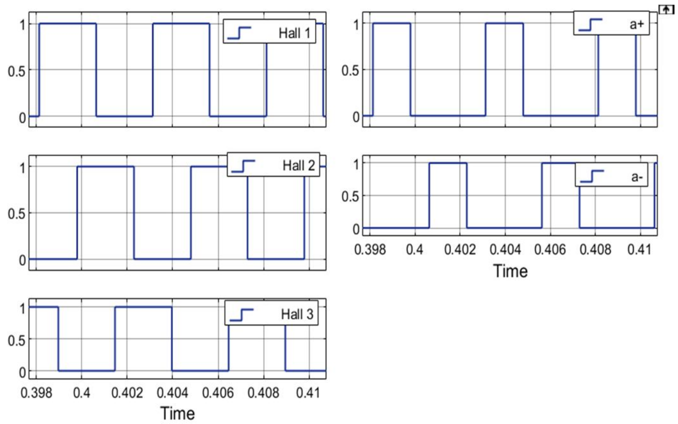


Fig.13 Positive and Negative trigger to inverter switch based on hall sensors under NO-LOAD

After obtaining all the required graphs under no-load condition we can say that, under no-load condition the torque of motor is around **28 N−m**, speed of motor is **3000 rpm** and we have observed the variation of rotor angle, how the inverter bridge is turning on and off based on hall sensor data acquired.

*B. Load AT 10 N-m*

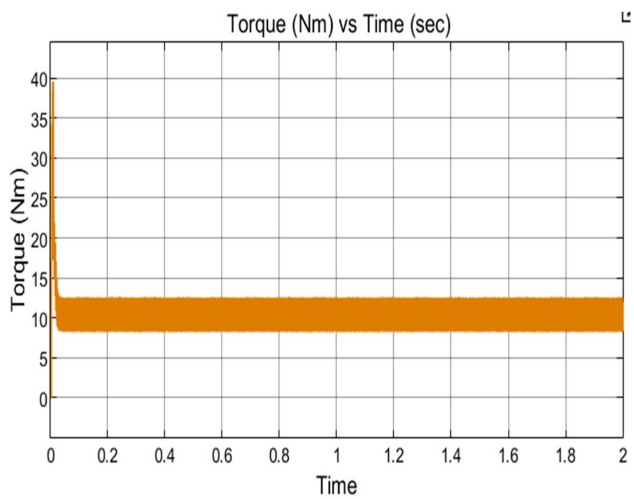


Fig. Torque of BLDC drive at **10 N− m** load

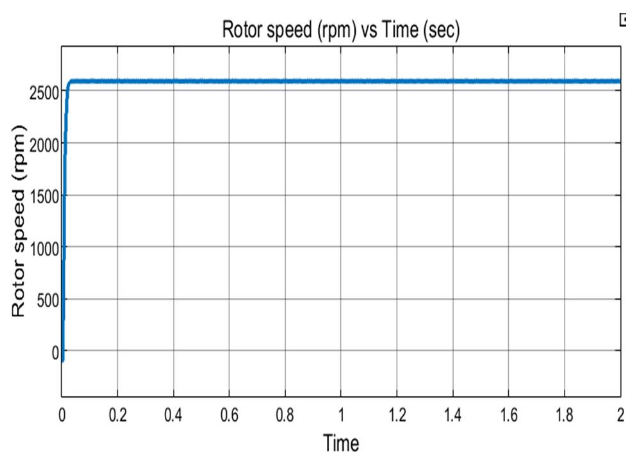


Fig. Speed of motor in rpm at **10 N−m** load

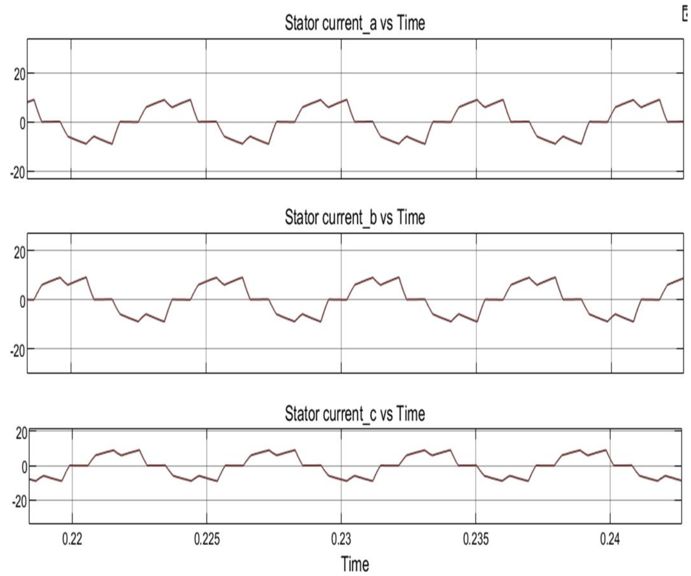


Fig. Stator emf of phase a, b, c at **10 N-m** load

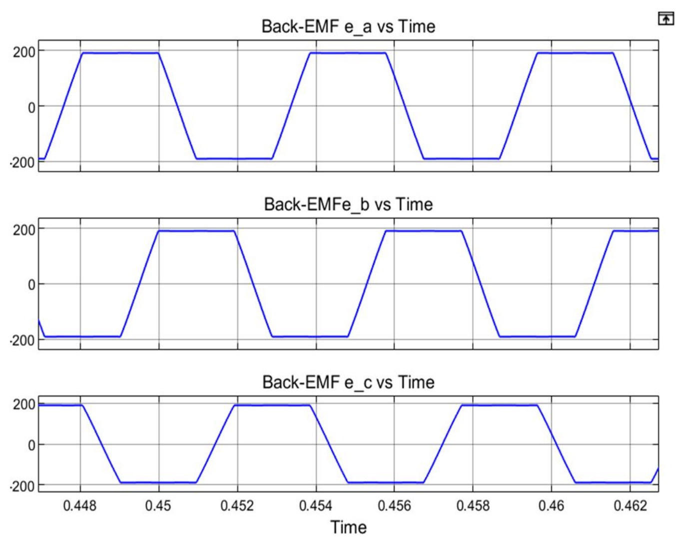


Fig. Current of phase a, b, c at **10 N-m** load

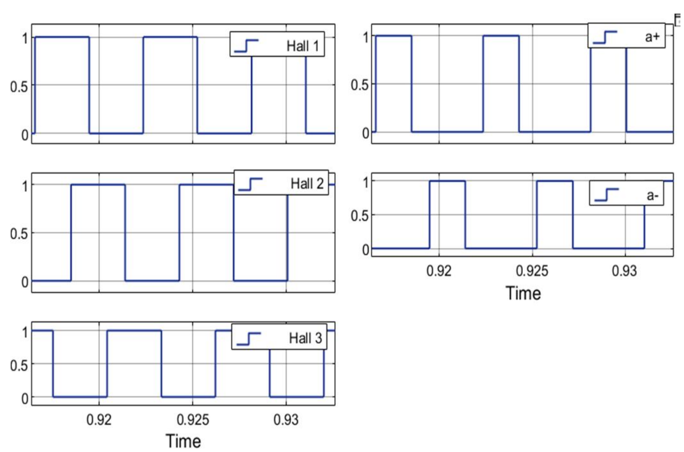


Fig. Positive and Negative trigger to inverter switch based on hall sensors at **10 N-m** load

In this case when applied load is 10 N−m, the obtained values are torque of motor is **40 N−m** and speed is **2500 rpm.**

*C. Load AT 25 N-m*

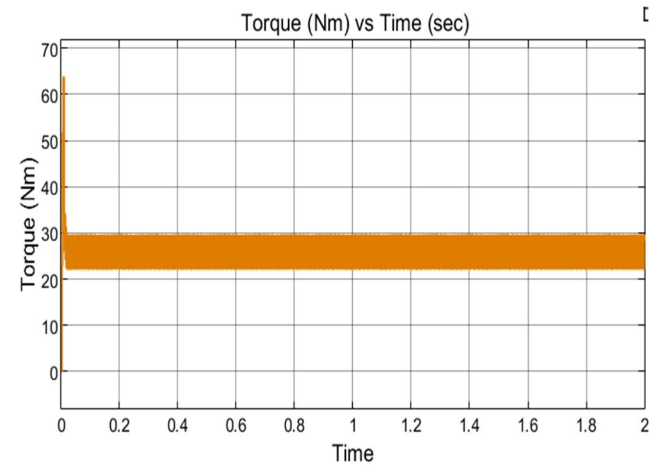


Fig. Torque of BLDC drive at **25 N−m** load

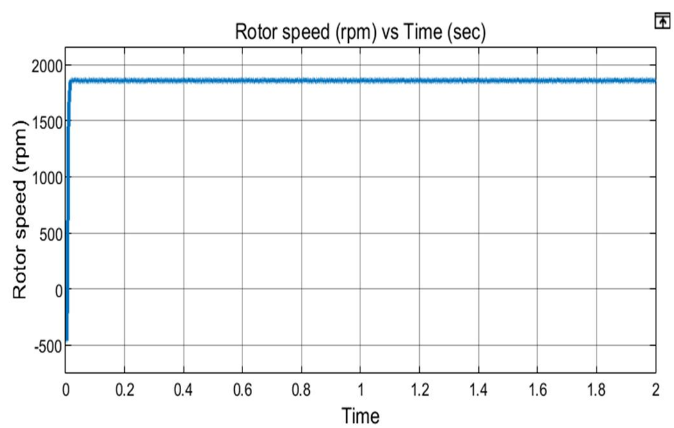


Fig. Speed of BLDC motor at **25 N-m** load

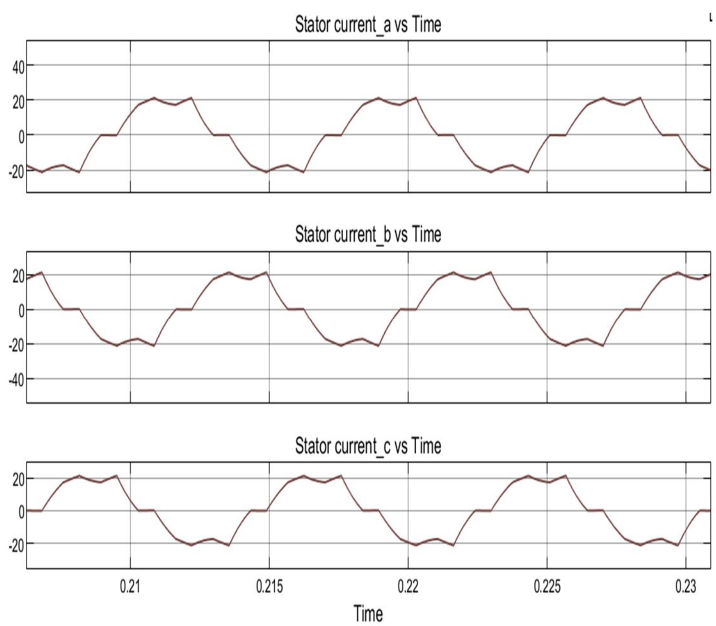


Fig. Stator current of phase a, b, c at **25 N-m** load

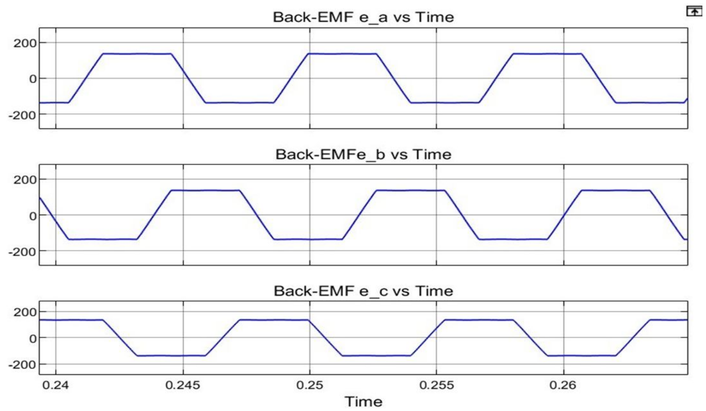


Fig. Back-EMF of phase a, b, c at **25 N-m** load

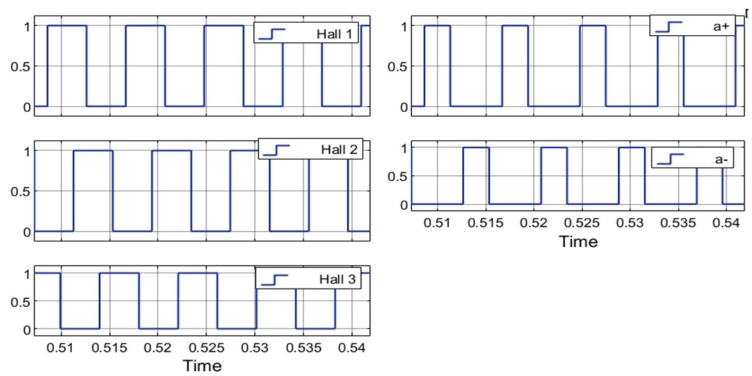


Fig. Positive and Negative trigger to inverter switch based on hall sensors at **25 N-m** load

In this case when applied load is **10 N−m,** the obtained values of torque of motor and speed is **40 N−m** and speed is **2500 rpm**.

## VI. CONCLUSION

The amount of pollution and greenhouse gases are being tremendously increasing day by day due to use of fuels like petrol, diesel and other for propulsion of vehicles. In such scenario Electric vehicles are to be considered as an alternative, as they come under zero emission vehicles. So, the use of Electric and Hybrid vehicles is going to increase in near future. In these vehicles motor plays a crucial because it is the major part that helps for the propulsion of vehicle. Therefore, we need to choose a motor with good torque and speed characteristics at various loads. We have modelled a Brushless DC motor drive which is a closed loop system in order to change the speed in much accurate way. The modelling is done by considering the block diagram of BLDC drive and we have used a continuous voltage source instead of Pulse with modulation to control the speed of motor. The model has been developed using MATLAB Simulink software at no-load and on load conditions and as a result we have obtained smooth performance of the motor at respective loads. By observing the performance of motor, these motors are suitable for application in Electric scooter, Electric cars, Vacuum cleaners, Drones, Washing machines and in various other fields. BLDC motors has low maintenance cost as it is brushless and it has high speed range, high power density, higher efficiency so, we can conclude that BLDC drives are suitable for using in Electric Vehicles.

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