PE GRADUATION PROJECT

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I. Introduction

In this paper, we will discuss electric vehicle motor control, hardware design of the driver circuit and develop the circuits and algorithms to reach the best and efficient driver configuration.

II. Difference Between Brushed DC Motor and BLDC Motor

Brushed DC Motor

It has permanent magnets inside the outer body and a rotor inside. And it spins 180-degrees we electric current is applied. Carbon Brushes contact the stator when the rotor spins and it flipping the magnetic field and enabling the rotor to spin 360-degrees.

Benefits

- High starting torque
- Low cost
- Suited to Industrial Environment

Disadvantages

- High Maintenance Cost
- Lower Speed

Brushless DC Motor

Like brushed motor, it works by alternating the polarity of windings inside the motor. It is essentially an inside out brushed motor, which eliminates the need for brushes. In a brushless DC motor, the permanent magnets are fitted to the rotor, with the windings on the stator.

Benefits

- Long lifespan
- Efficiency
- Quiet operation

Disadvantages

- Requires a controller
- Cost of the controller and the Driver Circuit.

III. Difference Between BLDC Motor and PMSM

As we said BLDC motor has a permanent magnet rotor and a three-phase windings stator, it is working on the Lorentz principle which states that whenever we placed a current-carrying conductor in a magnetic field it experiences a force. The stator windings in a trapezoidal manner. Hence, the motor back emf will be trapezoidal and it will produce torque repulsion.

Permanent Magnet Synchronous Motor

It is working the same as a synchronous motor, when a three-phase current energized the stator windings it creates an emf which affect the rotor and it start rotating at synchronous speed. The coil wound over is in a sinusoidal manner. Hence, the back emf will be sinusoidal and it will produce repulsion.

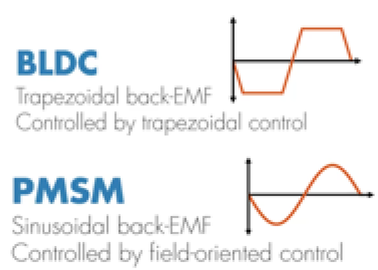


Figure 1:Back emf of BLDC Motor & PMSM Motor

Operation	BLDC M	PMSM
Current required	DC	AC
Back EMF wave	Trapezoidal	Sinusoidal

Torque ripple at commutation	Present	Absence
Performance	Poor	Good
Cost	Low	High
Torque and Efficiency	Lower	Higher
Noise	Lower	Lower

IV. Wheel Hub Motor Definition

The wheel hub motor (also called wheel motor, wheel hub drive, hub motor or in-wheel motor) is an electric motor that is incorporated into the hub of a wheel and drives it directly.

V. Why BLDC Motor is Commonly in E-bike

The BLDC motor has a longer life because no brushes are needed. so, it has a high starting torque, high no-load speed, high efficiency 95-98% and small energy losses. And due to traction characteristics, it is the most preferred motor for the electric vehicle.

It has two types:

1. Out-runner type BLDC Motor (Hub Motors)
2. In-runner type BLDC Motor
3. Low Noise (because no mechanical parts)

VI. BLDC Motor

BLDC Motor Structure

We can consider BLDC motors as a flipped version of brushed DC motors as we have:

- Permanent magnet represents the rotor
- 3 phase coils represent the stator

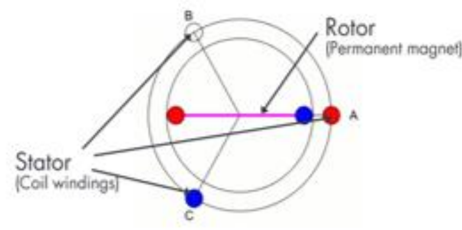


Figure 2: BLDC Motor Structure

Principle of Operation

We will use simple configuration where the rotor only consists of a single pole pair and the stator consists of three coils spaced at 120^{o}

Applying voltage across two phases A and C generates a combined magnetic field along (the dashed line)

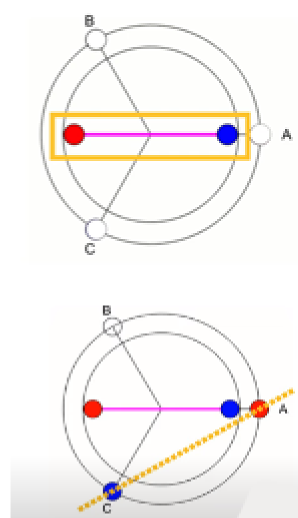


Figure 3: Rotor Movement

The rotor now starts to rotate to align itself with the stator magnetic field and There are six possible ways of energizing coil pairs

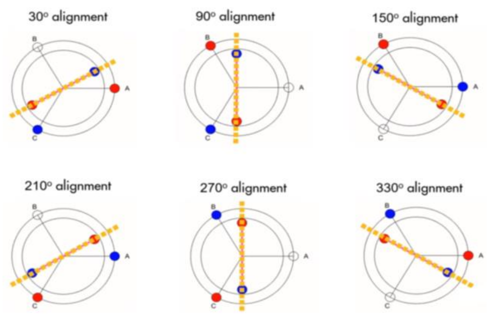


Figure 4: Possible ways of energizing coil pairs

How the poles interact with each other

These two poles of the same kind repel each other making the rotor turn counterclockwise at the same time the opposite poles attract each other and the rotor keeps on turning in the same direction

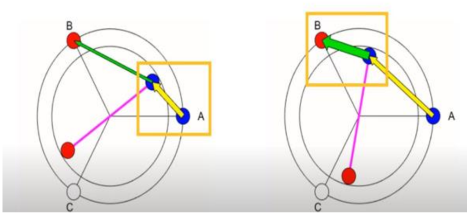


Figure 5: Interaction of the Poles

Once it complete 60-degrees of rotation the next commutation occurs.

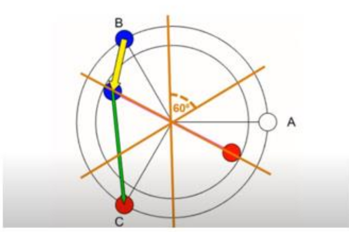


Figure 6: interaction of Poles every 60-degrees

The commutation occurs in such a way that the rotor never aligns with the stator magnetic field but it always chasing it, there are two facts that can explain this behavior:

1. When the rotor and stator magnetic fields align perfectly the motor creates zero torque so, we never let them align.

2. The maximum torque occurs when the fields are at 90-degrees to each other. So, the goal is to bring this angle close to 90-degrees. However, in BLDC motors we never achieve 90-degrees with six step commutation. But the angle fluctuates within some range and this is due to the simple nature of trapezoidal control.

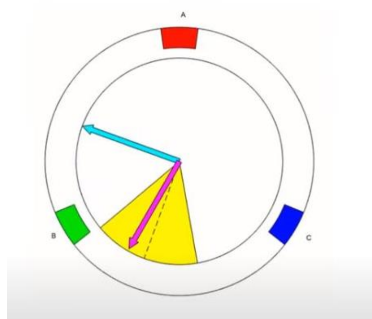


Figure 7: the angle between the stator and rotor magnetic fields fluctuates between [60-120] degrees

but more advanced techniques such as field-oriented control (FOC) allows to generate a large torque by achieving 90-degrees between the stator and the rotor magnetic fields.

VII. Hardware Design

Three-phase inverter

Component Selection of the inverter circuit

Component	Number
Microcontroller	STM32F103
MOSFET	IRFP064NPBF
Gate Driver	TLP250
Recovery Diode	BYW29-200
Gate Diode	1n4007

- ARM-based MC is selected in the control circuit to Drive the inverter
- MOSFET is selected to be the power switching device in the inverter, because it is preferred for wide load or line variations, low voltage (less than 250V), large duty cycles and high frequency (more than 200KHZ) applications. [IRFP064NPBF, $V_{DSS} = 55V\ R_{DS(on)} = 0.008, I_D = 110A$].
- Opto Coupler is selected to be the gate driver of the MOSFET, because it provides isolation between control input signals and the power circuit and it makes also signal conditioning because the output of the MC is 3.3V, so TLP250 rise it to 12V to turn on the gate of the MOSFET [Input threshold current: IF=5mA(max.), Supply current (ICC): 11mA(max.), Supply voltage (VCC): 10–35V, Output current (IO): ±1.5A (max.)].
- 50-ohm Gate resistance is selected to damp the oscillation in the V_{gs} signal.
- Gate diode to decrease the falling time of the V_{gs} signal. [1n4007, $I_{av} = 1A, V_{dc} = 35v$]
- Fast Recovery Diode to decrease reverse recovery time [BYW29-200, $I_{av} = 8A, V_{dc} = 200v, recovery\ time = 60\ ns$].

PCB Design

1. Old Version

PCB design of the inverter circuit:

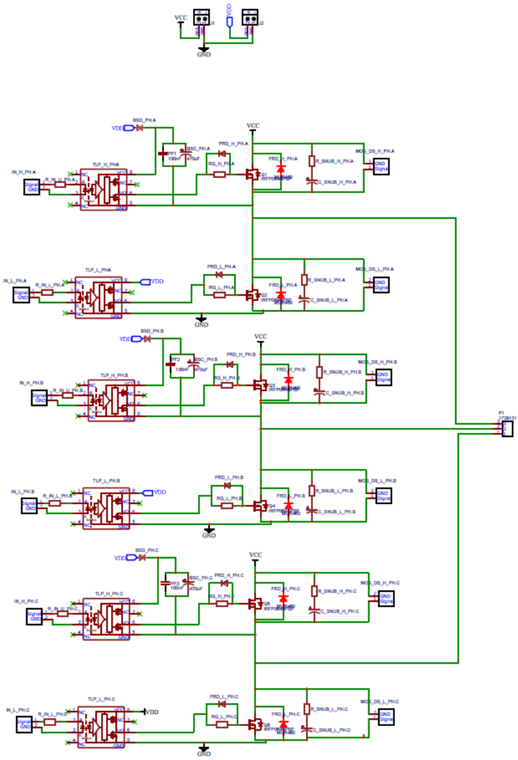


Figure 8: Schematic Diagram (Old Version)

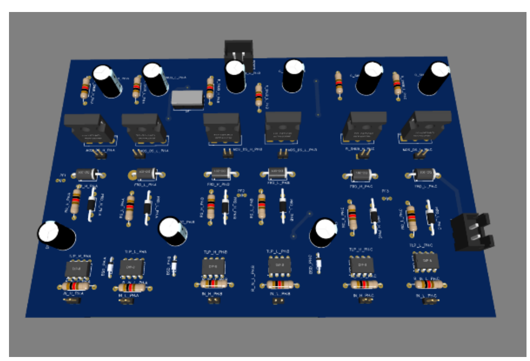


Figure 9: 3D Design (Old Version)

2. Updated Version

PCB design of the inverter circuit in EasyEDA program:

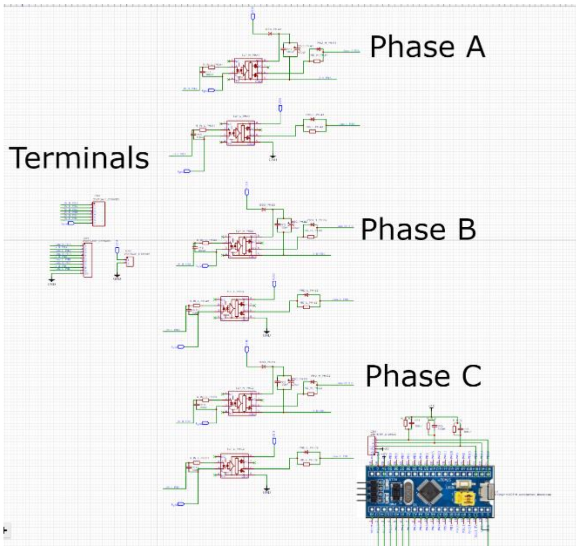


Figure 10: Schematic Diagram (Updated Version)

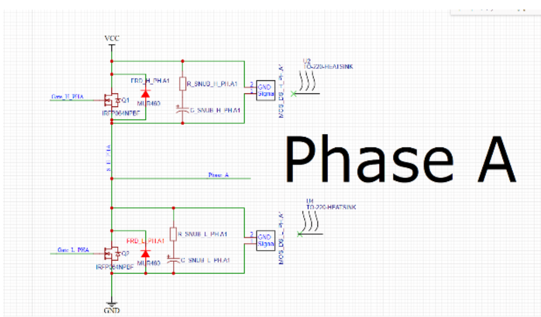


Figure 11: Schematic Diagram of phase A (Updated Version)

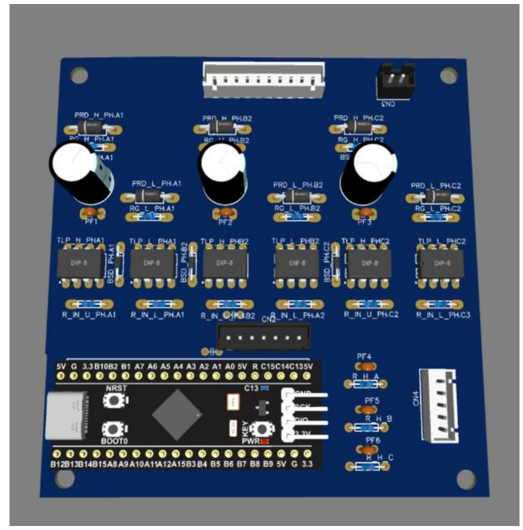


Figure 12: 3D design of Control Circuit (Updated Version)

Figure 13: 3D design of Power Circuit (Updated Version)

3. Final Version

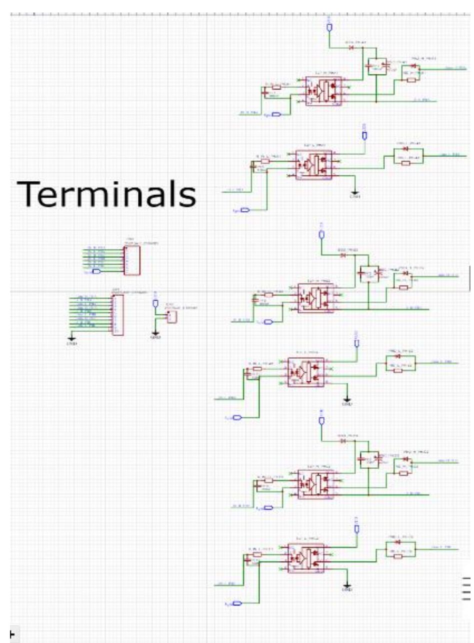


Figure 14: Schematic Diagram (Final Version)

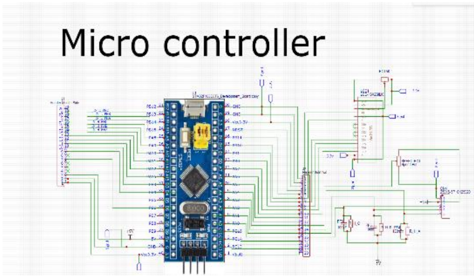


Figure 15: Microcontroller Connection

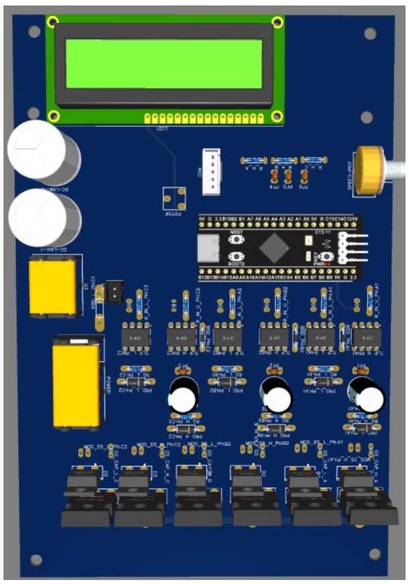


Figure 16: 3D Design Final Version

VIII. Hardware Implementation

Design the inverter circuit, Printing the Design on a thermal paper and cleaning the cupper board then putting the printed thermal paper on it and using the laminator to print the design on the board then Putting the PCB inside iron chloride solution.

- Welding the component in the PCB then testing it.

IX. Hardware Testing

Inverter Output with Inductive Load

Inverter circuit output line voltage with Inductive load without Snubber Circuit [R = 35 Ω, L = 1.5 mH].

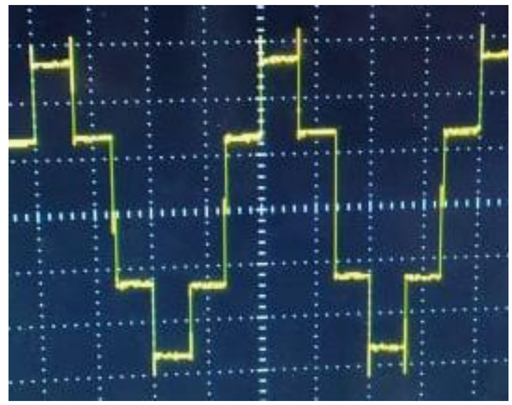
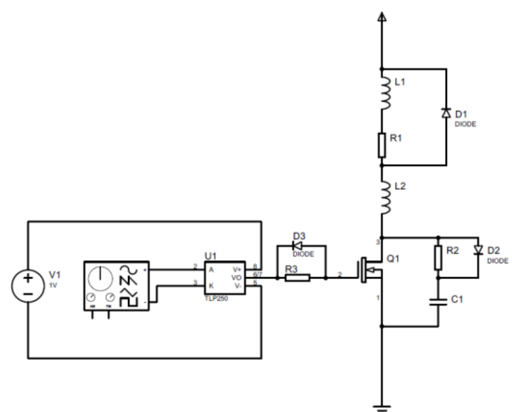


Figure 17: R-L load line voltage waveform without snubber

Snubber Circuit Design



$$F_r = \frac{1}{2\pi\sqrt{LC}}\ , \qquad R = \sqrt{\frac{L}{C}}$$

$$R_{Snubber} = 2\pi F L = 2\pi * 2.5 * 50 * 10^{-9}$$

$$= 1\ \Omega$$

$$P_{switching\ losses} = C_{snubber}\ V_{csnubber}^2\ F_{sw}$$

$$= \ 5\ \mu F$$

Inverter circuit output line voltage with Inductive load with Snubber Circuit [R = 35Ω, L = 1.5 mH].

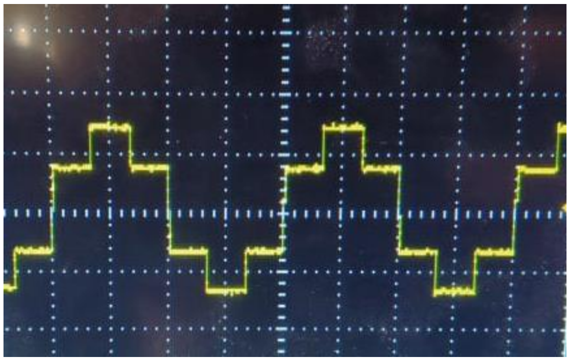


Figure 18: R-L load line voltage waveform with snubber

Testing Inverter with Motor

Inverter circuit output line voltage with Motor Load without Snubber.

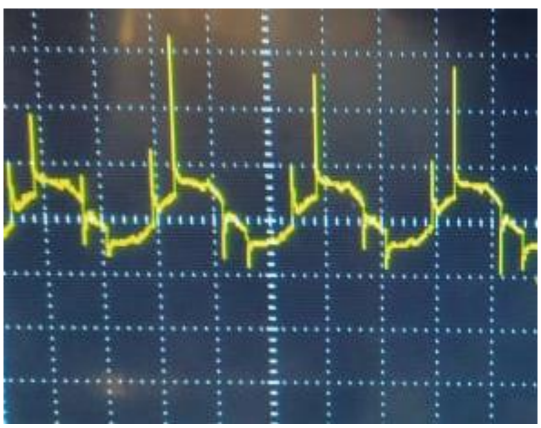


Figure 19: Motor Load Line Voltage without snubber

As we can see in the previous figure [Figure 19],

There are spikes in the line voltage waveform