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Article

Design and Implementation of BLDC Motor Drive for Electric Vehicle Applications

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Abstract

This work focuses on electric vehicles, with a particular emphasis on the Brushless DC (BLDC) motor as the most effective solution for green transportation due to its high efficiency and zero greenhouse gas emissions. The study examines various types of electric motors that have been utilized as propulsion systems for electric vehicles, including brushed Direct Current (DC) motors, induction motors, switched reluctance motors, and permanent magnet Brushless DC (BLDC) motors. The research also explores the implementation of speed control for brushless DC motors in electric vehicle applications and provides an overview of electric vehicle technologies. The study predicts that BLDC motors will replace traditional motors as the standard form of power transmission in industries by the year 2030 due to their high efficiency, high power factor, strong torque, and simple control. The research includes the creation of a model for the 120° mode using electrical and mechanical equations, as well as an investigation into the BLDC motor's capabilities at constant, dynamic, and torque speeds. The test results are verified using MATLAB/SIMULINK, with the real value achieving the reference value in the first two scenarios.

Keywords: A BLDC Motor, Pulse Width Modulation, Speed Control of BLDC Motors, electric vehicles.

1. Introduction

The world is headed in the creation using technologies produce energy from renewable sources, and technologists are working incredibly difficult to address challenges like the scarcity in the use of fuels and clean/renewable energy as a result of the growth in world population and energy use due to improved lifestyles environmental issues like high energy prices, global warming, and others concerns [Chow and Chau (2022)], We will concentrate relating to various storage methods, which are at the heart of the technological advancements required to plan and create green energy.

We have emphasized the key characteristics which compared the power/energy density, cost to meet the worldwide demand, and other characteristics of each of these technology issues. the capacity to control the limited availability of current resources and the competitiveness to achieve sustainability criteria [Yang et al.(2022)], because of straightforward design, high torque output, extended lifespan, and high efficiency, brushless DC motors (BLDCM) have found extensive use inside industrial automation, home appliances, automobile other, electronics, and aerospace industries.

Electric vehicles have historically used a variety of electrical motor types as their propulsion technology. they include a permanent magnet brushless. Brushed DC motor, induction motor (IM), switching reluctance motor (SRM), and DC motor (BLDC). The motor types and drives used in EVs have thus been reviewed. Choosing the best electric motor drives for applications in electric vehicles, a comparative analysis of the efficiency, cost, maximum speed, and reliability of switching resistance motors, an induction motors, a constant magnet motors, DC motors, in order to determine the most suitable electric motor drives for applications involving electric vehicles, research on and axial flux permanent magnet brushless dc motors is being done. Our studies indicate that the preferred option for electric vehicle motor drives is motor drivers for brushless dc motors with axial flux [Rajesh et al.(2022)].

Brushless DC motors have an expanded speed range, greater dependability, and efficiency. The biomedical and robotic applications [Jayakumar et al.(2021)], require strong torque to weight ratio and precise position control for accuracy since BLDC motors are quite widespread in many industrial and consumer durables due to these unique characteristics. As a result, BLDC motor may be thought of as an appropriate option [Alias and Josh (2020)], in comparison to its AC and DC counterparts; however, the barrier is electronic commutation in BLDC motors, which causes torque ripple [Sheng et al.(2017)], because of improper position sensor placement. Based on feedback from the rotor position, electronic commutation is used for BLDC motors instead of mechanical commutation. It is possible for Whether this feedback is sensor-based or sensor-free. It is position sensors vulnerable to changes in physical parameters including temperature, pressure, and humidity. Hence, it has become more popular to use sensor-less rotor position detection [Chen et al.(2016)]. the artificial intelligence-based strategy, the back EMF approach, the Flux Linkage approach, the inductance approach, and the technique based on back EMF are the key sensor-less methods.

Due to its inherent advantages of having a straightforward structure and reliable operation, the control using proportional integral and derivative (PID) method is frequently employed within the industry [Sriram and Sureshkumar (2014)]. Over 95% of industrial closed loop controllers are PID or PI based. even in the current environment [Goswami and Joshi (2018)], However, due to the nonlinear nature of the latter, this controller is not thought to be appropriate for BLDC motors. Since 1918, electric vehicles (EVs) have been a possibility [Yong et al.(2016)].

However, in the twenty-first century, permanent magnet brushless direct current (PMBLDC) motors were launched thanks to the accessibility of materials for rare earth permanent magnets of the highest quality as the metal's samarium cobalt (Sm-Co) and neodymium-iron-boron (Nd-Fe-B). which has high efficiency and power density [Whittingham (2012)]. Instead of brushes like a DC motor, the electrical commutation used by the PMBLDC motor. Nevertheless, electrical commutation makes the control algorithm difficult. Three components make up the design concept for an electric vehicle (EV), including advanced technologies that can boost the vehicle's performance. Yet these technologies must be chosen from current engineering in the fields of chemical, mechanical, automotive, electrical, and electronic. Employing a unique design, particularly in relation to EVs, and approaches from the automotive industry that are appropriate for EV [Blinov et al.(2021)]. The load is the BLDC motor. With the suggested BLDC motor converter control with AC operating at unity power factor mains is made possible. this improves operational effectiveness . An inside-out DC motor is a brushless DC (BLDC) motor. that lacks the brushes needed for commutation. The stator and rotor have three-phase armature windings attached. is made permanent magnets. Hence, since there are no brushes, the motor is maintenance-free, tough, and strong, making it perfect for industrial applications. BLDC motors have a low moment of inertia, high efficiency, and high volumetric torque thanks to the rotor's fixed magnetic field and the permanent magnets installed on it. [Skvarenina (2018)]. PWM (pulse width modulation) and control of the hysteresis current, which are related to continuous control theory, are two of the most often utilized control approaches for BLDC motors, as detailed in [Akhil et al.(2020)]. The sensorless BLDC motor drive with a high speed demonstrated and is fed through a constant dc supply that concentrates on producing a virtual back-emf for the third harmonic. If the motor is fed directly sourced from the grid. it is necessary to evaluate the grid's input power quality. The different methods created in [Pindoriya et al.(2015)], are mostly concentrated on the control portion after the converter, which employs either a three-stage or a constant dc source inverter. for applications where the motor needs to receive its power straight from the grid. Various motors' efficiency comparisons are displayed in table (1) electric vehicle manufacturing When compared to other motors, BLDC motors will operate more efficiently. Brushless DC motors (BLDCMs) provide a number of benefits in addition to their straightforward design, dependable operation, and ease of maintenance, including high DC motor efficiency, no excitation loss, and effective speed regulation [Tashakori et al.(2015)]. the conventional drive's DC link mechanism within these motors uses electrolytic capacitors with a high capacity. These capacitors lack the necessary stability because of their electrolyte liquid and sensitivity to temperature, and are typically among the first components in the drives to experience issues like high temperature or voltage, exploding or leaking under pressure. Electrolytic capacitors, unfortunately, are the root of failures in electric drive systems in 60% of cases [Zhang et al.(2021)].

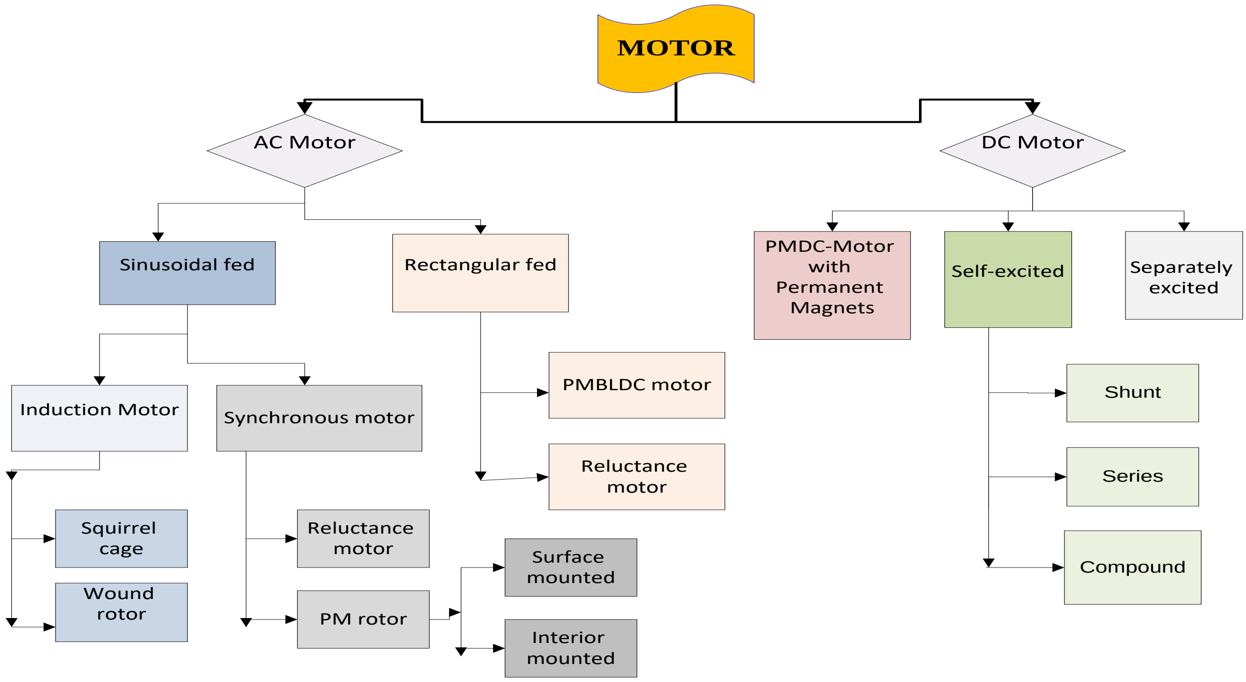

Figure 1. EV motor classification

BLDC motor is an electronically commutated a device that is comparable to an AC synchronous machine. It produces trapezoidal back emf, and depending on where the hall sensors are located in the motor's stator, the two stator windings are stimulated during each condition. Rotor magnet position will be detected through sensors. Anytime the rotor poles come into proximity to the hall sensors, high or low signals are generated. The precise commutation sequence is determined using the combination of hall sensors. The windings of the BLDC motor stator need to be activated sequentially in order to rotate [Wang et al.(2019)]. Table (1) summarizes comparison talks based on in-wheel technology and motor specifications:

Table 1: Motors Comparison According to the In-wheel Motor Specifications

Features	BLDC motor	SR motor	Induction motor	DC motor
Commutation	Electronic	electronic	-	Brushes
Slip	-	-	Applicable	-
Efficiency	5	3	3	2
high-speed rating	5	5	3	3
broader steady power speed range	3	5	4	2
Complexity of control	2	2	3	5
Torque/Speed	5	3	4	3
A responsive dynamic	5	2	3	4
Power-to-size ratio	4	4	3	3

Lifetime of an operation	5	5	3	2
maintenance requirements	5	5	4	2
Sensitivity to noise	5	2	3	3
In fault Speed	3	5	4	2
Torque during a fault	4	2	4	1
Speed during mechanical shocks	3	4	5	4
Torque during mechanical shocks	4	2	3	3
Cost of Production	2	4	5	5
Total	60	53	54	44

The induction motor, according to comparison results, is the most durable of all the motors under extreme conditions; however, due to its restricted speed range, weak dynamic response, motor slip at low speeds, and low efficiency at high speeds, for high-performance electric vehicles, it is not a good solution.

2. Mathematical modeling of a BLDC motor

The permanent magnet-mounted stainless-steel rotor of three phase symmetrical windings are present in the BLDC motor. Rotor current is disregarded as a result of the high resistance of permanent magnets and stainless steel [Aresta et al.(2016)]. As shown in Fig. 2, the basic equation determining a BLDC motor's armature voltage equation is as follows:

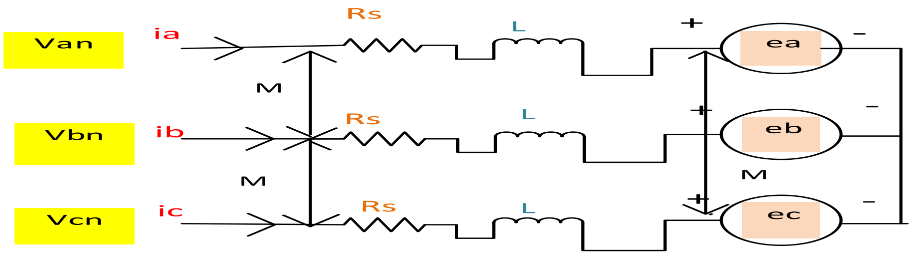

Figure 2. Circuit equivalent for a three-phase, Y-connected a BLDC motor

Three phase synchronous motor modeling can be used to compare BLDC motor modeling [Behera et al.(2018)]. The following mathematical equation can be used to represent the basic equation governing the armature voltage equation of a BLDC motor.

$$Va = L\frac{dIa}{dt} + R.Ia + ea \quad (1)$$

$$Vb = L\frac{dIb}{dt} + R.Ib + eb \quad (2)$$

$$Vc = L\frac{dIc}{dt} + R.Ic + ec \quad (3)$$

Where:

L: Self inductance

R: Resistance

The following form can be used to rewrite equations (1) through (3):

$$\begin{bmatrix} Van \\ Vbn \\ Vcn \end{bmatrix} = \begin{bmatrix} R & 0 & 0 \\ 0 & R & 0 \\ 0 & 0 & R \end{bmatrix} \begin{bmatrix} ia \\ ib \\ ic \end{bmatrix} + \begin{bmatrix} La & Lab & Lac \\ Lba & Lb & Lbc \\ Lca & Lcb & Lc \end{bmatrix} p \begin{bmatrix} ia \\ ib \\ ic \end{bmatrix} + \begin{bmatrix} ea \\ eb \\ ec \end{bmatrix} \quad (4)$$

Where:

P: Number of poles

It decreases to if we assume that the windings are not saturated, iron loss is minimal, the phase winding resistances are equal, there is no mutual inductance between the phase windings, and the self-inductance is constant.

$$La = Lb = Lc = L \quad (5)$$

$$Lba = Lbc = Lca \quad (6)$$

$$\begin{bmatrix} Va \\ Vb \\ Vc \end{bmatrix} = R \begin{bmatrix} ia \\ ib \\ ic \end{bmatrix} + Lp \begin{bmatrix} ia \\ ib \\ ic \end{bmatrix} + \begin{bmatrix} ea \\ eb \\ ec \end{bmatrix} + \begin{bmatrix} Vn \\ Vn \\ Vn \end{bmatrix} \quad (7)$$

The non-conducting phase's Back EMF is given by

$$ea = ke\, f(\theta e)\, wr \quad (8)$$

$$eb = ke\, f\left(\theta e - \frac{2\pi}{3}\right) wr \quad (9)$$

$$ec = ke\, f\left(\theta e + \frac{2\pi}{3}\right) wr \quad (10)$$

Where:

Ke: Back EMF constant = 0.06V/Rad/s

As a result, Figure 3 shows the schematic design of a BLDC motor with three phases. This diagram shows the dependence its BLDC motor's speed response.

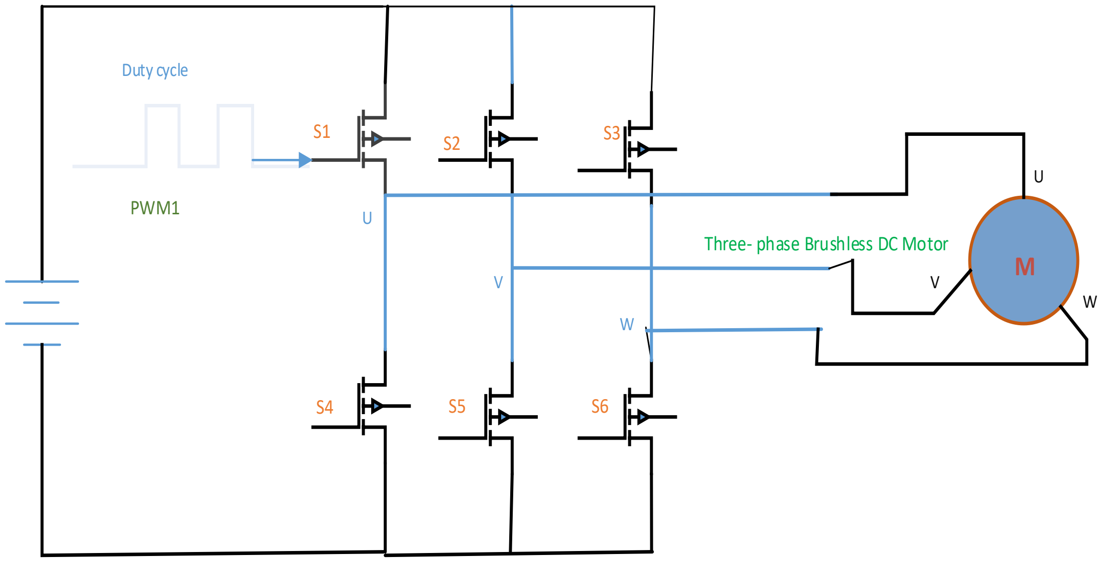

Figure 3. Three-phase BLDC motor schematic diagram

3. Proposed system

Inverter modeling with a 120° conduction mode is implemented in MATLAB-Simulink. For each of the six transportation sectors, the inverter model is derived. since the inverter control employs information from Hall effect sensors. The MATLAB blocks are used to determine the latter.

Hall Sensors detect coil placement, decoder circuit, and coil position activates and deactivates the relevant switches, and the motor is rotated by the voltage passing through the appropriate coils. the workings of the BLDCM. BLDC typically employs 3 phases with 120 degrees between each phase's conducting interval (see Figure 4). A brushless motor's movement or speed is controlled by an electronic speed controller by turning on the necessary MOSFETs, which cause the motor to rotate. The frequency or speed at which the ESC cycles over the six periods will determine how fast the motor will move.

Advantages of BLDC:

- Increased efficiency
- Longer life
- Decreased weight
- Reduced heat generation
- Less friction
- Lower noise

Disadvantages:

- Complex drive circuitry is needed
- There are more sensors needed
- The cost is higher
- Some systems require manual work. (Hand wound Stator Coils)

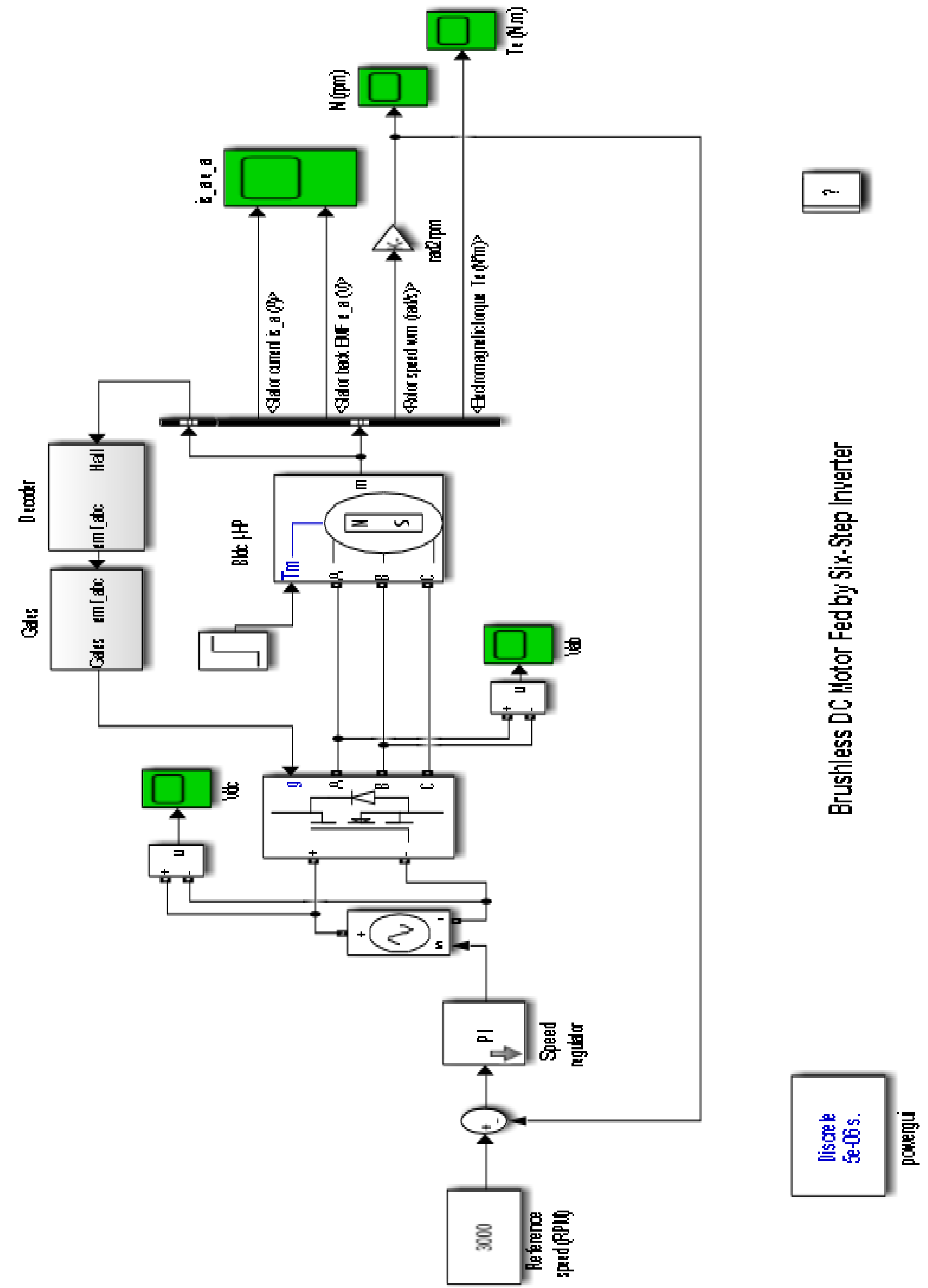

Figure 4. The proposed system of BLDC motor constructed on MATLAB/Simulink

4. Simulation results

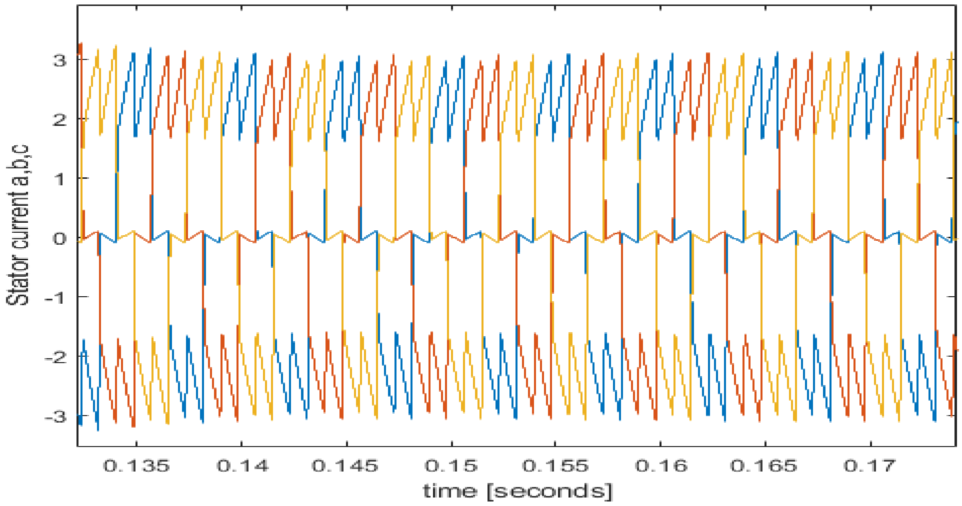

Figure 5. Simulated Stator Current a,b,c

The speed control was tested by running a few step responses; First, from standstill to 3100 RPM, then down to 2800 RPM before going back to standstill 3000 RPM. shown in figure 6.

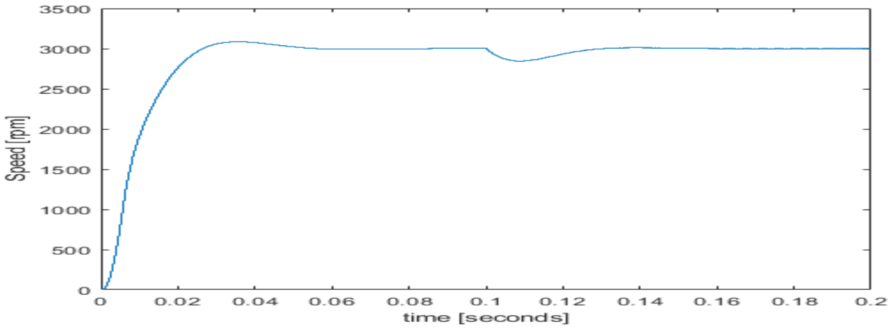

Figure 6. Simulated Speed

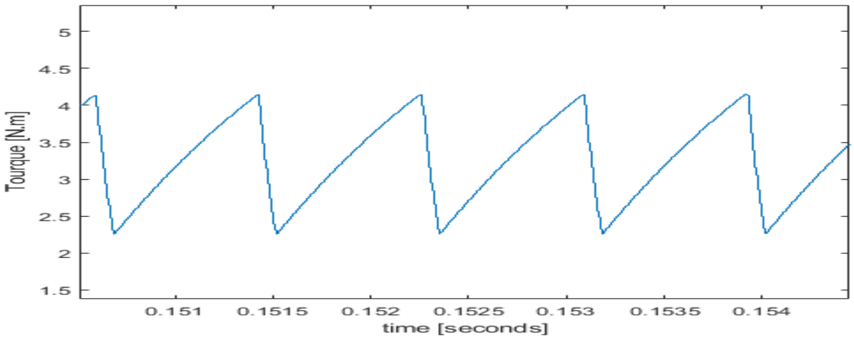

Figure 7. Simulated Torque

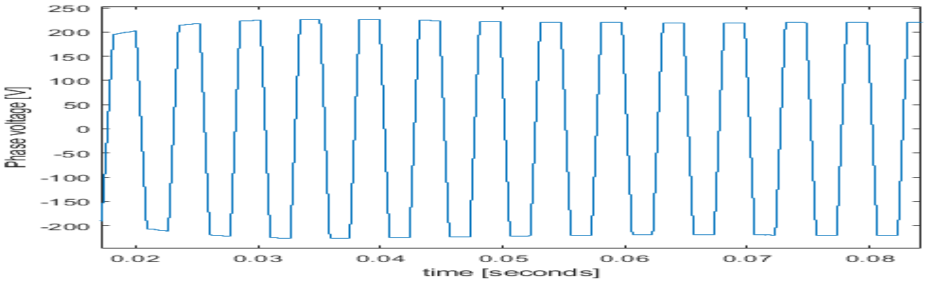

Figure 8. Simulated Phase Voltage

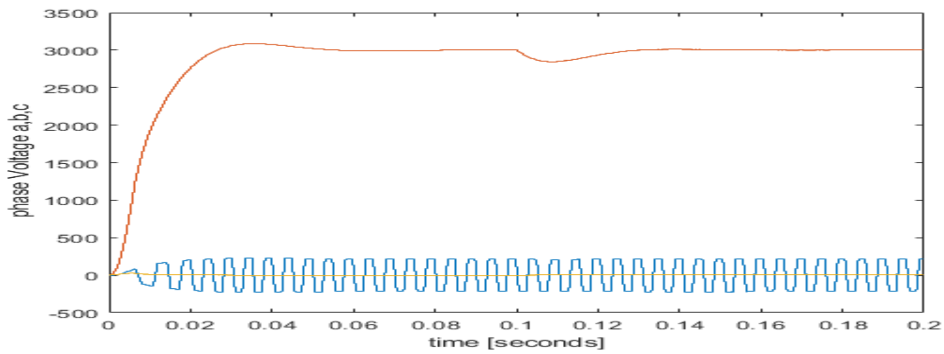

Figure 9. Simulated Phase Voltage a,b,c

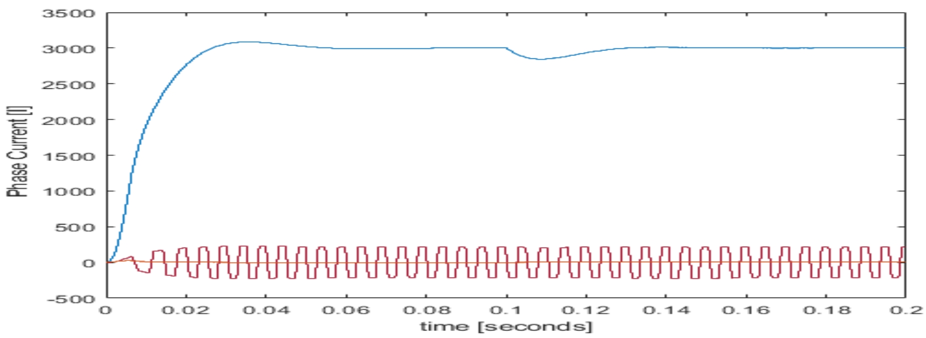

Figure 10. Simulated Phase Current

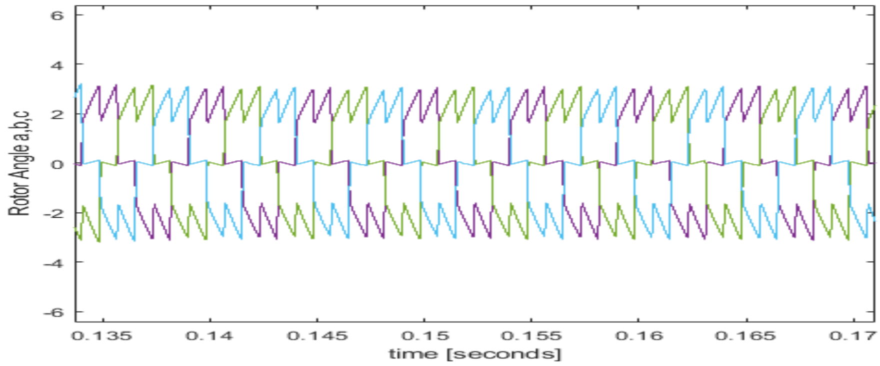

Figure 11. Simulated Rotor Angle a,b,c

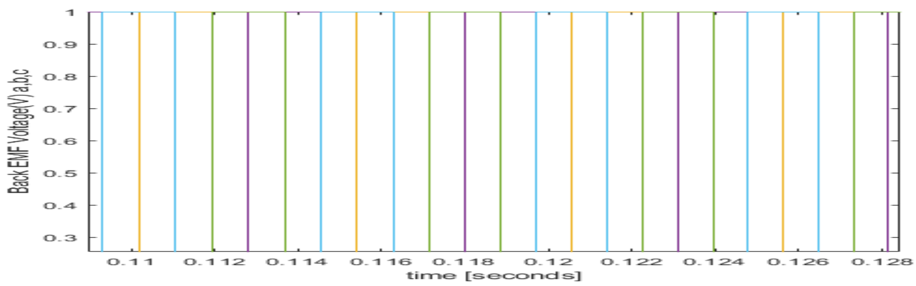

Figure 12. Simulated Back EMF Voltage

5. Experimental Setup

A stator and a rotor are the two primary components of a BLDC motor. In this example, the stator is made up of coils that are arranged as shown in the figure 13.

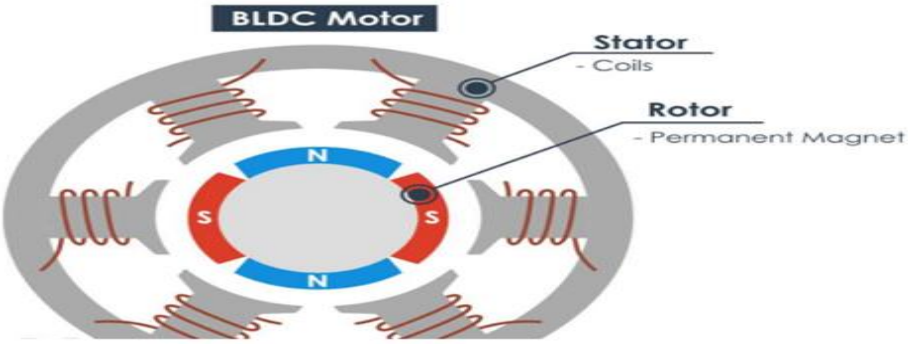

Figure 13. Coils of a BLDC motor

We all understand that if we put current through a coil, it will produce a magnetic field, and the direction of the current will determine the magnetic field's lines or poles. Therefore, if we use the right current, the coil will produce a magnetic field that pulls the permanent magnet of the rotor. Now, if we turn on each coil individually, the rotor will continue to turn due to the interaction of forces between the electromagnet and the permanent magnet.

- Arduino BLDC Motor Program

A PWM signal with a duty cycle ranging from 0% to 100% and a frequency of 50Hz is required. A potentiometer should be used to regulate the duty cycle so that we can regulate the motor's speed. Since controlling motors similarly requires a PWM signal with a 50Hz frequency, the code is comparable to that used to control motors, therefore we utilize the same motor library from the Arduino platform. Additionally, practice using PWM with Arduino if you are unfamiliar with either Arduino or PWM. The schematic created using Circuit Lab is show in figure 14.

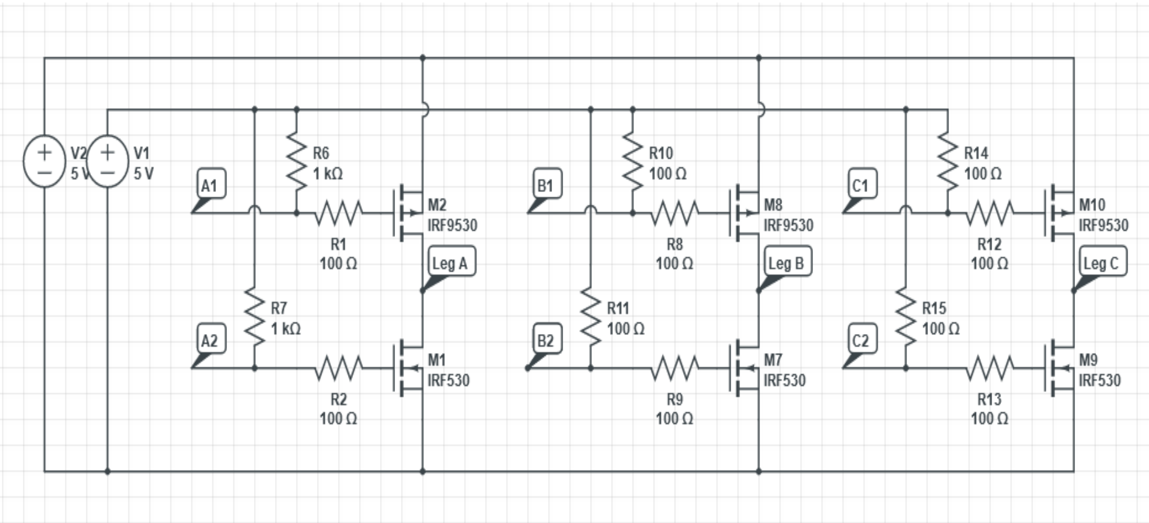

Figure 14. Hardware logic design structure of BLDCM using Circuit Lab

Firstly test commutation is required. To generate motion in a three-phase linear motor there must be switching between the phases to energize appropriate windings. The process of switching between the three phases is called commutation. One is able to turn one pole on at a time and have the motor turn to that position (or just measure the voltage at the motor). An oscilloscope would be really handy to make sure your waveform is working right. The parameters of circuit components are listed in Table 2.

Table 2. The parameters of circuit components

Reference	Type	Value	Package
BAT1	CELL	5V	ELECT-H20
BAT2	CELL	5V	ELECT-H20
Q1	IRF9530	IRF9530	TO220
Q2	IRF530	IRF530	TO220
Q3	IRF9530	IRF9530	TO220
Q4	IRF9530	IRF9530	TO220
Q5	IRF530	IRF530	TO220
Q6	IRF530	IRF530	TO220
R1	ERA-S33J102V	1K	RESC2012X50
R2	ERA-S33J102V	1K	RESC2012X50
R3	ERJ-1WYJ101U	100Ohm	RESC6432X70
R4	ERJ-1WYJ101U	100Ohm	RESC6432X70
R5	ERJ-1WYJ101U	100Ohm	RESC6432X70
R6	ERJ-1WYJ101U	100Ohm	RESC6432X70
R7	ERJ-1WYJ101U	100Ohm	RESC6432X70
R8	ERJ-1WYJ101U	100Ohm	RESC6432X70
R9	ERJ-1WYJ101U	100Ohm	RESC6432X70
R10	ERJ-1WYJ101U	100Ohm	RESC6432X70
R11	ERJ-1WYJ101U	100Ohm	RESC6432X70
R12	ERJ-1WYJ101U	100Ohm	RESC6432X70

The experiment was constructed several times and each time I faced some difficulties until the required circuit has been welded successfully. Then, the final shape of board of BLDC motor circle has been reached shown in figure 15.

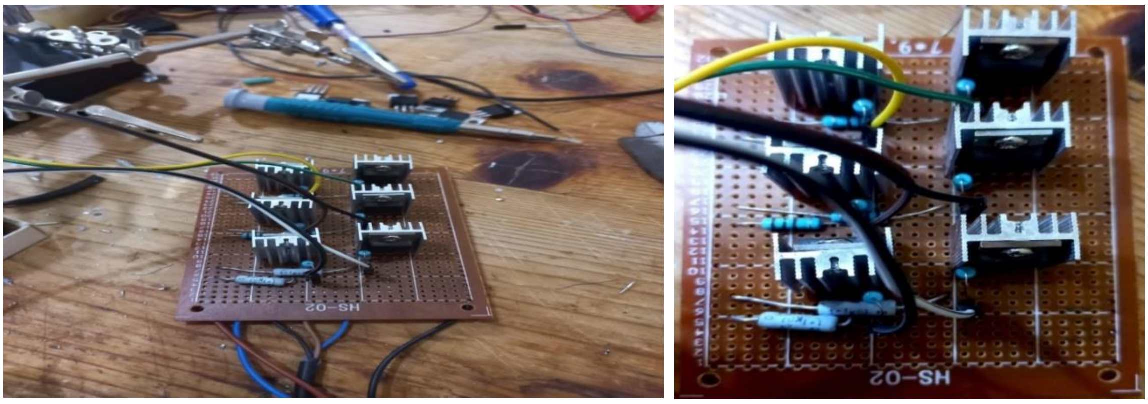

Figure 15. The BLDC motor's board

For the BLDC motor was connected to the designed circuit, and a test was made for it by connecting the voltage, and the beginning of the experiment was on 12 volt I noticed after connecting the motor did not start yet.so, I made a code for the Arduino and connected it to the laptop, uploaded the code to the Arduino chip (UNO), and tested the circuit again in the laboratory. The BLDC motor was wound at a very fast speed ranging from 2200 rpm to 2500 rpm. We can see this in Figure 16. Brushless DC motor was installed in a certain way either by using a fixing device or by using a wooden board on which the motor was fixed that the motor's speed can be determined.

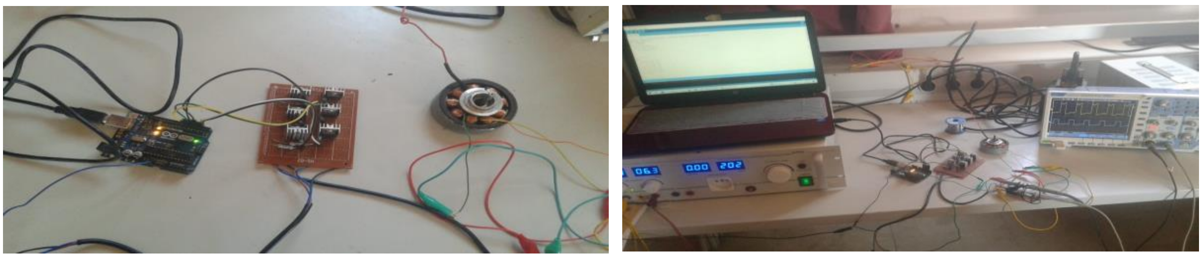

Figure 16. Run the Circuit required (BLDC motor) using Arduino UNO

The experimental phase voltage for phases a,b are shown in Fig. 17. The experimental results are in accordance with the simulated results. The experimental phase voltage for phases a,c are shown in Fig. 18 by using a microcontroller UNO.

Figure 17. The experimental phase voltage for phases a,b

6. Conclusions

In addition to describing electric vehicles technology in general, this study showed how to regulate the speed of a brushless DC motor for use in electric vehicles. the requirement to move towards greater efficiency Applications for and BLDC motors are widely used today. Since the reference value was attained, the actual value results from the simulation represented the various output waveforms. The output waveforms are BLDC motors with zero torque and variable speeds.

The BLDC motor's torque and RPM speed can be controlled considerably more easily and at far greater speeds because it is totally commutated electronically. Benefits of the suggested BLDC motor for electrical vehicle applications include high efficiency, clean, and safe transportation.

Consequently, it is expected that this straightforward control system for BLDC motor drives will help simplify motor control hardware, leading to a reduction in overall weight. Incorporating BLDC motors into significant sub-systems can also contribute to improving vehicle fuel efficiency. The torque and RPM speed of BLDC motors can be easily and significantly controlled due to their complete electronic commutation. Many countries worldwide are facing power shortages due to weak electrical power grids. Consequently, a limited number of nations are currently offering incentives for the more efficient utilization of BLDC motors or are planning to do so. The adoption of BLDCs is just one of several trends aimed at supporting the green movement and preserving the world's limited resources without negatively impacting our way of life.

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مقال أصلي

الملخص العربي

تصميم وتنفيذ محرك التيار المستمر عديم الفرش(BLDC) لتطبيقات السيارات الكهربائية

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تتناول هذه المقالة السيارات الكهربائية، مع التركيز بشكل خاص على محرك التيار المستمر عديم الفرش (BLDC) باعتباره الحل الأكثر فعالية للنقل الأخضر نظرًا لكفاءته العالية و انبعاثات غازات الاحتباس الحراري. تبحث الدراسة في أنواع مختلفة من المحركات الكهربائية التي تم استخدامها كأنظمة دفع للسيارات الكهربائية، بما في ذلك محركات التيار المستمر المصقولة ، والمحركات الحثية، ومحركات الممانعة التبديلية، ومحركات التيار المستمر عديم الفرش ذات المغناطيس الدائم (BLDC). يستكشف البحث أيضًا تنفيذ التحكم في السرعة لمحركات التيار المستمر عديم الفرش في تطبيقات المركبات الكهربائية ويقدم نظرة عامة على تقنيات السيارات الكهربائية. وتتوقع الدراسة أن تحل محركات التيار المستمر عديم الفرش BLDC محل المحركات التقليدية باعتبارها الشكل القياسي لنقل الطاقة في الصناعات بحلول عام 2030 بسبب كفاءتها العالية وعامل الطاقة العالي وعزم الدوران القوي والتحكم البسيط. يتضمن البحث إنشاء نموذج لوضع 120° باستخدام المعادلات الكهربائية والميكانيكية، بالإضافة إلى دراسة قدرات محرك BLDC عند السرعات الثابتة والديناميكية وعزم الدوران. يتم التحقق من نتائج الاختبار باستخدام برنامج محاكاة الماتلاب MATLAB/SIMULINK، مع تحقيق القيمة الحقيقية للقيمة المرجعية .

الكلمات المفتاحية: محرك التيار المستمر عديم الفرش BLDC، تعديل عرض النبضة، التحكم في سرعة محركات BLDC، المركبات (السيارات) الكهربائية.