UNIVERSITAT POLITÈCNICA DE VALÈNCIA

School of Aerospace Engineering and Industrial Design

Design of the electronic power converter for an electric scooter with a 500 W BLDC motor and a 48 V battery

End of Degree Project

Bachelor's Degree in Electrical Engineering

AUTHOR: Suh, Jung Ji

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Grado en Ingeniería Eléctrica

Design an electric scooter using a 48V BLDC motor

Trabajo Fin de Grado

AUTOR : Jung Ji, Suh

Tutor : Raul Gonzalez Medina

CURSO ACADÉMICO : 2023-2024

RESUMEN

Estoy diseñando un scooter eléctrico utilizando un motor BLDC de 48V. En primer lugar, proporcioné una definición de los scooters eléctricos, junto con sus ventajas, desventajas y potencial de mercado. Luego, expliqué los componentes de un scooter eléctrico: el motor, la batería y el convertidor.

Para el motor, describí los tipos de motores utilizados en los scooters eléctricos, detallando sus características y comparando sus pros y contras. En cuanto a la batería, primero expliqué las baterías primarias y secundarias. Dado que este diseño utiliza una batería secundaria, discutí los tipos, el rendimiento y las ventajas y desventajas de las baterías secundarias. Luego investigué la capacidad y los tipos de baterías utilizadas en los scooters eléctricos, describiendo sus características e incluyendo hojas de datos.

Finalmente, expliqué los convertidores DC/DC, detallando sus tipos, principios de funcionamiento y comparando sus ventajas y desventajas. Después de investigar cada componente, seleccioné tres modelos para cada componente de los mercados en línea y comparé sus hojas de datos para resaltar sus pros y contras.

Después de seleccionar los modelos para cada componente, utilicé sus valores de datos para diseñar un circuito básico en PSIM. Luego verifiqué la idoneidad y el funcionamiento adecuado de los componentes seleccionados a través de los valores y gráficos de salida de PSIM.

Finalmente, completé el diseño encontrando y comparando el rendimiento y los precios de los diodos, transistores y MOSFETs utilizados en el convertidor de los mercados en línea.

RESUM

Estic dissenyant un escúter elèctric utilitzant un motor *BLDC de 48V. En primer lloc, vaig proporcionar una definició dels escúters elèctrics, juntament amb els seus avantatges, desavantatges i potencial de mercat. Després, vaig explicar els components d'un escúter elèctric: el motor, la bateria i el convertidor.

Per al motor, vaig descriure els tipus de motors utilitzats en els escúters elèctrics, detallant les seues característiques i comparant els seus pros i contres. Quant a la bateria, primer vaig explicar les bateries primàries i secundàries. Atés que este disseny utilitza una bateria secundària, vaig discutir els tipus, el rendiment i els avantatges i desavantatges de les bateries secundàries. Després vaig investigar la capacitat i els tipus de bateries utilitzades en els escúters elèctrics, descrivint les seues característiques i incloent fulles de dades.

Finalment, vaig explicar els convertidors DC/DC, detallant els seus tipus, principis de funcionament i comparant els seus avantatges i desavantatges. Després d'investigar cada component, vaig seleccionar tres models per a cada component dels mercats en línia i vaig comparar les seues fulles de dades per a ressaltar els seus pros i contres.

Després de seleccionar els models per a cada component, vaig utilitzar els seus valors de dades per a dissenyar un circuit bàsic en *PSIM. Després vaig verificar la idoneïtat i el funcionament adequat dels components seleccionats a través dels valors i gràfics d'eixida de *PSIM.

Finalment, vaig completar el disseny trobant i comparant el rendiment i els preus dels díodes, transistors i *MOSFETs utilitzats en el convertidor dels mercats en línia.

ABSTRACT

I am designing an electric scooter using a 48V BLDC motor. Firstly, I provided a definition of electric scooters, along with their advantages, disadvantages, and market potential. Then, I explained the components of an electric scooter: the motor, battery, and converter.

For the motor, I described the types of motors used in electric scooters, detailing their characteristics and comparing their pros and cons.

Regarding the battery, I first explained primary and secondary batteries. Since this design uses a secondary battery, I discussed the types, performance, and advantages and disadvantages of secondary batteries. I then researched the capacity and types of batteries used in electric scooters, describing their features and including datasheets.

Lastly, I explained DC/DC converters, detailing their types, operating principles, and comparing their advantages and disadvantages. After researching each component, I selected three models for each component from online markets and compared their datasheets to highlight their pros and cons.

After selecting the models for each component, I used their data values to design a basic circuit in PSIM. I then verified the suitability and proper operation of the selected components through PSIM's output values and graphs.

Finally, I completed the design by finding and comparing the performance and prices of the diodes, transistors, and MOSFETs used in the converter from online markets.

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1. Introduction

This paper introduces the structural understanding and design of electric scooters, as well as the necessity of electric scooters and the advantages and disadvantages of each component. Using PSIM, I will design components with optimal efficiency and verify their operation without overload, followed by presenting the values of each measurement graph.

2. Background

In recent years, electric scooters have become a popular means of short-distance transportation across various fields. Especially in major cities with high population densities, the number of electric scooter users has been steadily increasing. Furthermore, companies are increasingly managing and operating shared electric scooters. The reasons for this trend are manifold, but a key reason is that many users in large cities prefer electric scooters due to issues like traffic congestion, parking, and space consumption. Additionally, electric scooters are favored for their economic efficiency, convenience, and effectiveness.

Figure 1. Many office workers commute to work by electric scooter. (obtained from solumpv.com)

Another major reason for the increasing demand is the environmental benefits they offer. The environmental issues of our time are urgent, and many countries are imposing significant restrictions and penalties on internal combustion vehicles and industries emitting carbon dioxide. In this context, electric-powered transportation options have gained popularity as viable alternatives. For instance, by 2022, the share of electric vehicles in Spain had expanded to 12%. Moreover, most public transportation in major cities is being replaced by electric and hybrid systems, and electric scooters are also being recognized as eco-friendly modes of transportation.

Figure 2. Many people also use share electric scooters.(obtained from phys.org)

Electric scooters run on lithium-ion batteries, making them a low-carbon and environmentally friendly mode of transport. Their small size and portability appeal particularly to younger generations, and their demand is increasing. Shared electric scooters are also popular due to the convenience of not having to own one and the ability to use them at desired locations.

Figure 3. The biggest advantage of electric scooters is convenience. (obtained from i.pinimg.com)

Given these trends, this paper aims to explore how electric scooters can be designed and engineered for greater efficiency. While electric scooters offer the advantages of portability and easy access, their compact size and design limit the distance they can travel on a single charge, and the motor constraints affect their speed and acceleration.

Therefore, through this experiment, we aim to design an electric scooter that can achieve the best efficiency and the longest travel distance using various motors, batteries, and converters.

2.1. What is an Electric Scooter?

Figure 4. There are various designs of scooters. (obtained from weareellectric.com)

An electric scooter is an innovative personal transportation device that offers mobility and convenience in urban environments. These scooters are composed of technical components such as electric motors, batteries, converters, and controllers, all of which work harmoniously to enable efficient driving.

2.2. Components of an Electric Scooter

2.2.1. Electric Motor

The electric motor of an electric scooter is one of the most crucial components of the vehicle. Typically, electric scooters use brushless DC (BLDC) motors rather than traditional DC motors.

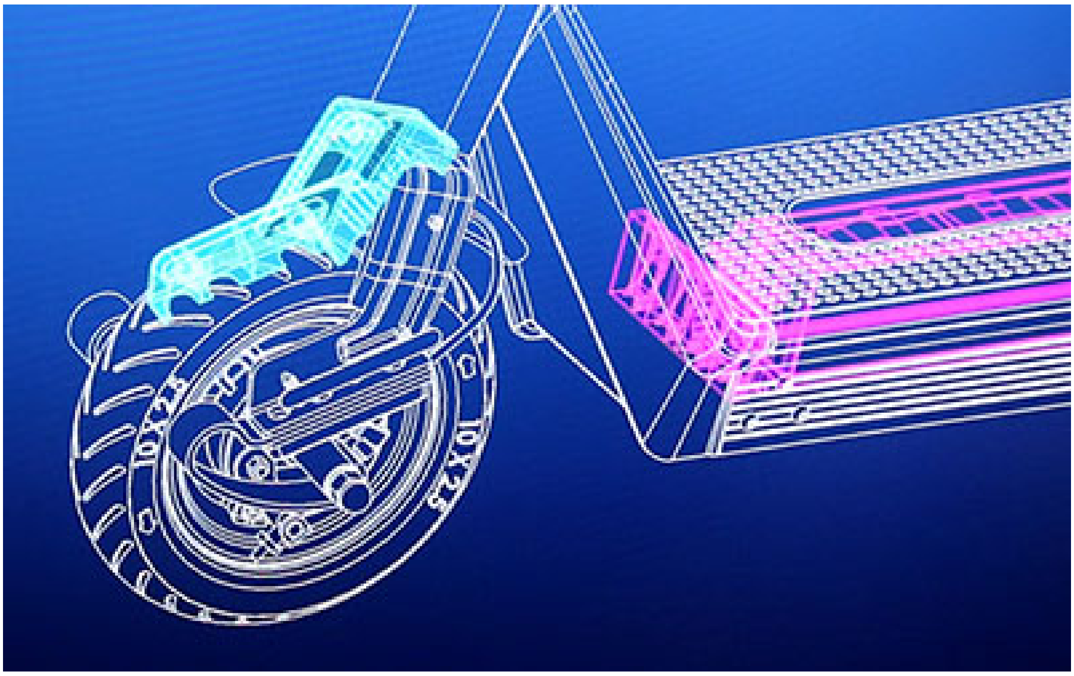


Figure 5. Most electric scooters have motors attached to the wheels.(obtained from xlt-scooter.com)

2.2.1.1. BLDC Motor

A brushless motor is defined as a motor designed to provide similar output characteristics to a DC motor but without brushes. The rotor does not have brushes, and electronic commutation is performed at specific rotor positions. A BLDC motor is a permanent magnet synchronous motor with a unique back EMF waveform that allows it to operate similarly to a brushed DC motor. However, BLDC motors do not operate directly from a DC voltage source; their fundamental operating principle is similar to that of a DC motor.

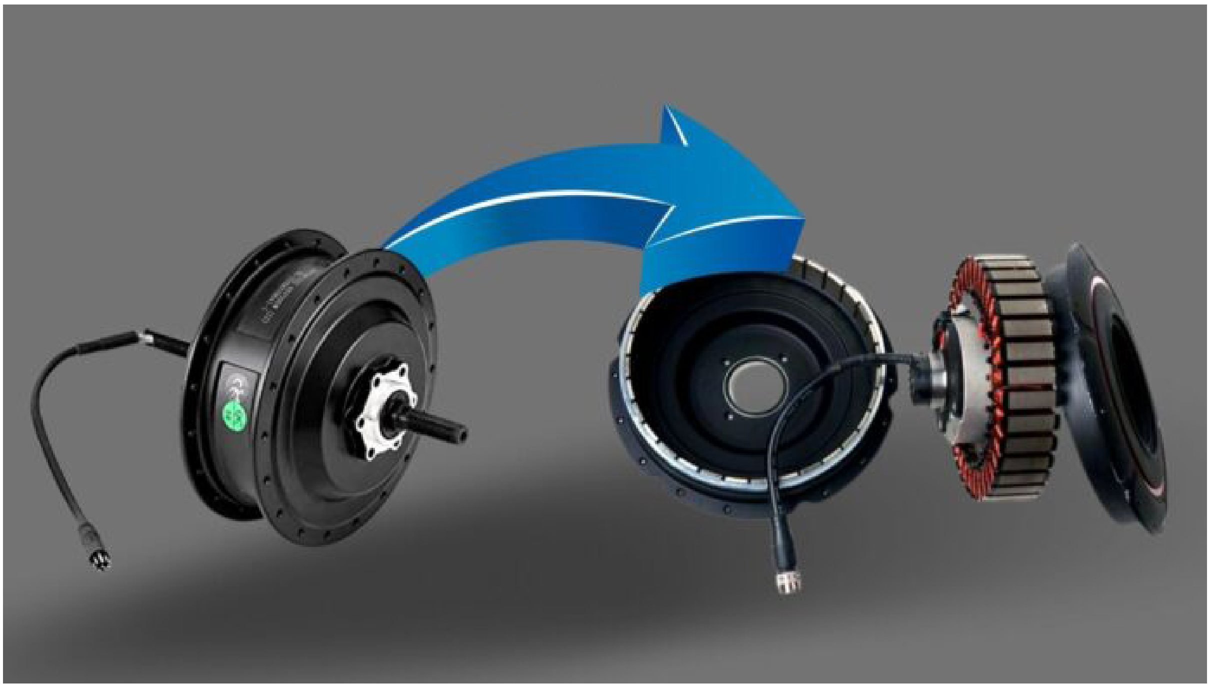


Figure 6. BLDC motor used in electric scooter(obtained from brushless.com)

A brushless DC motor consists of a rotor with permanent magnets and a stator with windings. Essentially, a BLDC motor is an inside-out DC motor. The brushes and commutator are eliminated, and the windings are connected to control electronics. These control electronics replace the commutator's function and supply power to the appropriate windings. Power is supplied to the windings in a rotating pattern around the stator. The powered stator windings guide the rotor magnets to align with the stator, ensuring smooth rotation.

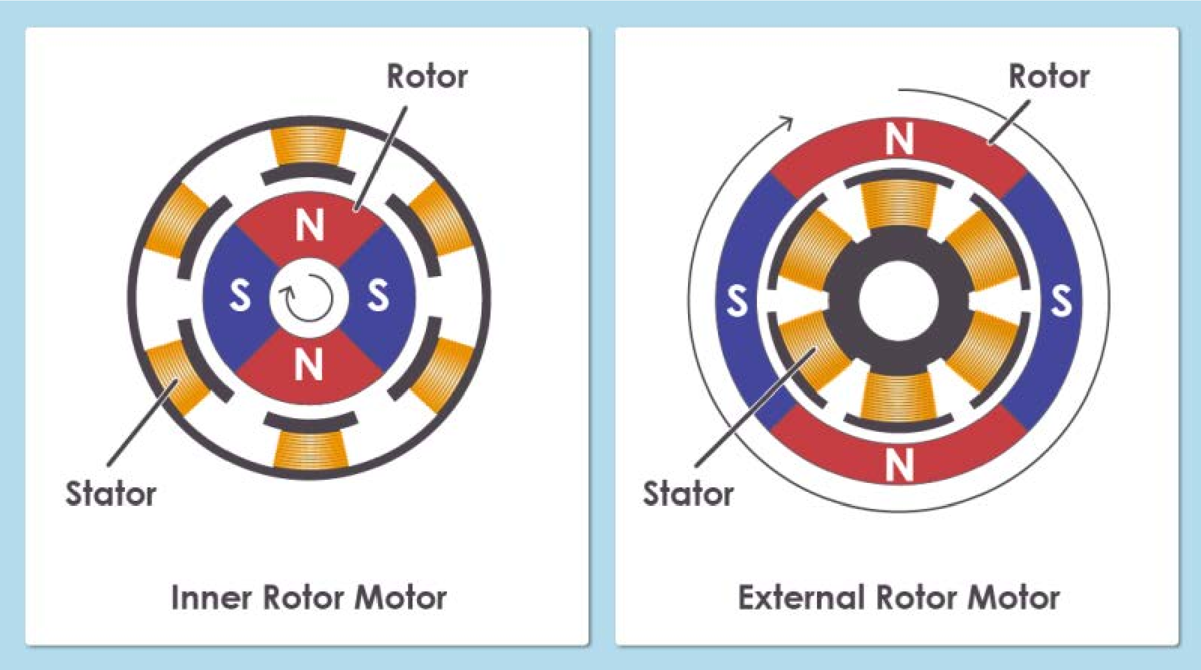


Figure 7. Structure of BLDC motor (obtained from ablic.com)

- **Advantages of BLDC Motors**

① High Reliability and Long Lifespan: Without brushes and commutators, which are the major drawbacks of traditional DC motors, regular maintenance is not required.

② Excellent Controllability: Since the field is a permanent magnet, it can control speed and torque similar to a DC motor, except for controlling the field flux.

③ High Efficiency: There is no voltage drop or friction loss from brushes compared to conventional DC motors.

④ Minimal Electrical (Spark Generation), Magnetic, and Mechanical Noise: BLDC motors produce little to no noise and interference.

⑤ Ease of Miniaturization and Thin Design: Without brushes and commutators, miniaturization is possible, and using coreless and flat configurations can achieve a thin design.

⑥ Capability of High-Speed Operation: BLDC motors can operate at high speeds efficiently.

⑦ High Ratio of Maximum Instantaneous Torque to Rated Torque: Unlike conventional DC motors which have commutation limits, BLDC motors do not have these limits, allowing for a higher maximum instantaneous torque.

⑧ Easy Cooling: In conventional DC motors, significant heat is generated on the rotor side, requiring careful consideration for heat dissipation. In BLDC motors, heat is generated only in the stator, making cooling easier.

- **Disadvantages of BLDC Motors**

① Difficult to Repair: Once a BLDC motor breaks down, it is challenging to repair.

② Higher Cost: Brushless motors are more expensive compared to brushed motors.

③ Additional Power Consumption for the Controller: BLDC motors require more power for their controllers.

2.2.1.2. DC Motor

A brushed DC (BDC) motor is named for the "brushes" used for commutation. Brushed DC motors are primarily used in household appliances and automotive applications. They also maintain a strong presence in powerful industrial niches because they offer the ability to change the torque-to-speed ratio used. BDC motors are easy to control because speed and torque are proportional to the applied voltage/current.

Figure 8. Electric Motor Brushed DC Motor Kit (obtained from amazon.de)

A brushed DC motor consists of four basic components: the stator, rotor (or armature), brushes, and commutator. The rotor, also known as the armature, is made up of one or more windings. When power is supplied to these windings, a magnetic field is generated. The poles of this rotor magnetic field are attracted to the opposite poles generated by the stator, causing the rotor to turn. As the motor rotates, the windings are powered in a different sequence so that the poles generated by the rotor do not overrun the poles generated by the stator. This switching of the magnetic field in the rotor windings is called commutation. By reversing the polarity of the brushes (i.e., reversing the battery leads), the direction of rotation can be easily changed to clockwise and/or counterclockwise.

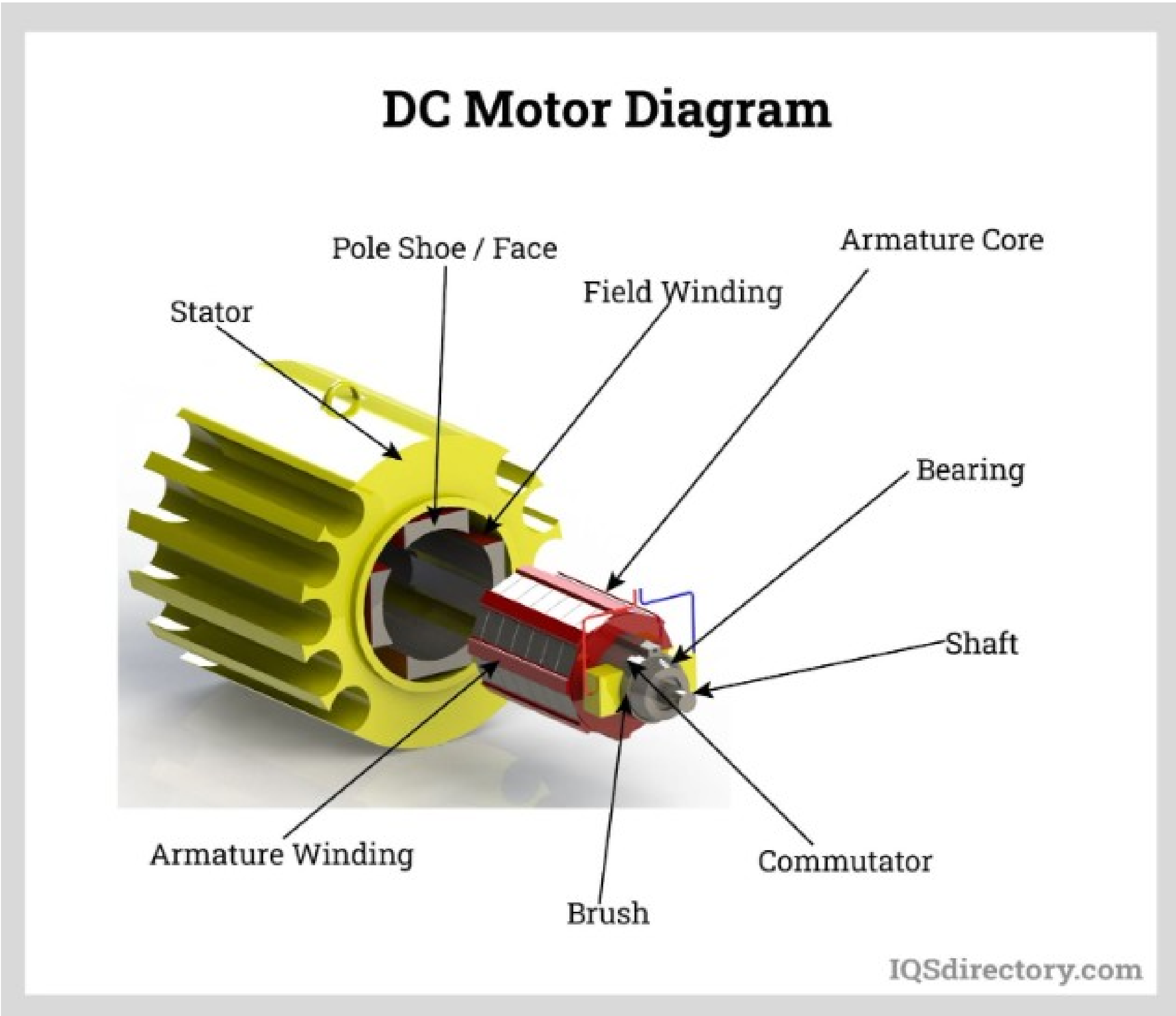


Figure 9. DC Motor Diagram (obtained from iqsdirectory.com)

➢ Advantages of DC Motors

① Low Cost: Brushed DC motors are generally inexpensive.

② Excellent Speed Control and Torque Characteristics: They provide precise control over speed and torque.

③ Simple Design: They have a straightforward design.

➢ Disadvantages of DC Motors

① Reduced Durability Due to Brush Friction: The brushes wear out over time.

② Mechanical Noise from Friction: The brushes create mechanical noise.

③ Heat Generation Due to Friction: The friction between the brushes and commutator generates heat.

These motors provide efficient and rapid acceleration and require less maintenance. The motor output of electric scooters typically ranges from 250W to 1000W, and the size and output of the motor affect the driving performance and maximum speed. Additionally, there is a difference in whether the motor is positioned on the front wheel or the rear wheel.

Front-wheel drive is often used in lightweight scooters. The advantage of front-wheel drive is that it allows for a simpler mechanical design. In lightweight scooters, the battery and controller are usually housed inside the tube beneath the handlebars. If the motor is front-wheel drive, the distance between components is shortened, making the design easier. However, the disadvantage is that most of the components and weight are concentrated at the front, which shifts the center of gravity forward. If the front part is not durable, there is a higher likelihood of component failure. Additionally, the shifted weight distribution can negatively impact the riding comfort.

Figure 10. Front Wheel Drive (obtained from inomile.com)

Rear-wheel drive is commonly used in most of the current electric scooters. The advantages of rear-wheel drive include improved riding comfort and reduced impact on the handlebars. It is also safer and more stable for heavier electric scooters. The disadvantage is that it may slip more easily on inclined surfaces, wet, or slippery roads.

Figure 11. Rear Wheel Drive (obtained from inomile.com)

As previously mentioned, most electric scooters use BLDC motors due to their advantages, and this design will also utilize a BLDC motor.

2.2.2. Batteries

A battery is a crucial power source for an electric scooter. It stores chemical energy and converts it into electrical energy to produce direct current power when needed, not only for electric scooters but also for devices such as flashlights, smartphones, and electric vehicles. The capacity of batteries used in electric scooters typically ranges from 36V to 48V, and the driving range and usage time depend on the battery's capacity and performance.

As technology advances, the importance of batteries has grown immensely. Batteries are now used in most machines, and their efficiency has become increasingly crucial. In previous eras, oil and coal were the primary energy sources, but now, due to eco-friendly policies, electrical energy is gaining the most attention. Consequently, the significance of batteries has become a focal point.

Figure 12. Batteries (obtained from hellot.net)

Batteries are broadly divided into primary and secondary batteries. Primary batteries, commonly used in households, are non-rechargeable after a single use.

Types of primary batteries include alkaline batteries, mercury batteries, and lithium batteries, with alkaline batteries being the most commonly used.

Figure 13. Primary Battery (obtained from electronics.howstuffworks.com)

- **Advantages of Primary Batteries**

① Long shelf life

② Ready to use immediately

③ Low cost

- **Disadvantages of Primary Batteries**

① Non-reusable

② Limited lifespan

③ Environmental pollution: Generates a lot of waste due to non-reusability

Secondary batteries are rechargeable batteries that can be used multiple times. These batteries store energy through internal chemical reactions and supply it as electrical energy when needed.

Types of secondary batteries include lithium-ion batteries, nickel-metal hydride batteries, lead-acid batteries, and lithium polymer batteries.

Figure 14. Several batteries are sometimes produced in this way. (obtained from shutterstock.com)

➢ Advantages of Secondary Batteries

① Reusable: Can be charged and used multiple times

② Long Lifespan: Can be used for a long period with multiple charges

③ High Efficiency: Provides high energy density

④ Compact and Lightweight: Can be made small and light

⑤ Eco-friendly: Generates less waste due to reusability

➢ Disadvantages of Secondary Batteries

① High Cost: More expensive to produce compared to primary batteries

② Charging Time: Requires time to recharge

③ Complex Maintenance: Requires proper maintenance to avoid performance degradation or reduced lifespan

Generally, the batteries used in electric products are secondary batteries such as lead-acid batteries, lithium iron phosphate batteries, lithium-ion batteries, and lithium polymer batteries.

2.2.2.1. Lead-Acid Battery

A lead-acid battery is a type of secondary battery that uses lead and sulfuric acid. It employs lead and lead dioxide as electrodes, with a sulfuric acid solution as the electrolyte. It is commonly used in internal combustion engine vehicles.

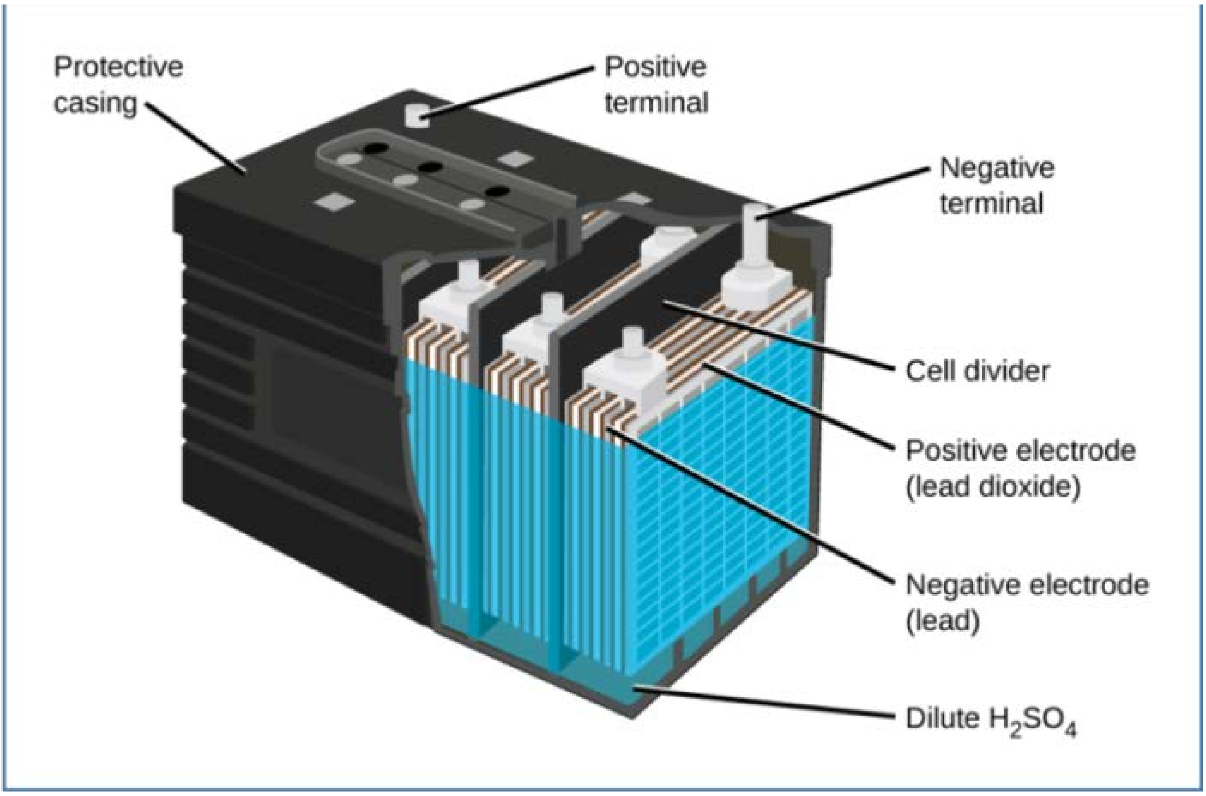


Figure 15. The basic structure of a lead-acid battery. (obtained from tycorun.com)

➢ Advantages of Lead-Acid Batteries

① Low Cost: Inexpensive to produce

② Eco-friendly: Mostly recyclable and made of reusable materials

③ Performance: Performs well in both low and high temperatures

➢ Disadvantages of Lead-Acid Batteries

① Short Lifespan: Has a relatively short lifespan

② Low Energy Density: Heavier compared to lithium-ion batteries for the same capacity

③ Maintenance: Requires maintenance procedures

2.2.2.2. Lithium Iron Phosphate Battery

Commonly known as LFP batteries, lithium iron phosphate batteries are composed of lithium (Li), iron (Fe), and phosphate (PO4). These batteries operate electrochemically through the movement of lithium ions and are used in low-cost electric vehicles.

Figure 16. Example of lithium phosphate battery (obtained from enix-power-solutions.com)

➢ Advantages of Lithium Iron Phosphate Batteries

① Structural Stability: More structurally stable compared to other cathode materials

② Cost-Effective: Inexpensive because they include iron and phosphate, which are abundant on Earth

③ Performance: Perform well in both low and high temperatures (-20°C to 75°C)

④ Eco-Friendly: Contain no harmful substances and are environmentally friendly even if damaged

➢ Disadvantages of Lithium Iron Phosphate Batteries

① Lower Energy Density: Lower energy density compared to lithium-ion batteries

② Cost: More expensive

2.2.2.3. Lithium-Ion Battery

Lithium-ion batteries are currently used in most small and portable devices. With technological advancements, lithium-ion batteries have garnered the most attention, and improving their efficiency and safety is now one of the industry's key concerns.

Lithium-ion batteries are a type of secondary battery in which lithium ions move from the anode to the cathode during the discharge process. During charging, the lithium ions move back from the cathode to the anode, restoring their original positions and storing energy.

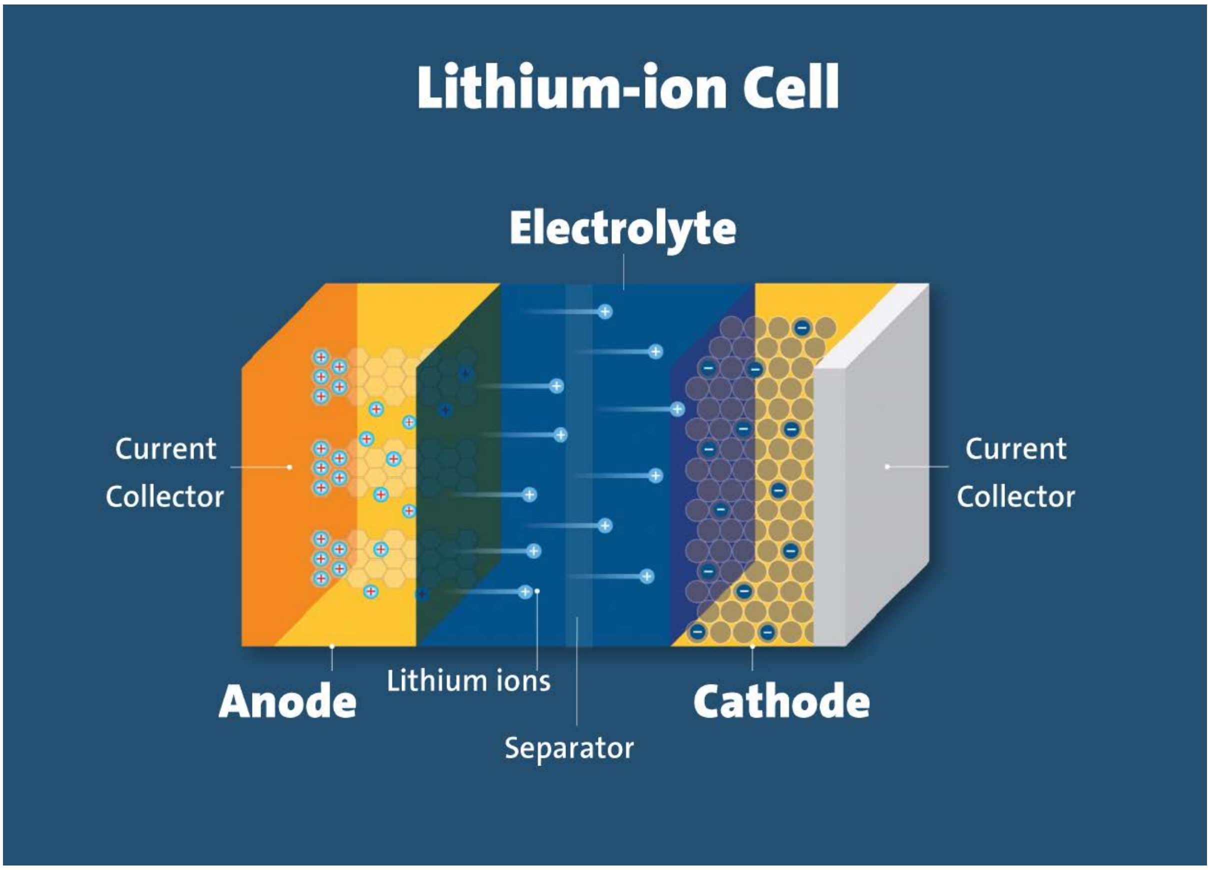


Figure 17. Basic principles of lithium-ion batteries. (obtained from ul.org)

- **Advantages of Lithium-Ion Batteries**

① High Energy Density: Lithium-ion batteries can store a large amount of energy per unit weight, making them suitable for portable electronic devices and electric vehicles.

② Long Lifespan

③ Fast Charging Speed

④ Low Self-Discharge Rate

⑤ Excellent Temperature Characteristics: Perform well in temperatures ranging from -55°C to 85°C

- **Disadvantages of Lithium-Ion Batteries**

① High Cost

② Safety Risks: There is a risk of fire or explosion under conditions such as overcharging, over-discharging, or high temperatures.

③ Leakage Potential: The electrolyte is in liquid form, which can lead to leakage.

2.2.2.4. Lithium polymer battery

Lithium polymer battery, a type of lithium-ion battery, was developed to address the stability issues of lithium-ion batteries. Its operational principle is similar to lithium-ion batteries, where a gel-like polymer serves as the separator between the cathode and anode, also acting as the electrolyte.

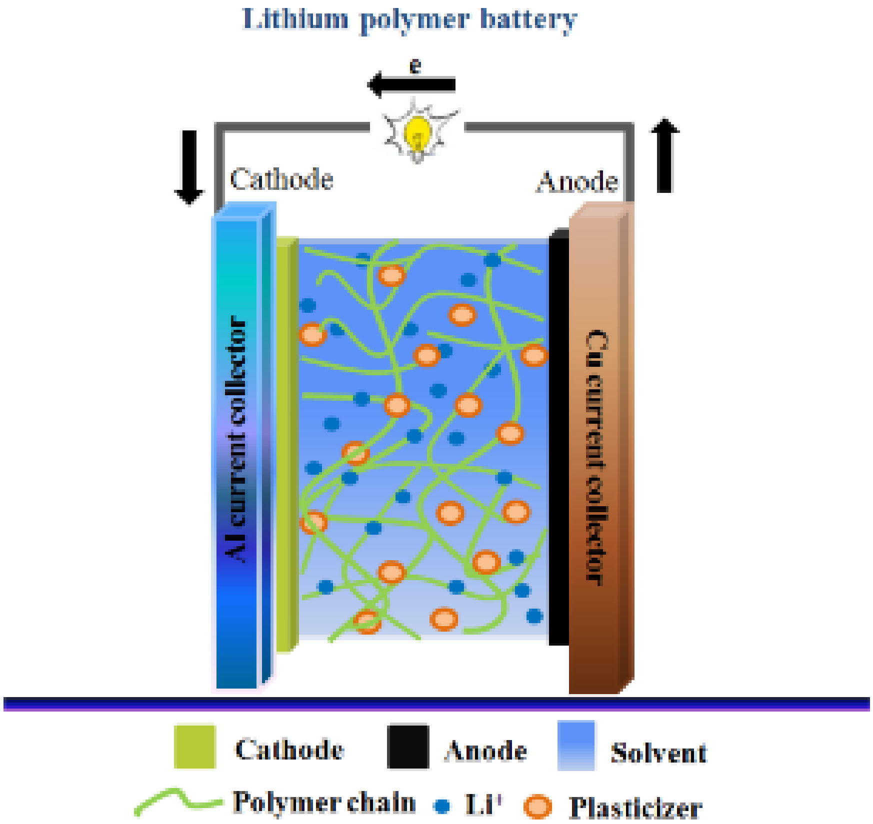


Figure 18. Basic principles of lithium polymer batteries. (obtained from researchgate.net)

- **Advantages include:**

① High energy storage density.

② High stability due to the use of polymer electrolyte.

③ Capability for diverse design shapes.

④ Ideal for portable devices due to lightweight construction.

- **Disadvantages include:**

① High manufacturing cost.

② Lower ion conductivity compared to liquid electrolytes.

③ Reduced performance in low temperatures.

Considering these battery characteristics, for the design of electric scooters, convenience is crucial, stability across diverse environments is essential, and high energy density is necessary to store more energy and cover longer distances. Therefore, for this design, I plan to use lithium-ion batteries.

2.2.3. DC/DC Converter

A DC/DC converter is a device that converts direct current (DC) from one voltage level to another. Many electronic devices, such as integrated circuits (ICs), have different operating voltage ranges and require specific voltages to function properly. Therefore, supplying an unstable power source can lead to malfunction or performance degradation. To convert or stabilize the voltage to the required levels, a DC/DC converter is necessary.

DC/DC converters are mainly categorized into Buck Converters, Boost Converters, and Buck-Boost Converters.

Figure 19. There are various types of converters. (obtained from eu.mouser.com)

2.2.3.1. Buck-Converter

A Buck Converter, also known as a Step-Down Converter, is a DC/DC switch-mode power supply designed to stabilize and reduce the input voltage from an unregulated DC power source to a lower output voltage. Unlike traditional voltage regulators, the Buck Converter has the advantage of being able to output most of the input power, boasting a very high conversion efficiency of over 95%. However, it also has the drawback of potentially generating switching noise.

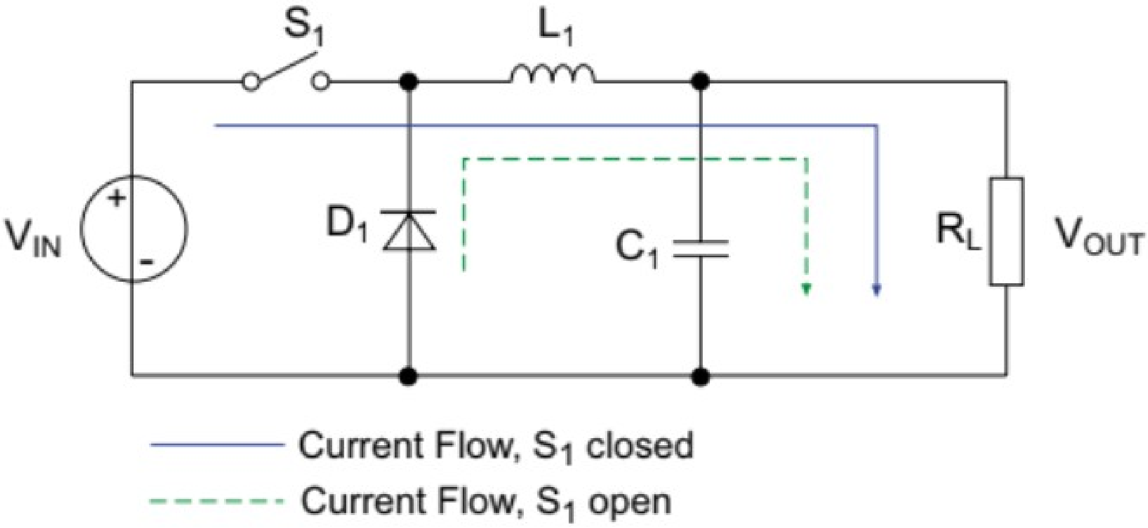


Figure 20. This schematic is a simplification and shows how the buck converter draws current during a switching event. (obtained from Willy Technical Reference Blog)

When looking at the circuit diagram, when switch S is closed, energy is stored in the inductor L due to the input voltage, and energy is transferred from the input side to the output side. At this time, the Free Wheeling diode D is blocked. In the next moment, when switch S opens, the energy stored in inductor L is delivered to the output side through the Free Wheeling diode D. By adjusting the time ratio of the switch S opening and closing, the desired DC output voltage can be obtained.

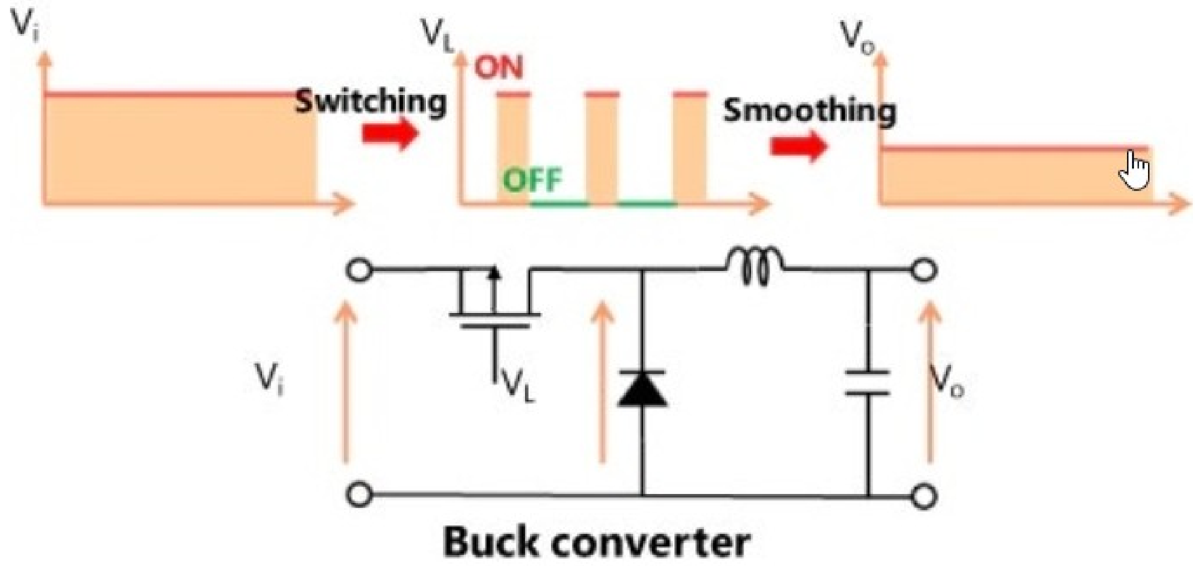


Figure 21. Figure showing a graph of lowered voltage. (obtained from Willy Technical Reference Blog)

The Buck Converter is widely used in various fields, including MCU microcontrollers, communication equipment, and control systems.

2.2.3.2. Boost-Converter

The Boost Converter, also known as a step-up converter, is a DC/DC switch-mode power supply designed to stabilize and increase the input voltage from an unregulated DC supply to a higher output voltage. Similar to the Buck Converter, the Boost Converter uses an inductor, diode, capacitor, and power switch to regulate the output voltage. However, the placement of these components differs slightly from that in the Buck Converter.

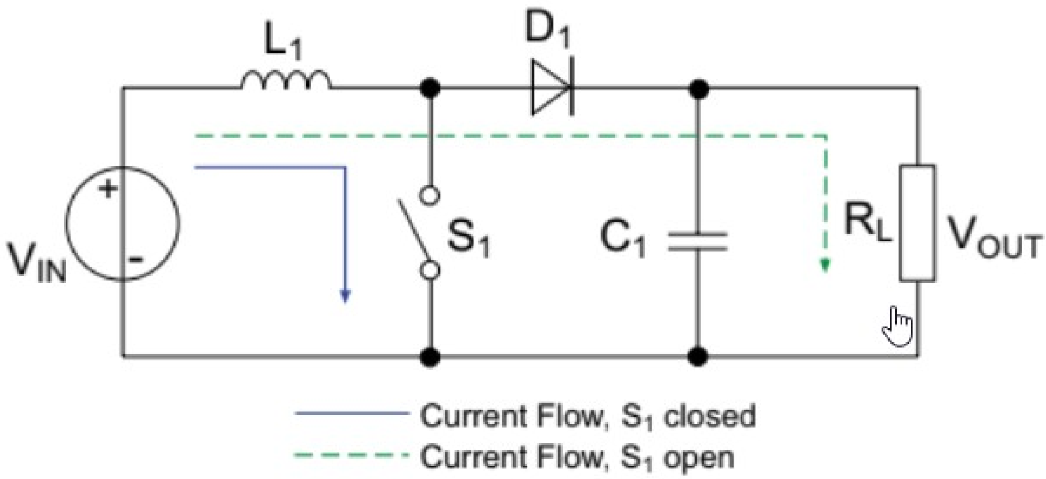


Figure 22. This schematic is a simplification and shows how the buck converter draws current during a switching event. (obtained from Willy Technical Reference Blog)

When looking at the circuit diagram above, when switch S is closed, energy is stored in inductor L due to the input voltage, and diode D is blocked. During this time, the charge stored in capacitor C discharges through the load resistor R on the output side. In the next moment, when switch S is open, the energy stored in inductor L is released to the output side through diode D. In this way, by adjusting the time ratio of switch S opening and closing, the desired DC output voltage can be obtained.

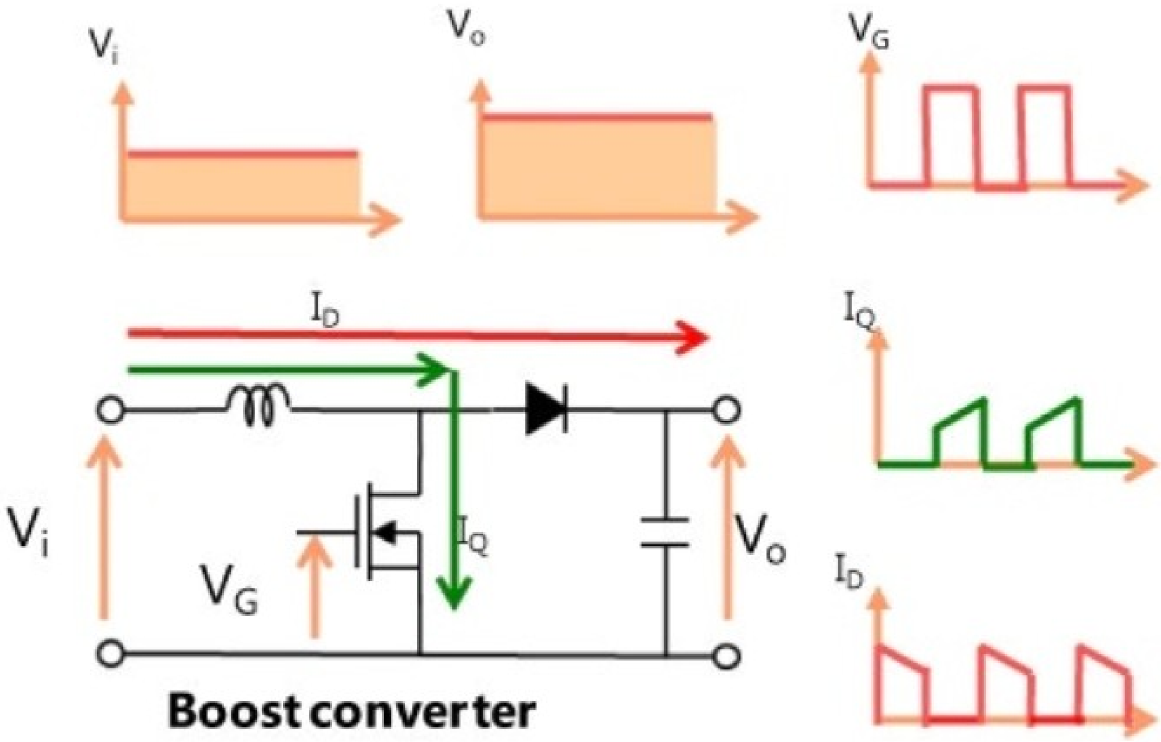


Figure 23. Figure showing a graph of increased voltage. (obtained from Willy Technical Reference Blog)

In a boost converter, the output voltage is converted to a value higher than the input voltage (Vin) depending on the ratio of the switch's opening and closing. However, the power level remains constant. Therefore, a boost converter with an output voltage three times the input voltage will have an output current that is one-third of the input current. In practice, boost converters are widely used in battery-powered devices where a pair of batteries provide 3V but need to supply a 5V circuit.

2.2.3.3. Buck-Boost Converter

A Buck-Boost Converter is a type of DC/DC converter that can either step up or step down the voltage. The circuit of a Buck-Boost Converter combines the elements of both a Buck Converter and a Boost Converter, which may result in a physically larger design.

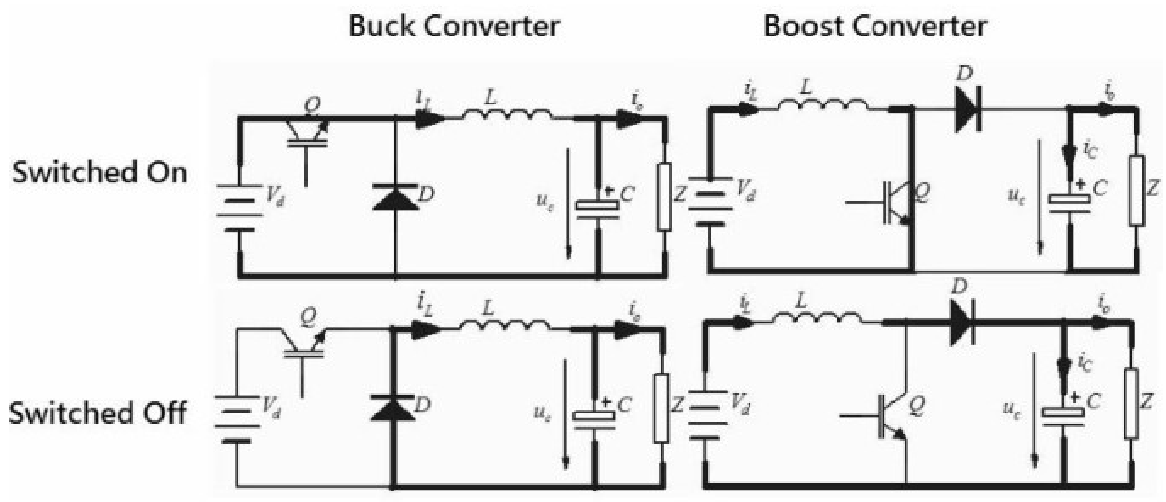


Figure 24. Simplified circuit diagram of Buck-Boost Converter (obtained from Willy Technical Reference Blog)

A Buck-Boost Converter can either step up or step down the input voltage, resulting in a wide range of input voltages. Due to its ability to maintain high efficiency within this wide input voltage range, the Buck-Boost Converter is used in many applications.

However, compared to Buck Converters or Boost Converters, the Buck-Boost Converter tends to have lower efficiency. Additionally, it must withstand both the maximum input voltage and high input current, which makes it more expensive.

An example application for a Buck-Boost Converter is powering 9-14V LED lighting from a 12V lead-acid battery.

3. Component Selection

In this section, I will select the components necessary for designing an electric scooter. As mentioned in the previous chapter, I will use the most critical components for an electric scooter: the motor, battery, and converter. I will select suitable components from the market for each part to design the scooter.

When building a machine, it is essential to consider various factors such as price, efficiency, and functionality of each component to ensure they work together seamlessly and produce optimal results. Therefore, I will research online marketplaces to compare the price and performance of each component, select the most suitable ones, and describe them. In the next section, I will proceed with the design using these selected components and appropriate software.

3.1. Motor

As previously mentioned, I will use the most commonly employed BLDC (Brushless DC) motor for the motor. This decision is based on the advantages of BLDC motors, such as long lifespan, compact size, and high efficiency. Additionally, the majority of electric scooters use BLDC motors, which makes them versatile and easily accessible in the market.

Electric scooter motors generally come in specifications of 24V, 36V, and 48V. Based on market research, I have identified three models.

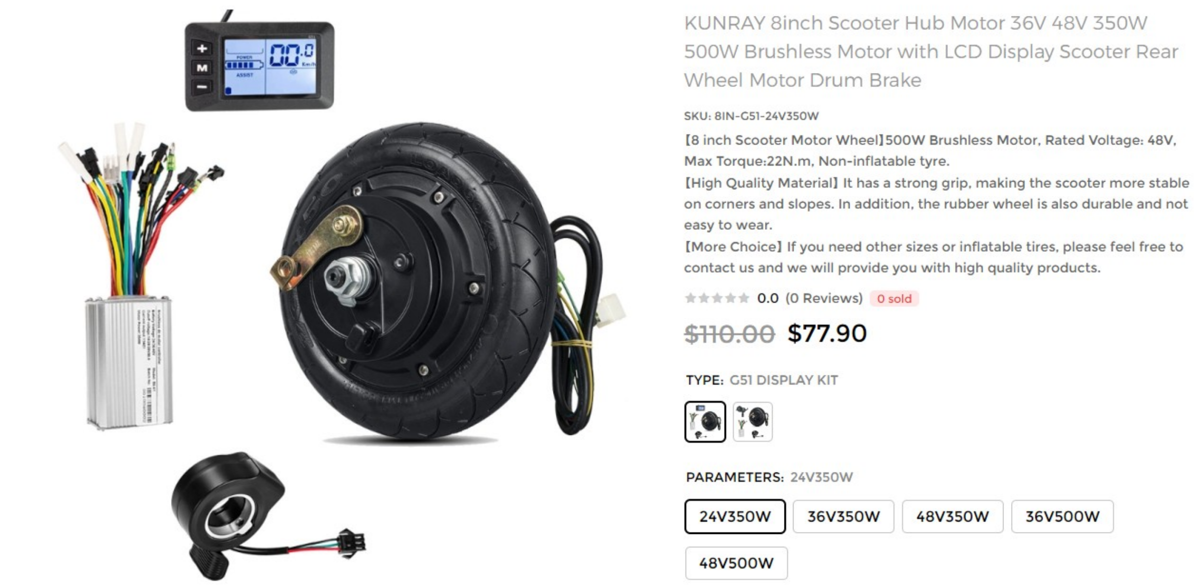


Figure 25. BLDC motor with specifications of 24V 350W (obtained from cnkunray.com)

Figure 26. BLDC motor with specifications of 36V 350W ((obtained from volrad.com)

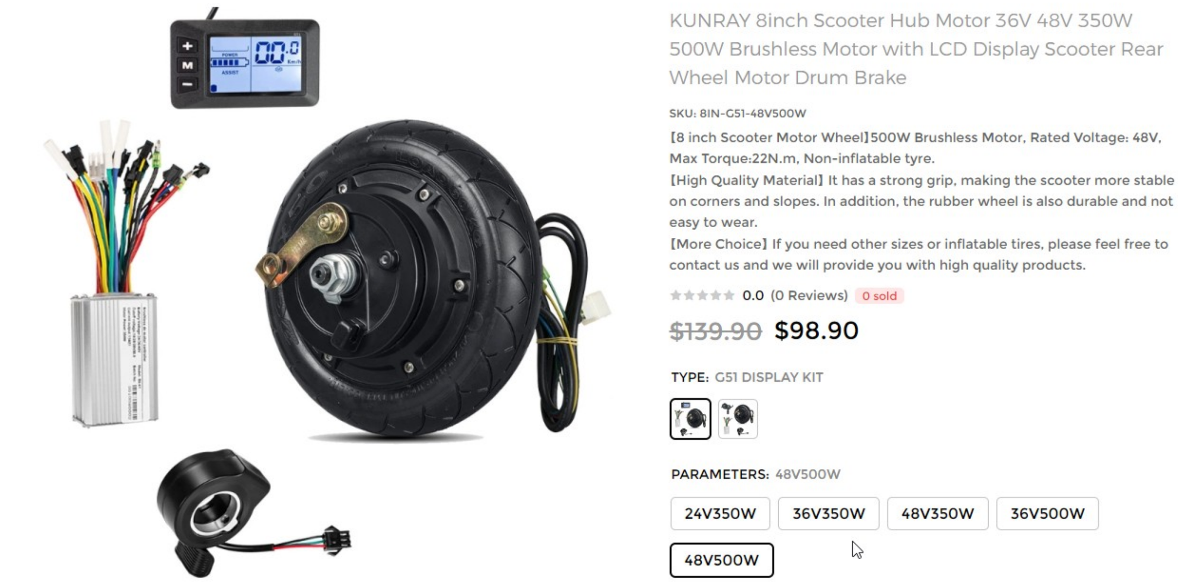


Figure 27. BLDC motor with specifications of 48V 500W (obtained from cnkunray.com)

The following table shows the specifications of each motor.

Type	**24V, 350W**	**36V, 350W**	**48V, 500W**
Rated Power	350W	350W	500W
Rated Voltage	24V	36V	48V
Rated Current	14A	11A	11A
Speed	950 RPM	7415RPM	950RPM
Diameter	200MM	67MM	200MM
Max Torque	22Nm	0.45Nm	22Nm
Efficiency	>80%	>89%	>80%
Weight	3 KG	1.6 KG	5 KG
Price	77.90$	-	98.90$

Figure 28. Table comparing each motor (obtained from each motor specifications)

When looking at the following table, it can be observed that as the voltage increases, both weight and price also increase. The advantage of higher voltage is improved power efficiency and enhanced power output of the electric scooter, enabling it to operate smoothly in various environments.

$$\mathbf{P = V * I}$$

However, considering the price and weight, I have decided to adopt the 36V motor. The reasoning is that using a 24V motor may not be suitable for various environments and could result in lower climbing power. On the other hand, using a 48V motor would increase the bulk, weight, and cost. Therefore, for this design, I will opt for the 36V motor. By the way, the 36V motor I intend to use may look somewhat different from the conventional wheel-integrated motor design. However, this type of motor is often used in many electric scooters, primarily operating when mounted on the rear wheel.

Figure 29. Electric kickboard with a motor mounted outside the rear wheel(obtained from scootercity.co.uk)

3.2. Battery

As previously mentioned, I will use lithium-ion batteries for this design. The reasons for choosing lithium-ion over lithium-polymer batteries include market availability and performance characteristics. Lithium-ion batteries are widely used in various transportation devices and other applications, making them more readily available and cost-effective. Additionally, lithium-polymer batteries have lower conductivity compared to lithium-ion batteries, and given the nature of electric scooters, the components need to perform well even in low-temperature environments. Hence, lithium-ion batteries are deemed more suitable.

Lithium-ion batteries are generally categorized into 48V types such as 18650, 21700, and 32650. The numbers indicate the size of the battery (e.g., 18650 = 18mm diameter, 65mm length; 21700 = 21mm diameter, 70mm length). The physical size difference of the batteries also results in differences in their Ah capacity. Typically, 18650 batteries have a charging capacity of 2000-3500mAh, while 21700 batteries have a capacity of 3000-5000mAh.

Parameter	36V 10.4AH	36V 13AH	36V11.6AH	36V 14.5AH	36V 17.4AH	36V 20.3AH
Cell Capacity	26CN 2600mah	26CN 2600mah	2900mah	2900mah	2900mah	2900mah
Composed Type	10S4P	10S5P	10S4P	10S5P	10S6P	10S7P
Cell Type	Li-ion 18650 / 21700					
BMS	25Amp					
Fit Motor Power	36V250W-500W					
Dimensions	75*68*215 (mm)	77*68*265 (mm)	75*68*215 (mm)	77*68*265 (mm)	90*68*253 (mm)	90*68*290 (mm)
Battery Weight	4.2KG	4.8KG	2.7KG	3.25KG	3.8KG	4.35KG

Parameter	48V 10.4AH	48V 13AH	48V 11.6AH	48V 14.5AH	48V 17.4AH	48V 20.3AH
Cell Capacity	26CN 2600mah	26CN 2600mah	2900mah	2900mah	2900mah	2900mah
Composed Type	13S4P	13S5P	13S4P	13S5P	13S6P	13S7P
Cell Type	Li-ion 18650 / 21700					
BMS	30Amp					
Fit Motor Power	48V250W-1000W					
Dimensions	75*68*270 (mm)	90*68*270 (mm)	75*68*270 (mm)	90*68*270 (mm)	90*68*320 (mm)	108*70*320(mm)
Battery Weight	4.9KG	5.6KG	3.4KG	4.1KG	4.8KG	5.5KG

Figure 30. 18650 battery information on Aliexpress (obtained from Aliexpress.com)

Figure 31. 21700 battery information on Aliexpress (obtained from Aliexpress.com)

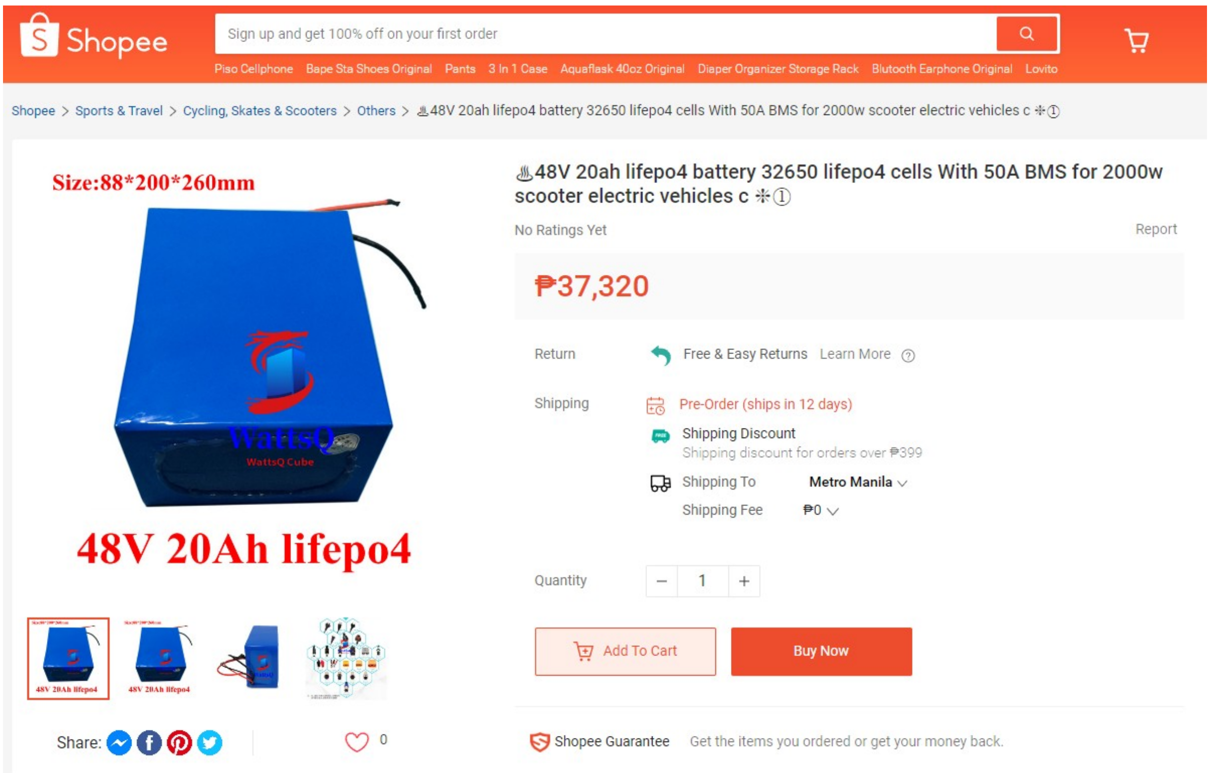


Figure 32. 32650 battery information on Shopee (obtained from Shopee.com)

Below is a comparison table of the basic specifications:

Type	**18650**	**21700**	**32650**
Cell Capacity	2600mAh	5000mAh	-
Dimensions	270*90*68 MM	230*130*75 MM	88*200*260 MM
Weight	5.6 Kg	4.5 Kg	6 Kg
Ah	13Ah	30Ah	20Ah
Discharge Temperature	-20˚C to 65˚C	-20˚C to 65˚C	-20˚C to 60˚C
Price	140.29€	221.29€	587.08€

Figure 33. Table comparing each battery (obtained from each battery specifications)

Based on the previous table, the 32650 battery may appear to be the best option in terms of electrical efficiency. However, for this design, I will be using the 18650 battery. The reason for this is that as battery size increases, the weight and volume of the electric scooter will also increase. This could result in a scooter that is almost the size of a motorcycle, negatively impacting its portability.

Additionally, the 18650 battery is more versatile due to its smaller size. It allows for more compact designs and there is a wide variety of 18650 battery packs available on the market in different shapes and sizes. Therefore, I will be using the 18650 battery for this design.

3.3. Converter

In this design, since I will be using a 48V battery with a 36V motor, I need to adjust the voltage accordingly. Therefore, the installation of a converter is unavoidable, and I will use a Buck-Converter for this purpose. Converters vary based on the different voltages they handle.

In this design, a 48V – 36V converter will be installed, and the most important factors to consider are the converter's maximum current capacity, efficiency, price, and size.

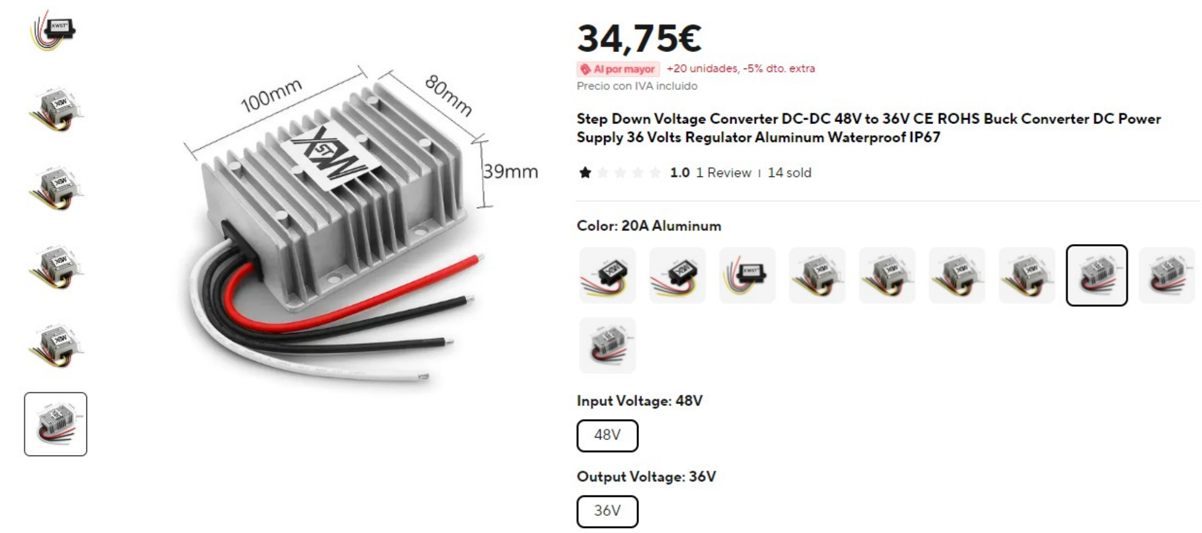


Figure 34. 48V to 36V converter information on Aliexpress (obtained from Aliexpress.com)

Figure 35. 48V to 36V converter information on Aliexpress (obtained from Aliexpress.com)

Figure 36. 48V to 36V converter information posted in other stores (obtained from nelsotech.com)

Below is a comparison table of the basic specifications:

Type	**Figure 34**	**Figure 35**	**Figure 36**
Current	20A	10A	10A
Weight	300 g	250g	1.2 Kg
Size	58*40.5*22 MM	74*74*32 MM	193*142*70 MM
Efficiency	>93%	>95%	>80%
Working Temperature	-30 ˚C to 80 ˚C	-40 ˚C to 80 ˚C	-40 ˚C to 80 ˚C
Price	34.75€	13.85€	45.38€

Figure 37. Table comparing each converter (obtained from each converter specifications)

After comparing the table, it appears that the Figure 31 product is the most suitable. While the Figure 32 product is better in terms of size and efficiency, it has a lower current rating of 10A compared to the Figure 31 converter.

Since the battery used in this design has an amperage of 11.6Ah, which exceeds the maximum allowable amperage of the Figure 32 converter, the Figure 31 converter is deemed the most appropriate for this design.

4. Circuit diagram creation using PSIM

Before proceeding with the design, it is important to note that there are various applications available for drawing electrical circuits. In this design, I used the PSIM program to create the BLDC circuit diagram and the converter circuit diagram.

4.1. PSIM

PSIM is an electronic circuit simulation software package designed for use in power electronics and motor drive simulations. Developed by POWERSIM, PSIM includes simulations for control theory, electric motors, solar power systems, and various other circuits. It is widely used across different industries, research, and product development.

4.2. Starting Circuit Design

First, run the PSIM program. Next, click on the 'File' button in the top menu and select 'Open Examples...'. This will display various circuit diagrams provided by PSIM. For this design, I will be creating a circuit using a BLDC motor, so navigate to the 'Motor Drive' folder and open the 'brushless dc motor drive - current & speed feedback' file.

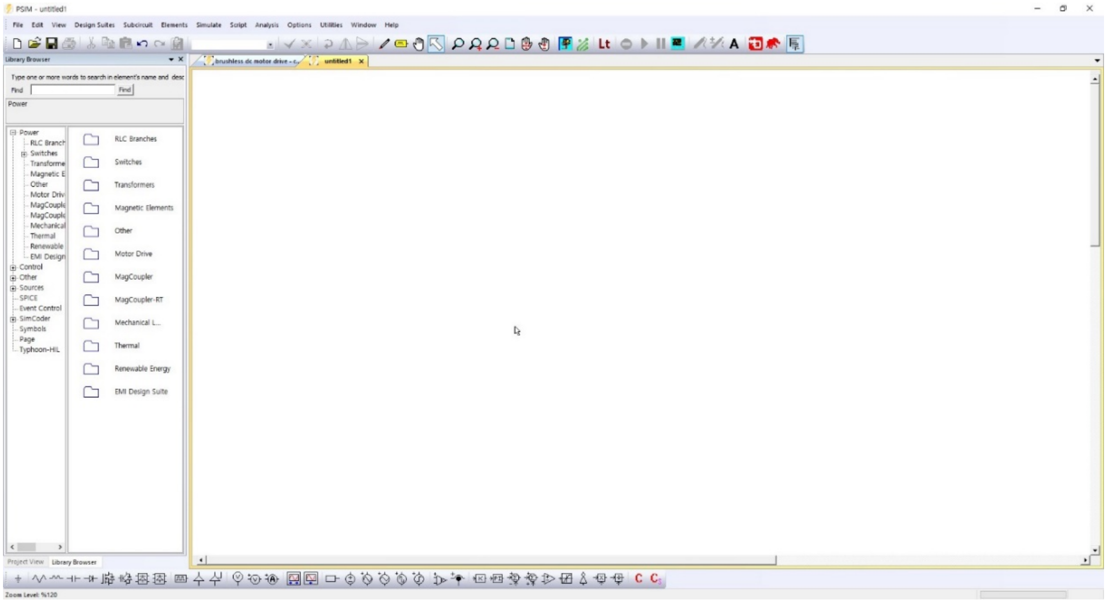


Figure 38. PSIM program home screen (obtained from PSIM)

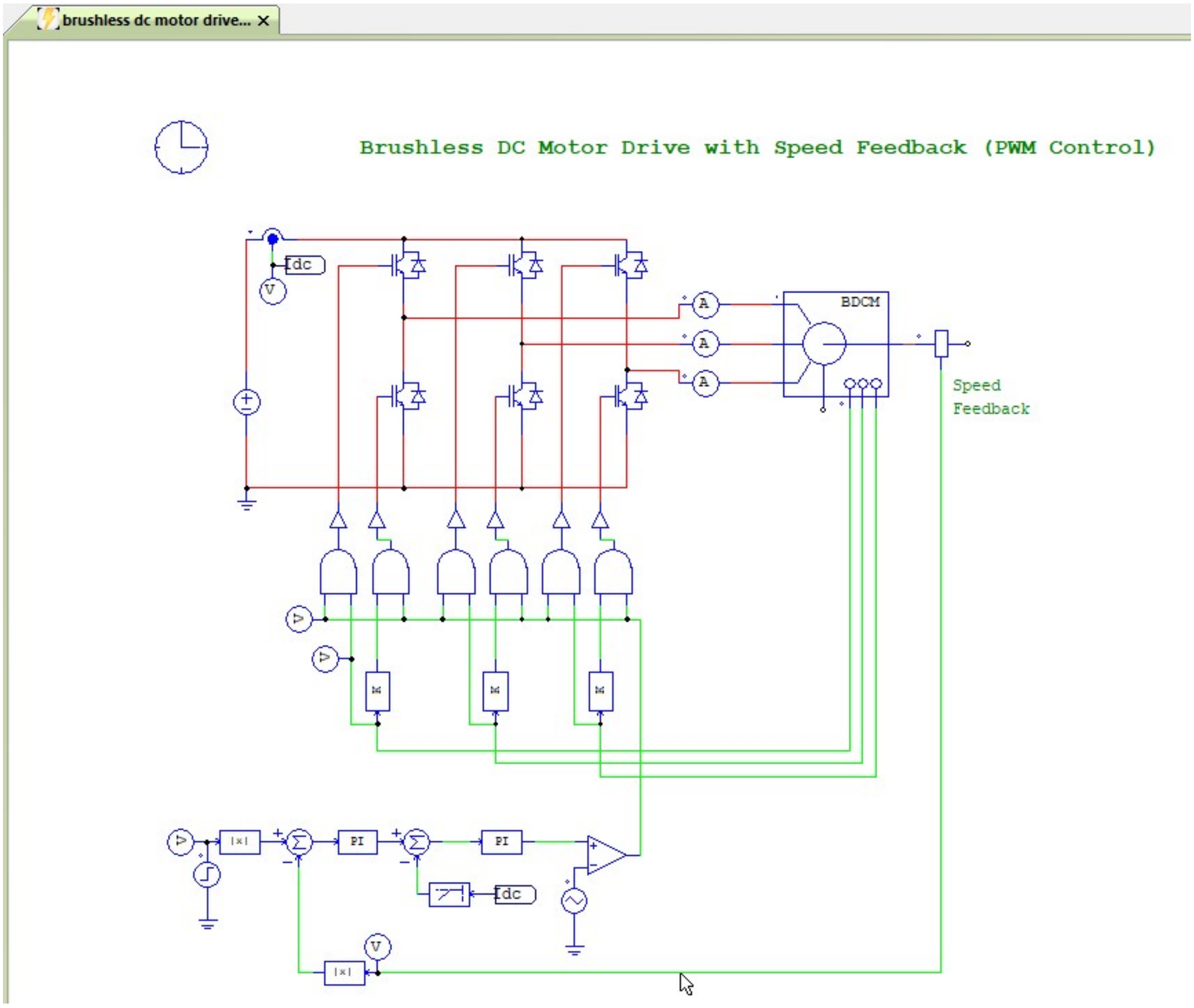


Figure 39. 'brushless dc motor drive - current and speed feedback' file schematic (obtained from PSIM)

Using this circuit, I can input the data values for each of my components to achieve the desired results. However, this circuit diagram contains elements that are either necessary or unnecessary for this particular design. Therefore, I need to remove the unnecessary parts and add any required components.

First, for this design, the part of the circuit related to Speed Feedback is not needed, so I will delete that section.

Next, to add the frequency value and modulation, include the following circuit diagram:

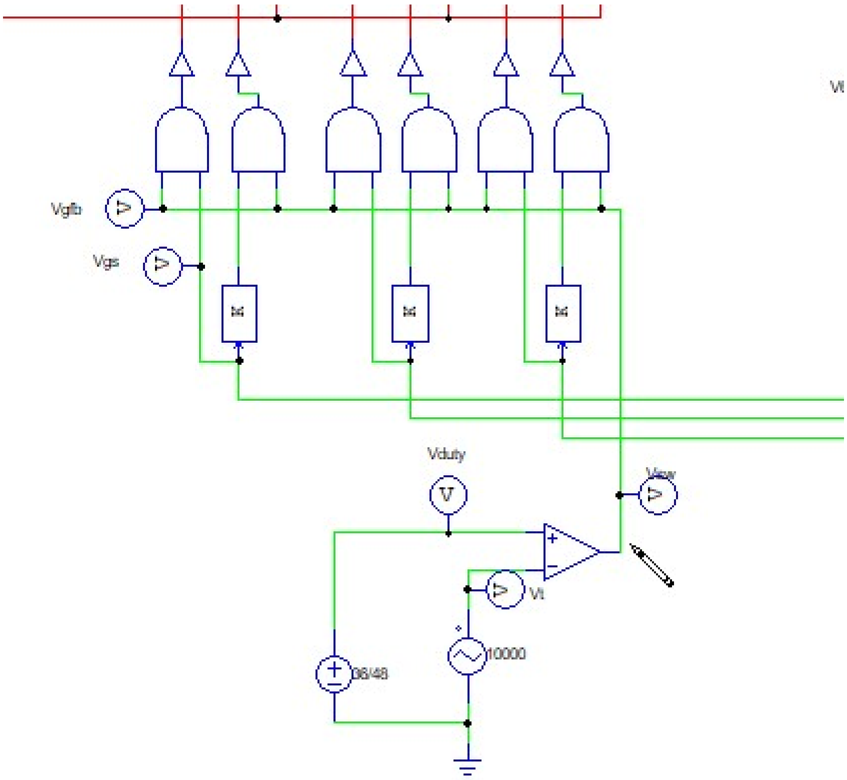


Figure 40. Circuit diagram with unnecessary parts removed and modulator added (self-made in PSIM)

Since I are using a battery for power supply in this design, I need to add the impedance values to the battery section by including resistance and capacitor components. This is because each battery has its own impedance values that need to be incorporated.

If the datasheet does not provide the impedance values, use the default values: 10mΩ for Rbat and 1m (1*10^-3) for Cbat. For the battery selected in this design, only the resistance value is provided. Therefore, add the R value from the datasheet and use a general value of 10m for Cbat. Additionally, depending on the capacitor chosen later, the ESR_C value will be added. Each capacitor also has its own impedance value, so the impedance value specified for the selected capacitor component will be added accordingly.

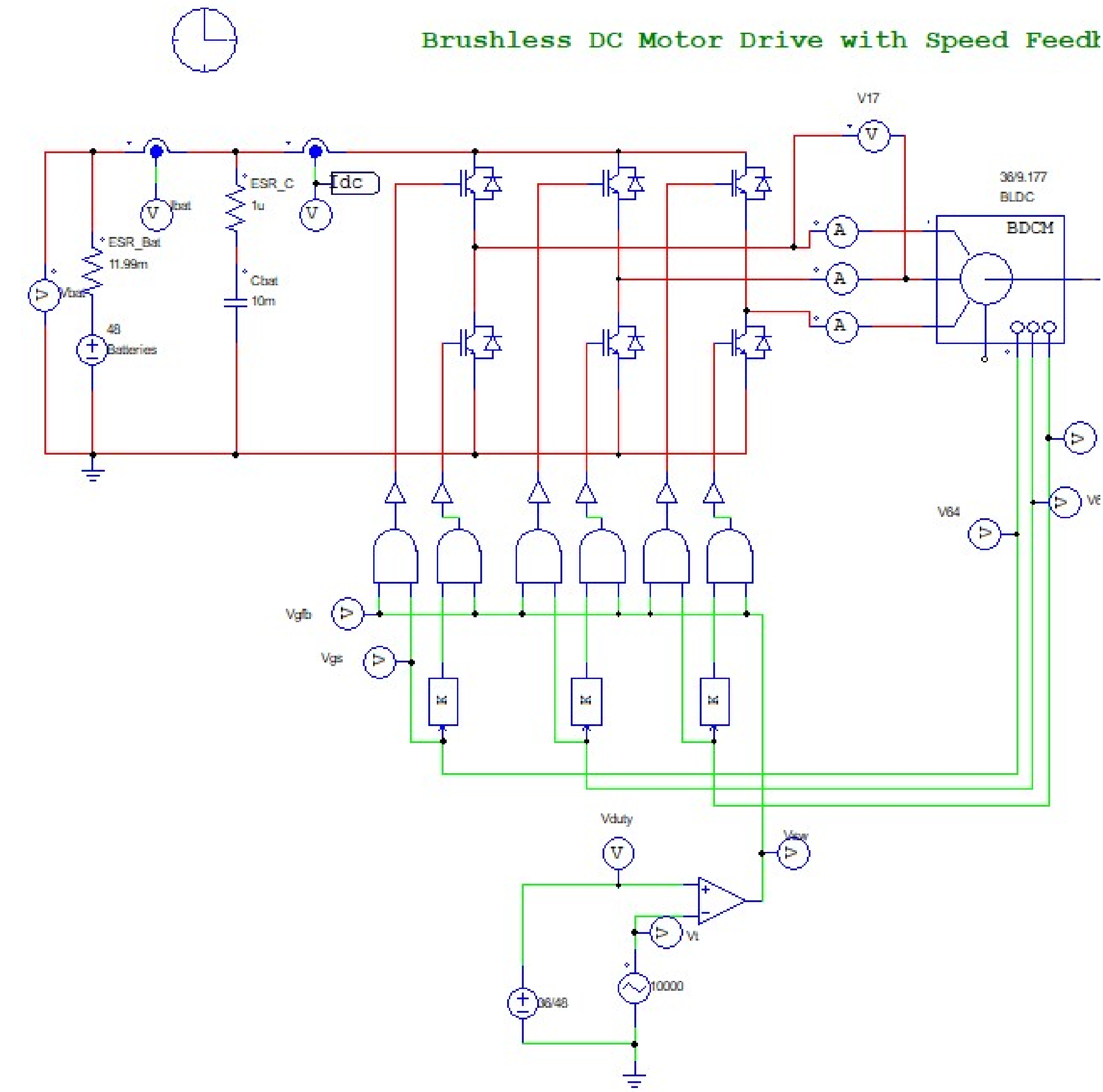


Figure 41. Added a sensor to measure the resistance value entering the battery (self-made in PSIM)

To input the torque value for the motor, connect the 'Mechanical Load (constant-torque)' component to the BLDC motor. Next, add a 'Torque sensor' to measure the torque value.

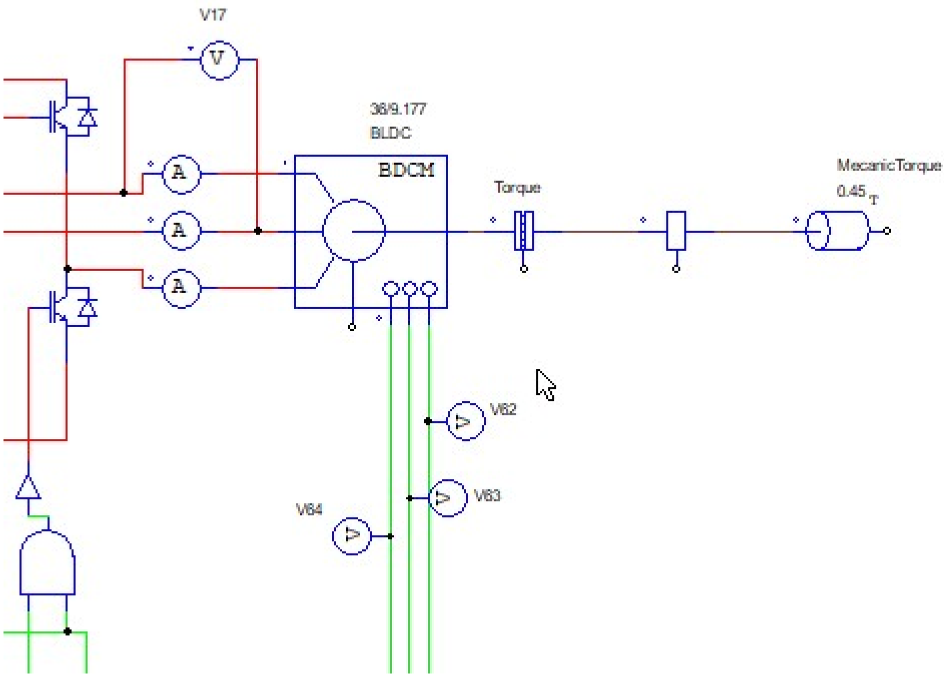


Figure 42. Circuit diagram photo added for motor torque value and measurement (self-made in PSIM)

Finally, place probes at the connection points of each component and in the sections where I want to take measurements.

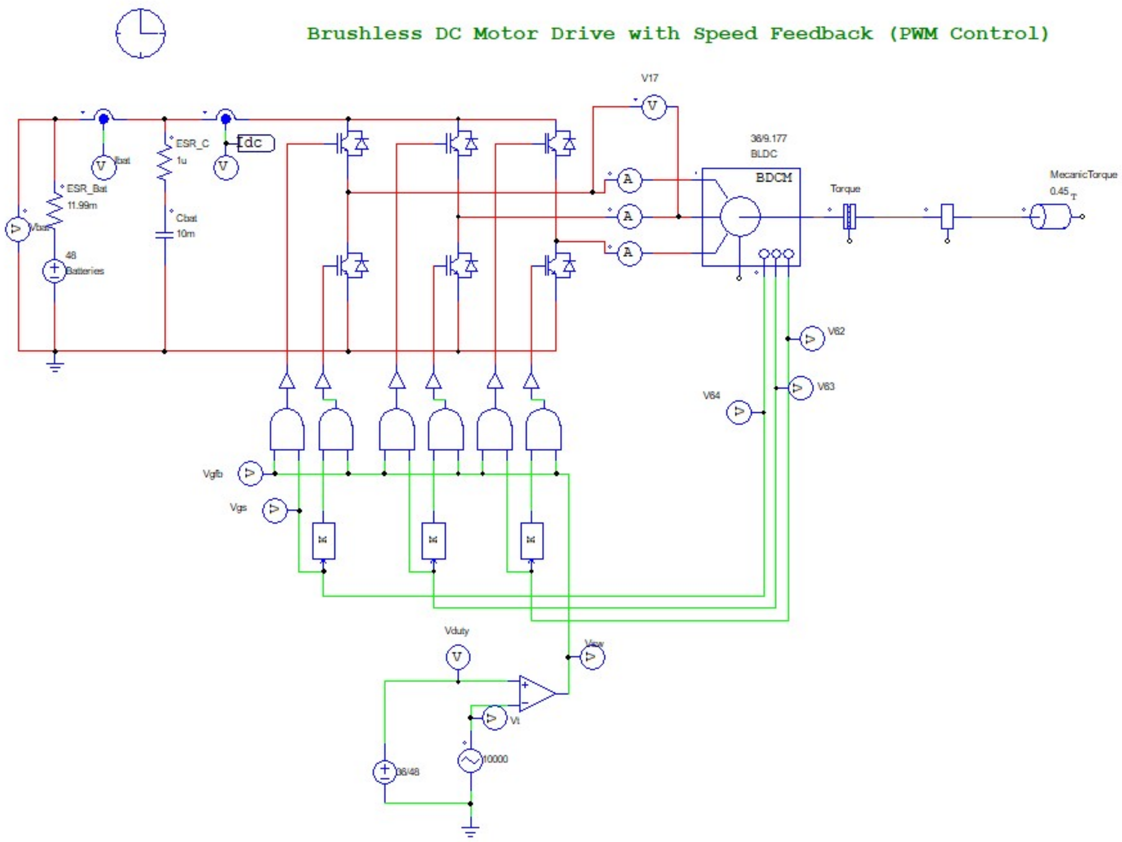


Figure 43. Photo of completed circuit diagram design (self-made in PSIM)

With this, the circuit design is complete.

4.3. Inputting and calculating parameter values

In the previous chapter, I completed the basic circuit design needed for the project. Now, I need to input the values from the datasheets of the components I have selected into the circuit components in the schematic.

4.3.1. BLDC Motor

TECHNICAL DATA

Model			350 W 67x67	
Voltage		24V	36V	48V
Product Number		VMHT3524H1C1-67	VMHT3536H1C1-67	VMHT3548H1C1-67
BASIC MOTOR PARAMETERS				
Nominal Speed	rpm	6962	7415	6961
Nominal Power	W	350	350	350
Maximum Continuous Torque	Nm	0.48	0.45	0.48
Nominal Current	A	14.76	9.70	7.38
No-Load Speed	rpm	8740	9177	8740
Efficiency	%	89	89	89
Stall Torque	Nm	10	10	10
Stall Current	A	405	301	202
ELECTRICAL CHARACTERISTICS				
Number of Phases		3	3	3
Number of Poles		8	8	8
Operating Temperature	°C	-55 >> +85	-55 >> +85	-55 >> +85
Phase-to-Phase Resistance	mΩ	59.04 ± 10%	119.34 ± 10%	236.76 ± 10%
Phase-to-Phase Inductance	mH	0.118 ± 10%	0.24 ± 10%	0.47 ± 10%
Rated-Torque Constant	Nm/A	0.029 ± 10%	0.041 ± 10%	0.058 ± 10%
Back -EMF Constant	Vs/rad	0.026 ± 10%	0.037 ± 10%	0.052 ± 10%
Dielectric Strength at 1000V	MΩ	500 (min.)	500 (min.)	500 (min.)

Figure 44. BLDC Motor Datasheet (obtained from volrad.com)

First, I will input the data values of the selected BLDC motor into the PSIM circuit. To enter the data values, double-click on the component shown in the picture.

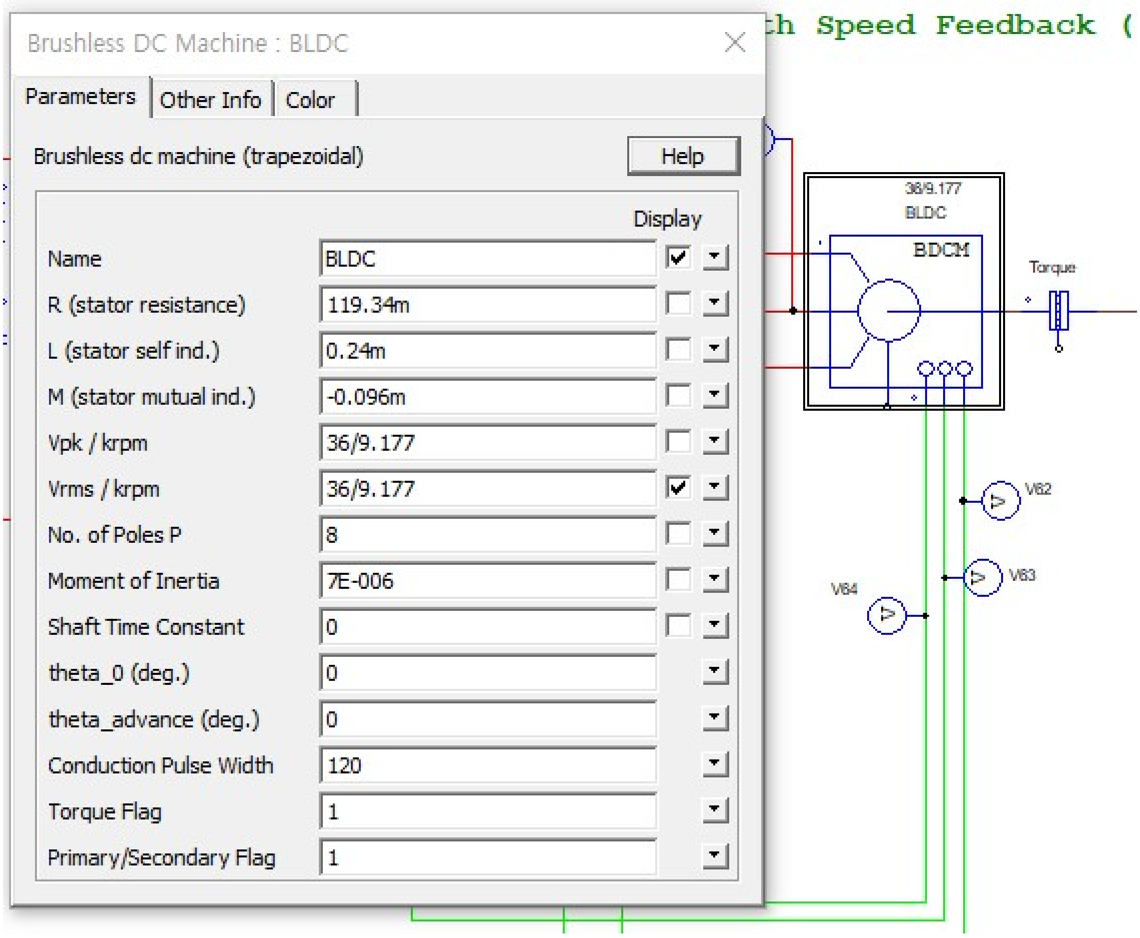


Figure 45. Brushless DC Machine Parameters (self-made in PSIM)

This will open a window where various parameters can be entered. The data I need to enter are as follows:

① R (stator resistance): The R value from the table in the datasheet.

② L (stator self inductance): The L value from the table in the datasheet.

③ M (stator mutual inductance): If this value is not provided, click the 'Help' button in the Parameters window to see the formula for calculating it.

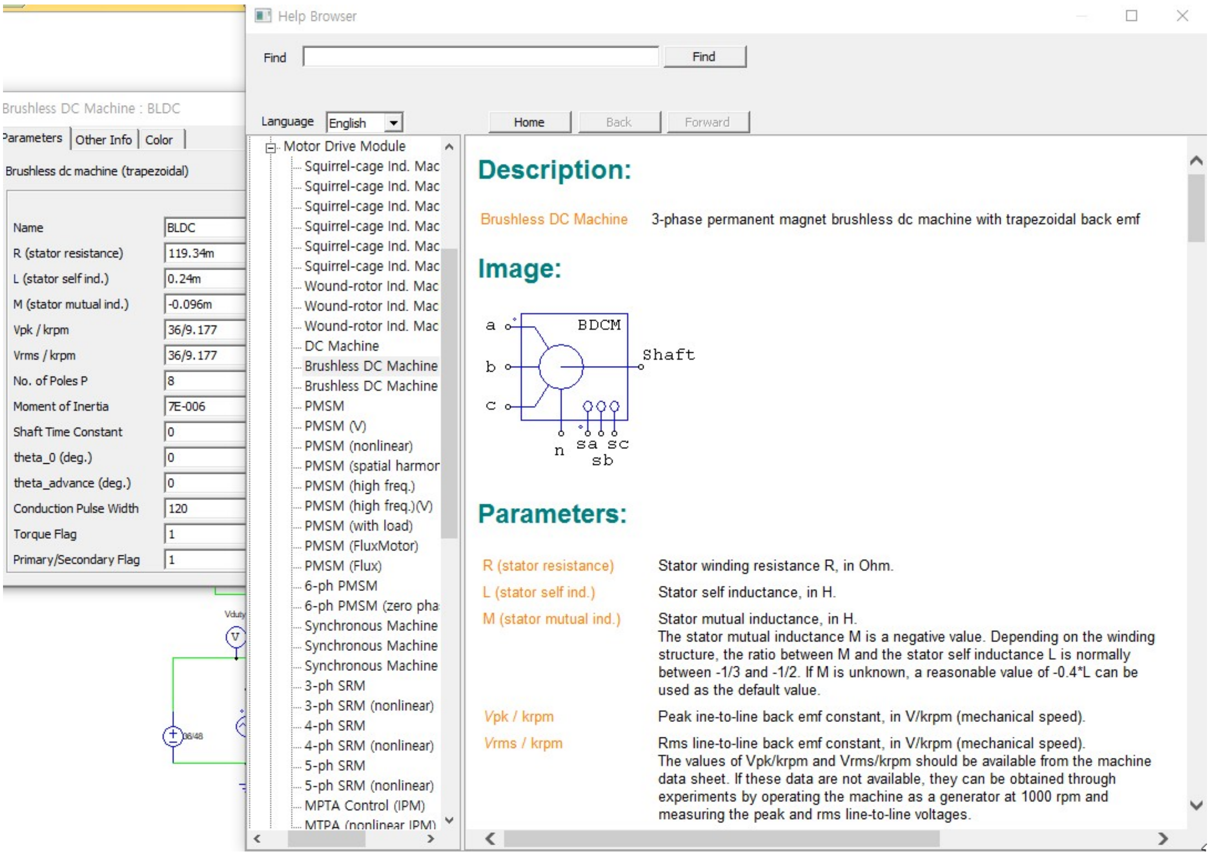


Figure 46. Definition and calculation of each parameter (obtained from PSIM)

According to the explanation, the mutual inductance M is calculated as:

$$\mathbf{M = -0.4 * L}$$

④ Vpk/krpm: Since the BLDC motor operates with a square wave, I use the same value as Vrms, which is 36V.

⑤ Vrms/krpm: The V value from the table in the datasheet.

⑥ No. of Poles P: The Poles value from the table in the datasheet.

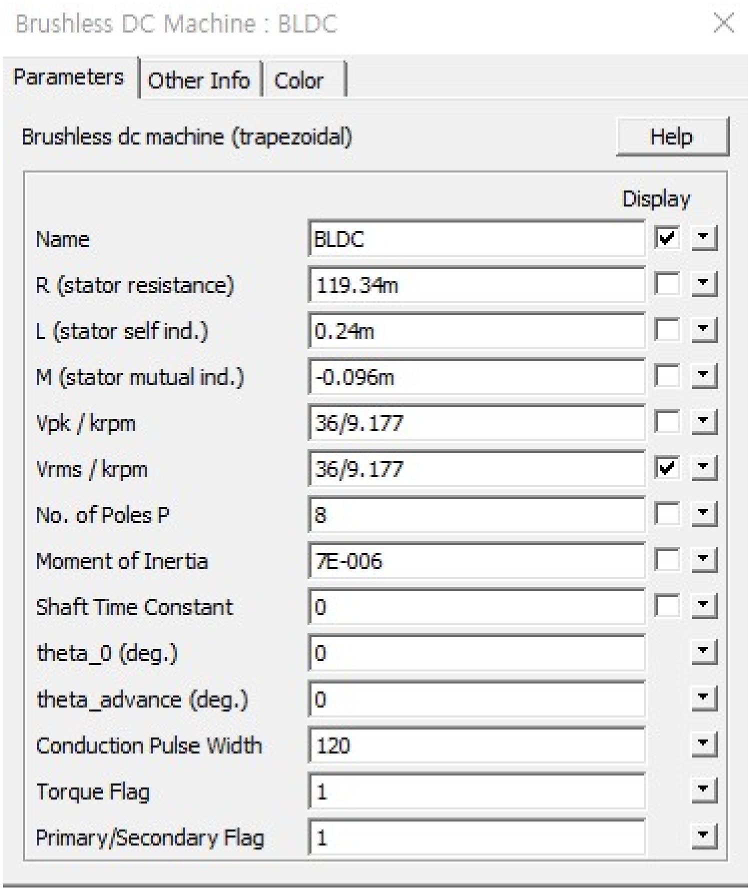


Figure 47. Photo of completed BLDC Parameters (self-made in PSIM)

Other parameter values that are not provided in the datasheet will use the default values in PSIM.

4.3.2. Battery

Parameter	36V 10.4AH	36V 13AH	36V11.6AH	36V 14.5AH	36V 17.4AH	36V 20.3AH
Cell Capacity	26CN 2600mah	26CN 2600mah	2900mah	2900mah	2900mah	2900mah
Composed Type	10S4P	10S5P	10S4P	10S5P	10S6P	10S7P
Cell Type	Li-ion 18650 / 21700					
BMS	25Amp					
Fit Motor Power	36V250W-500W					
Dimensions	75*68*215（mm）	77*68*265（mm）	75*68*215（mm）	77*68*265（mm）	90*68*253（mm）	90*68*290(mm）
Battery Weight	4.2KG	4.8KG	2.7KG	3.25KG	3.8KG	4.35KG

Parameter	48V 10.4AH	48V 13AH	48V 11.6AH	48V 14.5AH	48V 17.4AH	48V 20.3AH
Cell Capacity	26CN 2600mah	26CN 2600mah	2900mah	2900mah	2900mah	2900mah
Composed Type	13S4P	13S5P	13S4P	13S5P	13S6P	13S7P
Cell Type	Li-ion 18650 / 21700					
BMS	30Amp					
Fit Motor Power	48V250W-1000W					
Dimensions	75*68*270（mm）	90*68*270（mm）	75*68*270（mm）	90*68*270（mm）	90*68*320（mm）	108*70*320(mm）
Battery Weight	4.9KG	5.6KG	3.4KG	4.1KG	4.8KG	5.5KG

Figure 48. Battery Datasheet (obtained from Aliexpress.com)

Figure 49.Resistance value of the battery (obtained from Aliexpress.com)

To enter the battery parameters, double-click on the Vbat component to open the window where I can enter the parameter values. The parameters to be modified are as follows:

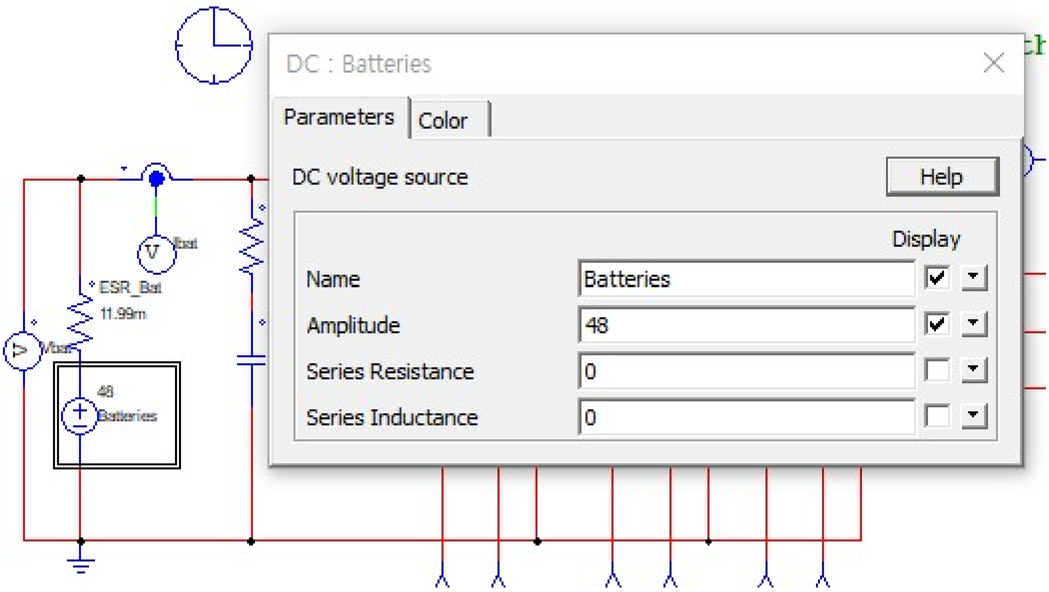


Figure 50. Batteries Parameters (self-made in PSIM)

Amplitude: Enter the V value from the table in the datasheet.

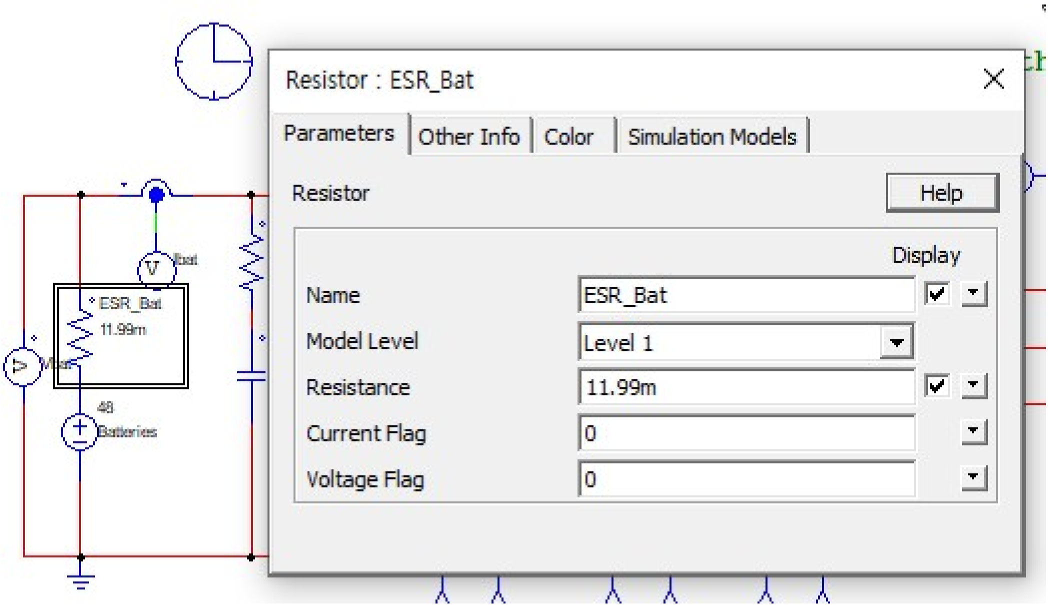


Figure 51. Resistance value of the battery (self-made in PSIM)

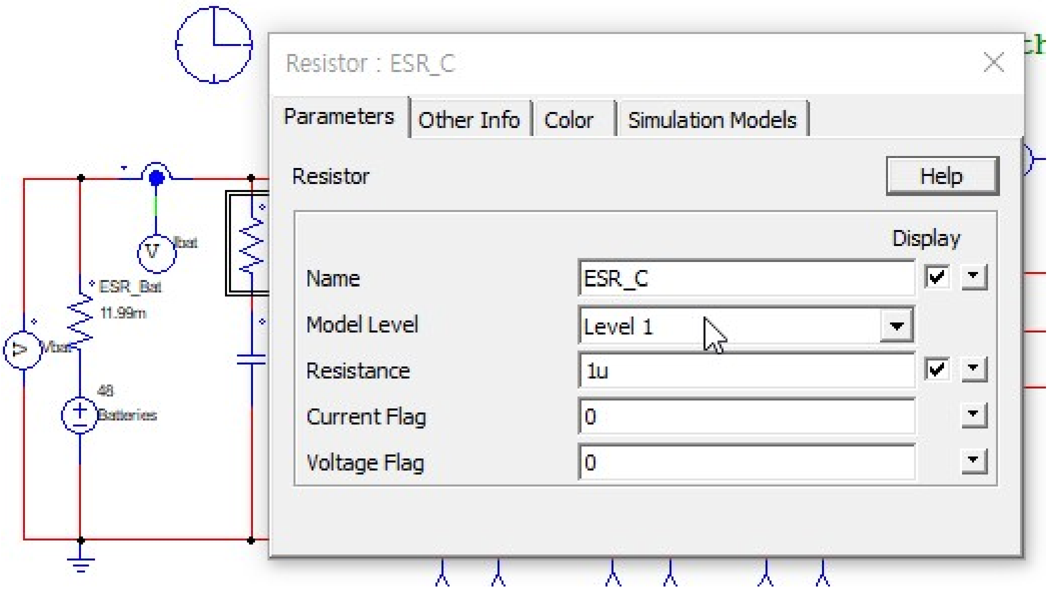


Figure 52. Resistance value of the condenser (self-made in PSIM)

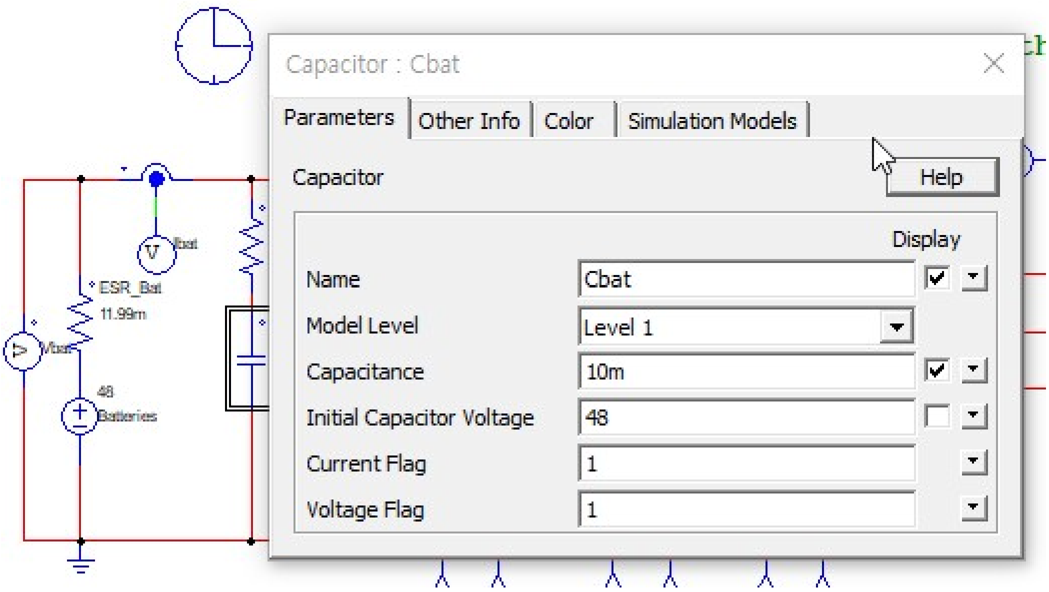


Figure 53. Capacitor value (self-made in PSIM)

For the added impedance values:

① ESR_bat: Enter the R value from the datasheet.

② ESR_C: This value will be obtained from the datasheet of the capacitor selected later. For now, I will use a minimal value of 1μΩ.

③ Cbat: Since the datasheet does not provide this value, I need to calculate it. The calculation method is as follows:

$$\mathrm{Zc} = 11.99\mathrm{m}\Omega$$

$$Z_{cESR} = \frac{Zc}{10} = 1.199m\Omega$$

$$Z_{cESR} = \frac{1}{2 * \pi * f * C_{teorica}}$$

$$C_{theory} = \frac{1}{2 * \pi * f * Z_{cESR}} = \frac{1}{2 * \pi * 10000 * 1.199 * 10^{-3}} = 13.27mF$$

However, since this calculated value is very precise, I used a value of 10mF for this design.

4.3.3. PWM digital controller parameters

Next, go to the digital controller and double-click on the component shown in the image to adjust the values according to the design.

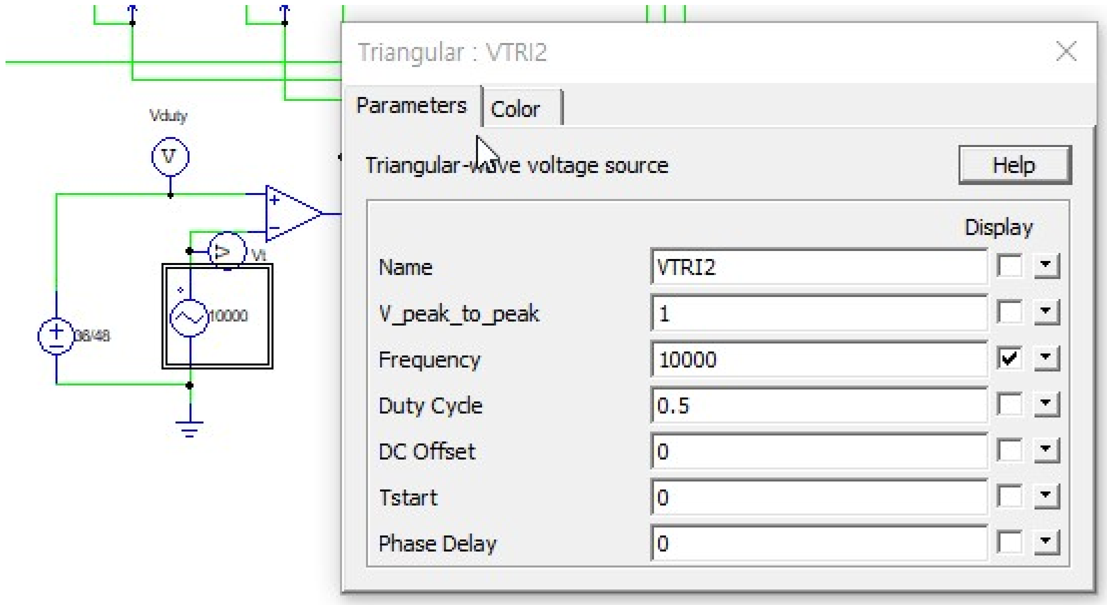


Figure 54. PWM digital controller parameters (self-made in PSIM)

① Frequency : Since the datasheet does not provide this value, a common range of 1-10kHz is used. For this design, I selected 10kHz.

② Duty Cycle: I selected the default value of 0.5.

All other values remain the same as previously set.

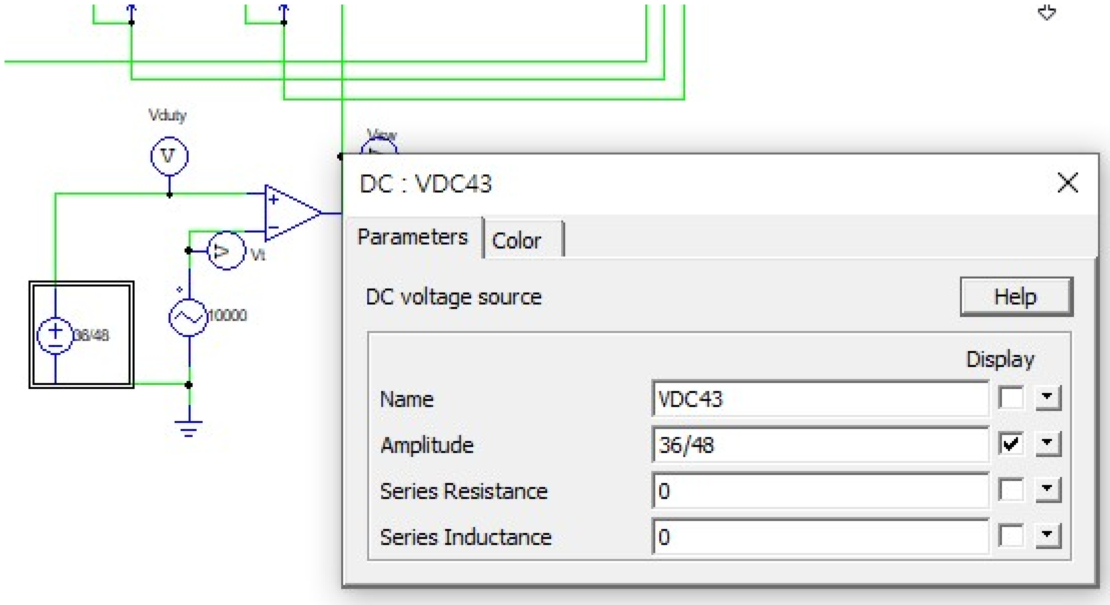


Figure 55. PSIM Duty value (self-made in PSIM)

Amplitude :

$$\text{Duty} = \frac{Vout}{Vin} = \frac{36}{48} = 0.75$$

All other values remain the same as previously set.

4.3.4. Torque Value

Finally, to change the torque value, double-click on the component shown in the image to adjust the value according to the design.

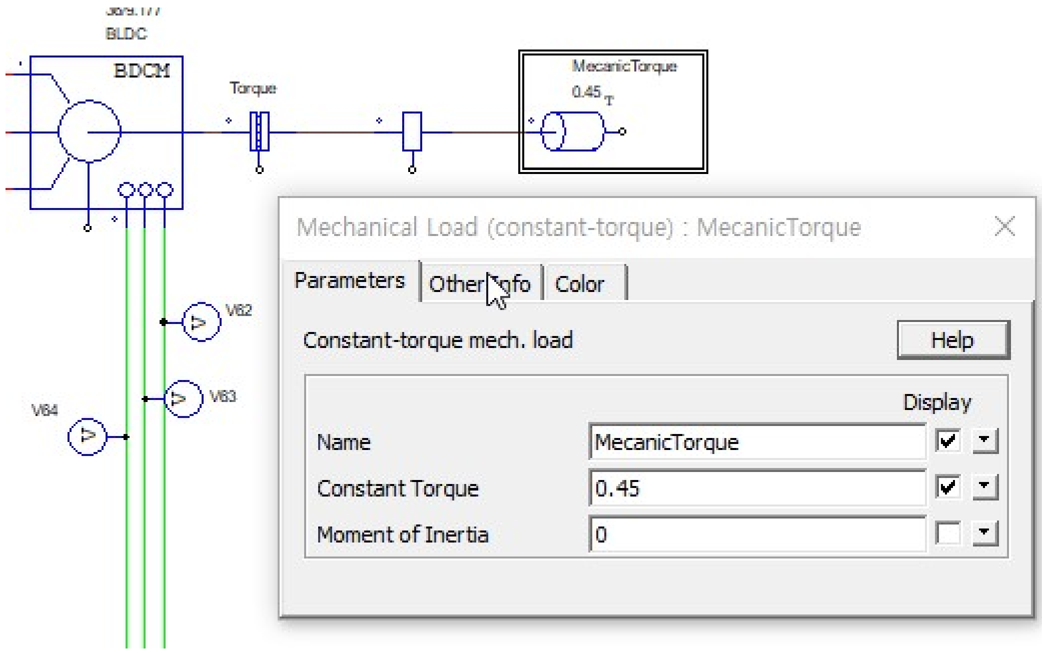


Figure 56. Torque Value (self-made in PSIM)

Constant Torque : Enter the Torque value from the datasheet.

All other values remain the same as previously set.

5. Results and Graphs

With the circuit design complete, I can now obtain the results. To run the simulation, click on the button labeled "Run PSIM Simulation" as shown in the image.

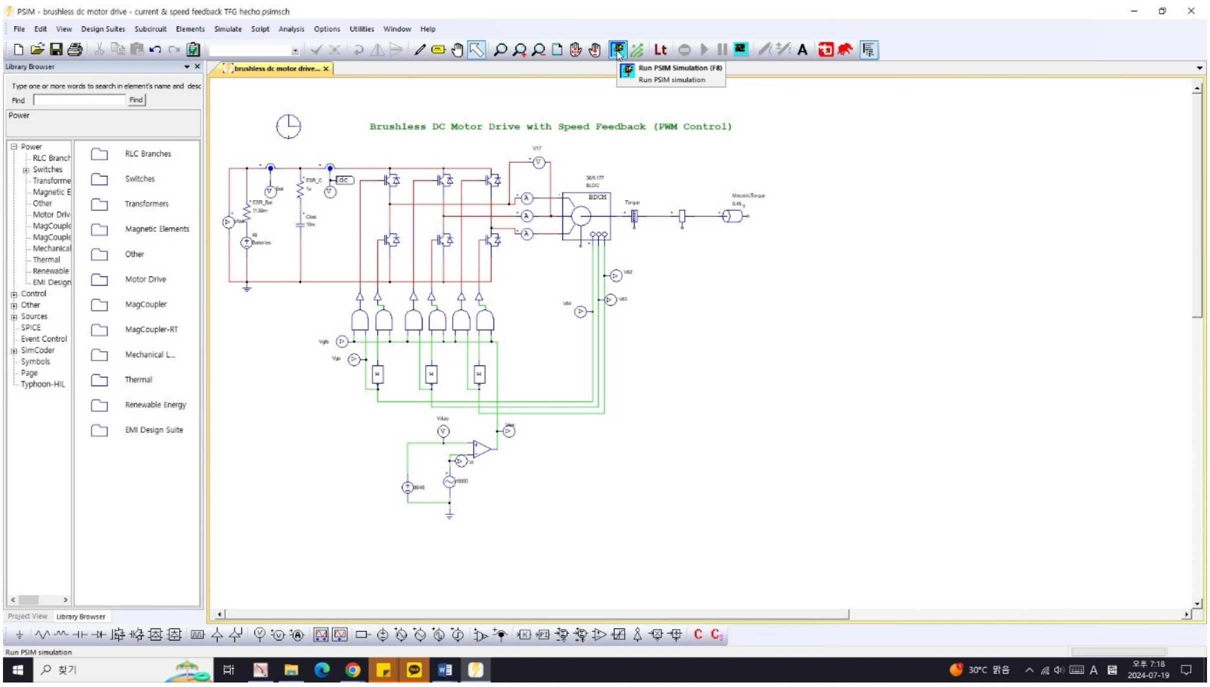


Figure 57. Run PSIM Simulation. (self-made in PSIM)

This will provide various data points that can be used to plot the necessary graphs. By inputting the required values, I can generate graphs such as:

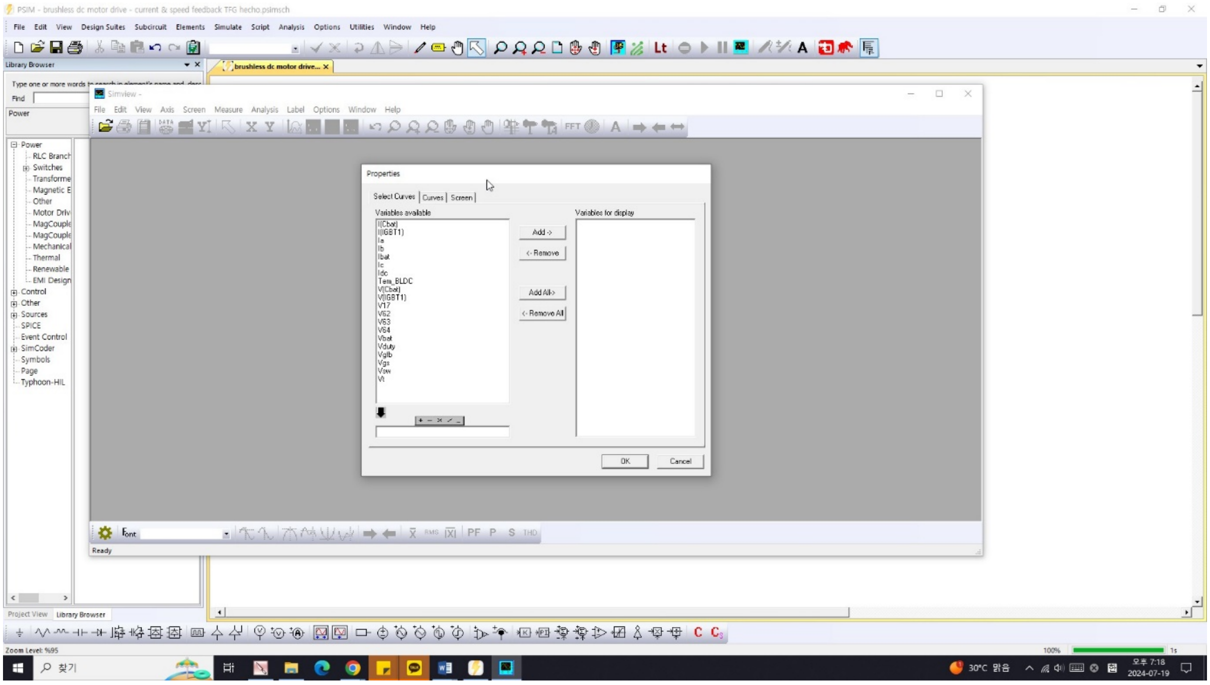


Figure 58. Selection Parameters. (obtained from PSIM)

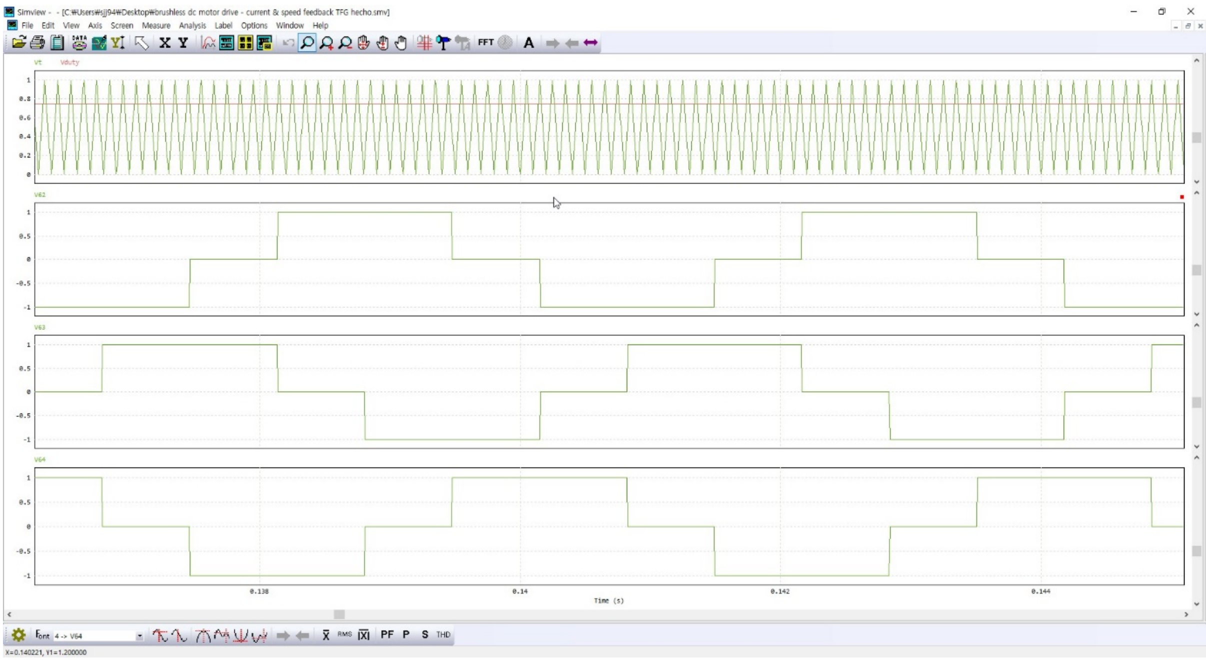


Figure 59. Vt, Vduty, V62, V63, V64 value graphs (obtained from PSIM)

By examining the graphs, I can observe that the $\mathbf{V_t}$ graph forms a triangular wave oscillating between 0 and 1. The $\mathbf{V_{duty}}$ value displays the calculated 0.75 for this design.

Additionally, the graphs for $\mathbf{V_{62}}$, $\mathbf{V_{63}}$, $\mathbf{V_{64}}$ show values oscillating between 0 and 1, each with a phase difference. This phase difference aligns with the back EMF for each phase of the BLDC motor and the signals from the Hall sensors positioned at 120° intervals. As shown in figure 56, the back EMF for each phase alternates every 120°, causing current to flow through each phase. The three-phase switches, activated by the Hall sensor positions, send current to the connected motor coils, thereby energizing them and causing the rotor to rotate. This results in the observed phase differences in the graphs.

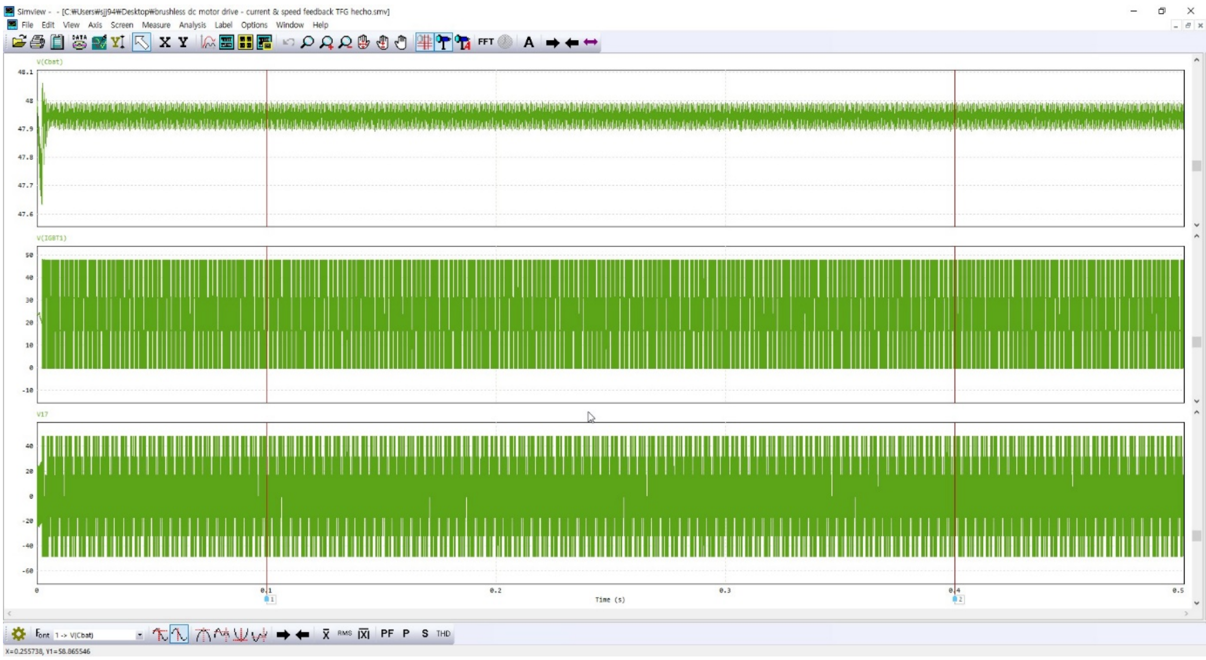


Figure 60. V(Cbat), V(IGBT1), V17 value graphs (obtained from PSIM)

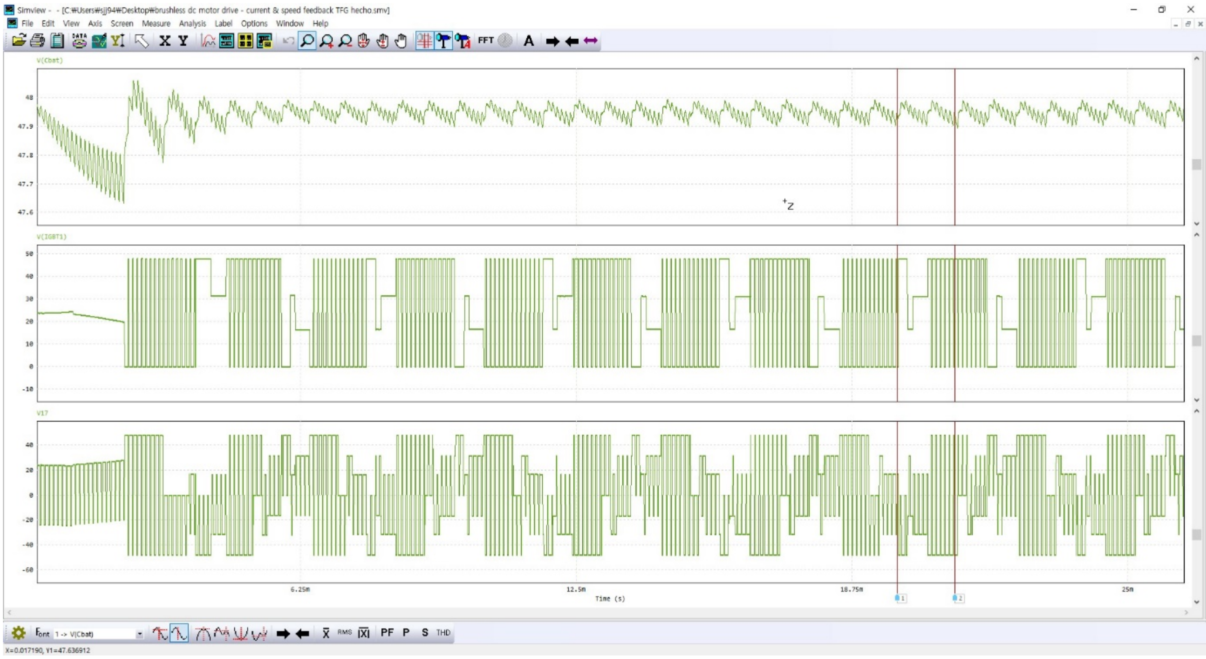


Figure 61. V(Cbat), V(IGBT1), V17 value graphs (obtained from PSIM)

From the graphs, I can confirm that the battery outputs 48V and the motor operates at 36V. The changes in the graph values are due to the periodic switching in the transistors, which adjust the supplied voltage to achieve the desired voltage variation. Examining the RMS values in the table below, I can see that they are close to the nominal values of 48V and 36V.

Measure

	X1	X2	Δ	RMS
Time	2.20193e-02	1.79570e-02	-4.06230e-03	
V(Cbat)	4.79612e+01	4.79813e+01	2.00910e-02	4.79472e+01
V(IGBT1)	-6.50950e-06	-1.21650e-05	-5.65548e-06	3.20091e+01
V17	4.79611e+01	-7.58940e-05	-4.79612e+01	3.59509e+01

Figure 62. V(Cbat), V(IGBT1), V17 Table (obtained from PSIM)

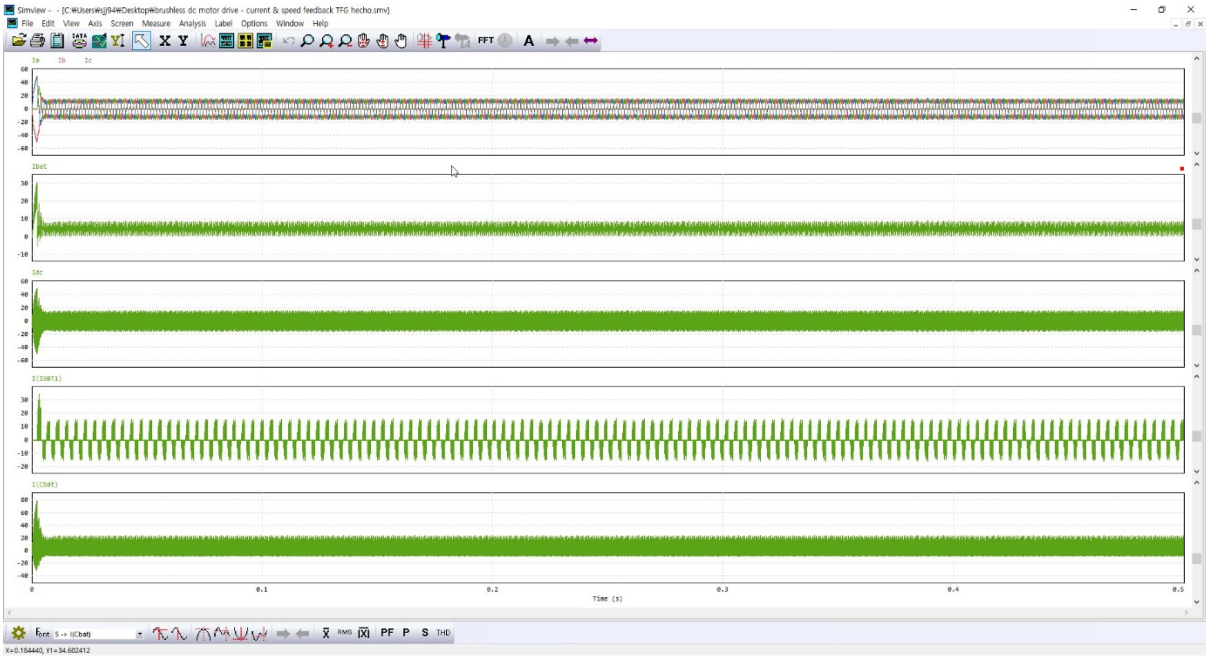


Figure 63. Ia, Ib, Ic, Ibat, Idc, I(IGBT1), I(Cbat) Value Graghs (obtained from PSIM)

The graph shows the current values from each sensor's position. To get a clearer view, let's zoom in:

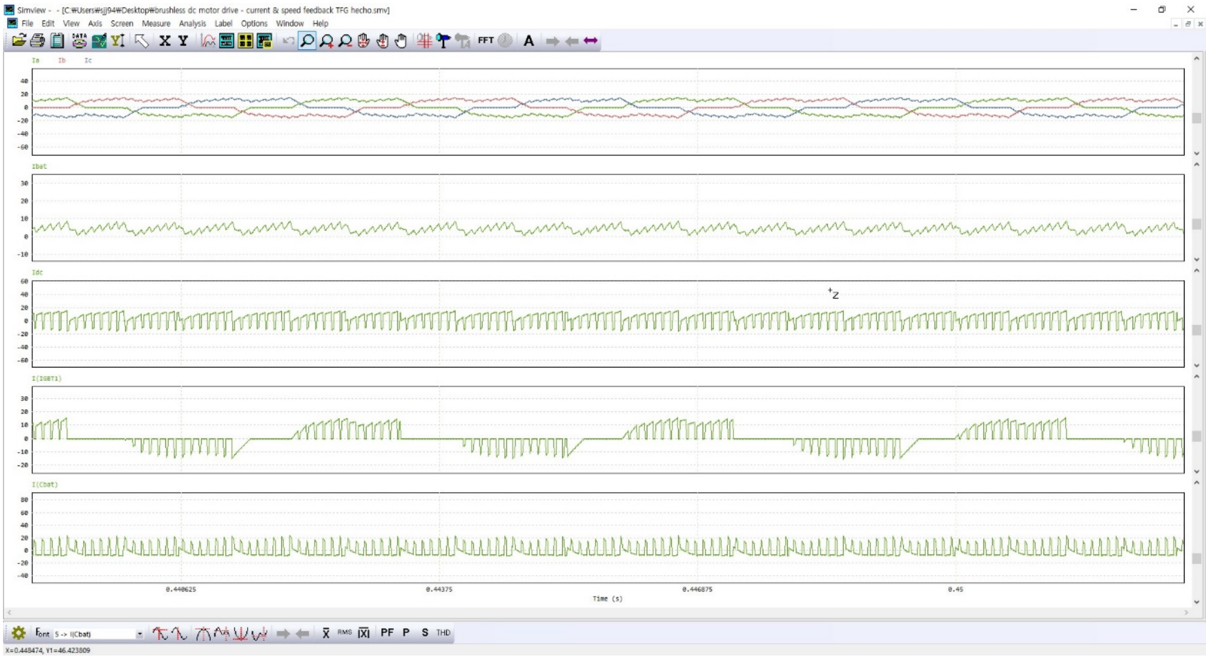


Figure 64. Ia, Ib, Ic, Ibat, Idc, I(IGBT1), I(Cbat) Value Graghs (obtained from PSIM)

As previously mentioned, due to the nature of the BLDC motor, the current also exhibits phase differences, resulting in the plotted graphs. These graphs help us determine the current values for each component.

To select the appropriate MOSFET and capacitor in subsequent chapters, I need the **I(IGBT1)** value. Thus, I derive the RMS values for each graph as follows:

Measure

	X1	X2	Δ	RMS
Time	3.81462e-01	3.85482e-01	4.01923e-03	
Ia	9.58008e-02	5.31300e-01	4.35499e-01	9.85492e+00
Ib	-1.34490e+01	-1.31035e+01	3.45483e-01	9.79578e+00
Ic	1.33532e+01	1.25722e+01	-7.80982e-01	9.46639e+00
Ibat	5.25506e+00	4.93968e+00	-3.15382e-01	4.74437e+00
Idc	-1.38054e+01	8.96640e+00	2.27718e+01	1.10192e+01
I(IGBT1)	9.58038e-02	5.31305e-01	4.35501e-01	6.91282e+00
I(Cbat)	1.16338e+01	4.22546e+00	-7.40836e+00	9.93148e+00

Figure 65. Ia, Ib, Ic, Ibat, Idc, I(IGBT1), I(Cbat) Table (obtained from PSIM)

These data values will be used to select the necessary semiconductors in the following chapters.

Finally, using these values, I will select the appropriate components from online markets to finalize the design.

6. MOSFET and Capacitor selection

In this chapter, I will proceed with selecting capacitors and transistors from the market that fit into my previously designed circuit. Each MOSFET and capacitor has specific specifications, and it is crucial to select components that meet or exceed these specifications. This is because the machine must operate reliably in various environments, and thus, always consider the margin of error. For instance, the datasheet for I selected motor specifies tolerances such as ±10% for R, L, and torque values. This margin accounts for manufacturing variations, implying that selecting components with slightly higher specifications than the calculated values is prudent.

6.1. MOSFET Selection

Before selecting MOSFETs, I'll briefly explain the reasons for their choice, along with their advantages and disadvantages. A MOSFET (Metal-Oxide-Semiconductor Field-Effect Transistor) is a semiconductor device that controls the flow of current by creating or blocking the path for electrons based on the applied voltage.

- **Understanding MOS Structure:**

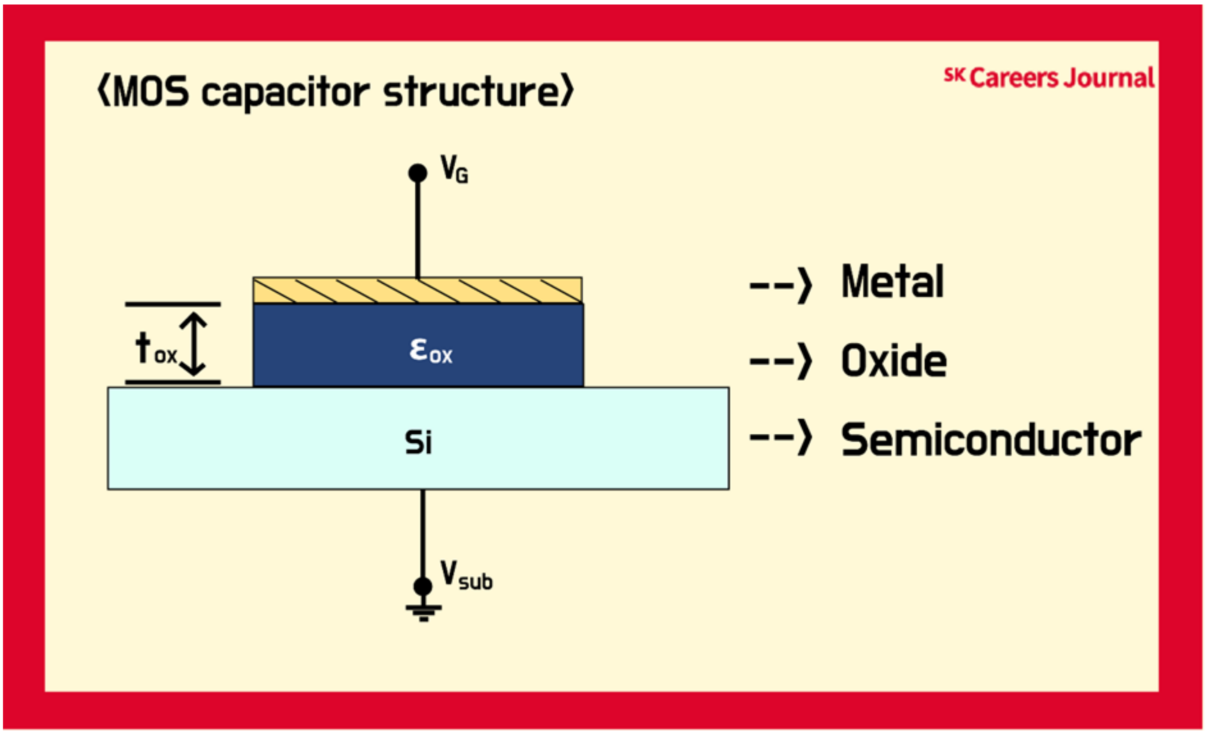


Figure 66. MOS Description (obtained from skcareersjournal.com)

To grasp the concept of a MOSFET, it's essential to understand the MOS structure first. MOS stands for Metal-Oxide-Semiconductor, indicating a layered structure where a non-conductive oxide is sandwiched between a metal and a semiconductor. If the semiconductor substrate is N-type, it is called NMOS, and if it is P-type, it is called PMOS. The oxide is typically SiO2, which is an insulator. This structure is similar to a capacitor, thus sometimes referred to as a MOS capacitor. Key parameters determining the properties of a MOS structure are the thickness of the oxide layer and its dielectric constant.

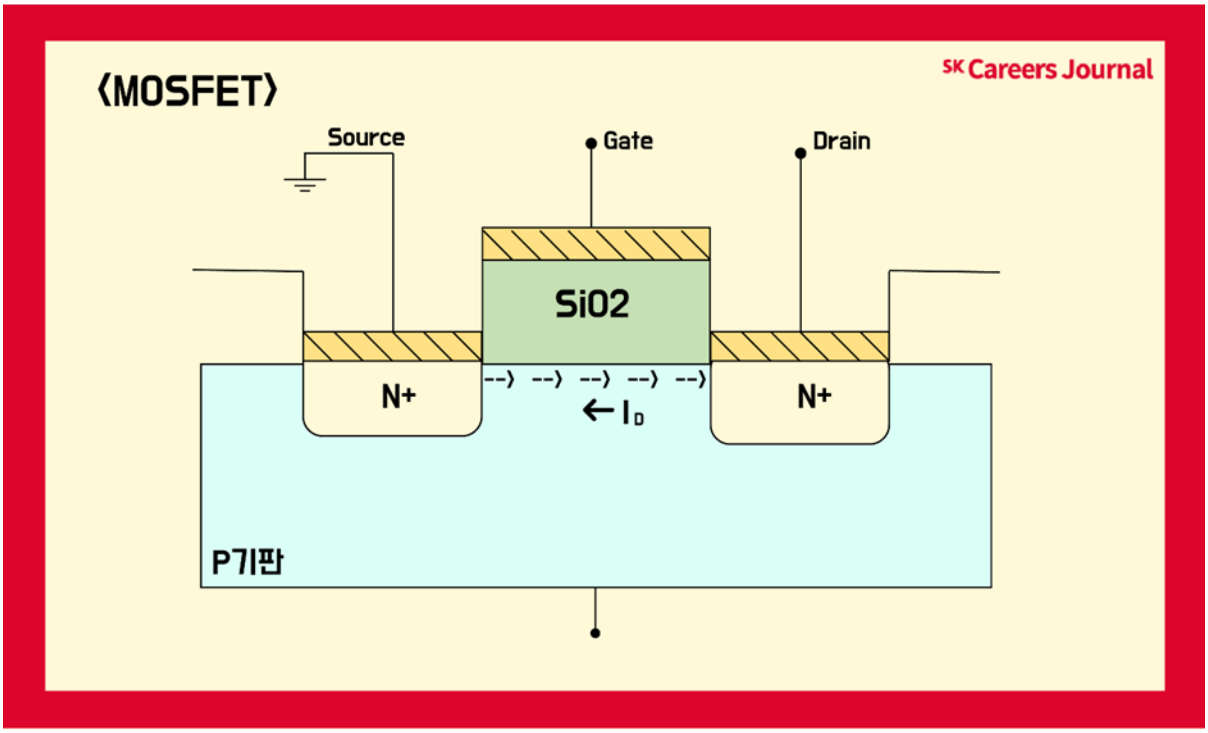


Figure 67. MOSFET Description (obtained from skcareersjournal.com)

MOSFET combines this MOS structure with a Field-Effect Transistor (FET). The basic operation involves controlling the current flow between the source and drain terminals through the voltage applied to the gate terminal.

Other Types of Transistors:

① IGBT (Insulated Gate Bipolar Transistor): Combines the characteristics of bipolar transistors with the gate control of MOSFETs, making it suitable for high voltage applications.

② BJT (Bipolar Junction Transistor): Consists of P-type and N-type semiconductor materials and controls output current based on input current.

Despite the availability of other transistors, I chose MOSFETs for this design due to their advantages:

① Suitability for High-Frequency and Low-Voltage Applications: MOSFETs are ideal for these environments, which aligns well with my design.

② Low Power Consumption: MOSFETs have low power requirements.

③ High Switching Speed: The fast switching capability is crucial for my circuit.

When selecting a MOSFET, consider the following specifications:

Voltage Rating (Vds): Ensure it exceeds the operating voltage by a significant margin.

Current Rating (Id): Should be higher than the maximum current expected in the circuit.

Frequency value: It must have a frequency value that can accept the data value of the experiment.

Thermal Performance: Ensure the MOSFET can dissipate heat effectively.

The data values I have are as follows:

Parameters	Value
Vds	48 V
Id	6.91 A
F	10kHz

Figure 68. Data values to use (obtained from self-made PSIM)

Therefore, since they are the Vds and Id values that I have first, I selected them based on this data.

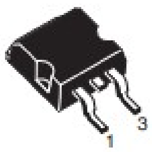
STB40NF10L

N-channel 100V - 0.028Ω - 40A - D^2PAK
Low gate charge STripFET™ II Power MOSFET

General features

Type	V_{DSS}	$R_{DS(on)}$	I_D
STB40NF10L	100V	<0.033Ω	40A

- Exceptional dv/dt capability
- 100% avalanche tested
- Application oriented characterization



D^2PAK

Description

This Power MOSFET series realized with STMicroelectronics unique STripFET process has specifically been designed to minimize input capacitance and gate charge. It is therefore suitable as primary switch in advanced high-efficiency isolated DC-DC converters for Telecom and Computer application. It is also intended for any application with low gate charge drive requirements.

Applications

- Switching application

Internal schematic diagram

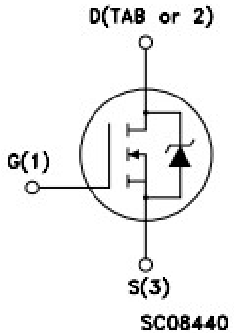


Figure 69. Datasheet information for selected MOSFET (obtained from st.com)

Table 3. On/off states

Symbol	Parameter	Test conditions	Min.	Typ.	Max.	Unit
$V_{(BR)DSS}$	Drain-source breakdown voltage	I_D = 250µA, V_{GS} =0	100			V
I_{DSS}	Zero gate voltage drain current (V_{GS} = 0)	V_{DS} = Max rating V_{DS} = Max rating, T_C = 125°C			1 10	µA µA
I_{GSS}	Gate-body leakage current (V_{DS} = 0)	V_{GS} = ± 20V			±100	nA
$V_{GS(th)}$	Gate threshold voltage	V_{DS} = V_{GS}, I_D = 250µA	1	1.7	2.5	V
$R_{DS(on)}$	Static drain-source on resistance	V_{GS} = 10V, I_D = 20A V_{GS} = 5V, I_D = 20A		0.028 0.030	0.033 0.036	Ω Ω

Table 4. Dynamic

Symbol	Parameter	Test conditions	Min.	Typ.	Max.	Unit
g_{fs} (1)	Forward transconductance	V_{DS} = 15V, I_D = 20A		25		S
C_{iss} C_{oss} C_{rss}	Input capacitance Output capacitance Reverse transfer capacitance	V_{DS} = 25V, f = 1MHz, V_{GS} = 0		2300 290 125		pF pF pF
$t_{d(on)}$ t_r $t_{d(off)}$ t_f	Turn-on delay time Rise time Turn-off delay time Fall time	V_{DD} = 50V, I_D = 20A R_G = 4.7Ω V_{GS} = 4.5V (see *Figure 13*)		25 82 64 24		ns ns ns ns
Q_g Q_{gs} Q_{gd}	Total gate charge Gate-source charge Gate-drain charge	V_{DD} = 80V, I_D = 40A, V_{GS} = 4.5V, R_G = 4.7Ω (see *Figure 14*)		46 12 22	64	nC nC nC

Figure 70. Datasheet information for selected MOSFET (obtained from st.com)

I selected the MOSFET from STMicroelectronics, given the vast range of manufacturers and specifications available. Selecting an appropriate MOSFET requires careful consideration of the following factors:

- **Voltage Peaks and V_{DSS} Selection:**

The semiconductor will be subjected to consistent high-frequency switching (1MHz), which can cause voltage peaks. To prevent damage from these peaks, the MOSFET must have a V_{DSS} rating significantly higher than the operating voltage of 48V. I have chosen a MOSFET with a V_{DSS} rating of 100V to ensure reliability.

- **Current Rating (I_D) Considerations:**

The current value I have is an average, as shown in Figure 65. However, the actual current can increase with temperature. To ensure the MOSFET operates reliably under various conditions, it is prudent to select a MOSFET with a current rating (I_D) that is 2-3 times higher than the average current. Therefore, I selected a MOSFET with an I_D rating of 25A at 100ºC.

- **Thermal Resistance, Junction-to-Case (RθJC):** 1°C/W

MOSFET must be checked to ensure that it can operate normally in various environmental temperature situations and that it can dissipate heat efficiently.

6.2. Capacitors

Capacitors are components that temporarily store electrical energy within an electronic circuit, consisting of two facing electrode plates. There are several types of capacitors, such as electrolytic capacitors, ceramic capacitors, and film capacitors. For this design, I have chosen to use electrolytic capacitors.

Reasons for Choosing Electrolytic Capacitors:

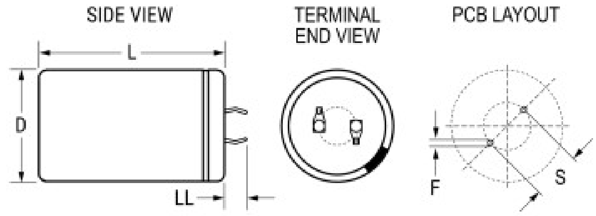
- **Ceramic Capacitors:** These are generally not suitable for circuits with high voltage levels due to their relatively low capacitance and rated voltage characteristics. Additionally, they have poor temperature characteristics.
- **Film Capacitors:** Although they are suitable for high voltage circuits, they are larger in size and more expensive compared to electrolytic capacitors, making them less ideal for this design.

Capacitor Selection Process:

- **Voltage Rating:** Must exceed the operating voltage.
- **Capacitance Value:** As calculated or specified in the design.
- **Equivalent Series Resistance (ESR):** Preferably low for better performance

The site used in this selection is called **Farnell.**

Figure 71. Capacitors selected from Farnell.com (obtained from farnell.com)



Click here for the 3D model.

Dimensions	
D	40mm +1mm
L	60mm +/-2mm
S	10mm +/-0.1mm
LL	4mm +/-1mm
F	2mm +/-0.1mm

Packaging Specifications	
Sleeving	Yes
Packaging	Bulk, Bag

General Information	
Series	ALC80
Dielectric	Aluminum Electrolytic
Description	Snap-In, Aluminum Electrolytic
RoHS	Yes
Lead	2 Pin Short
AEC-Q200	No
Halogen Free	Yes
Typical Component Weight	125 g
Notes	Dimensions D And L Include Sleeving.
Shelf Life	156 Weeks

Specifications	
Capacitance	8,200 uF
Capacitance Tolerance	20%
Voltage DC	100 VDC, 115 VDC (Surge)
Temperature Range	-40/+105°C
Rated Temperature	105°C
Life	9000 Hrs (Rated Voltage And Ripple Current At 105C), 14000 Hrs (Rated Voltage At 105C)
ESR	42.8 mOhms (100Hz 20C), 36.36 mOhms (10kHz 20C)
Ripple Current	8.654 Amps (100Hz 105C), 10.59 Amps (10kHz 105C)
Leakage Current	2460 uA (5min 20°C)

Figure 72. Selected Capacitor Datasheet (obtained from farnell.com)

Selected Capacitor:

I have chosen a specific capacitor from Farnell that meets the design requirements. However, since the calculated theoretical capacitance value differs from the available capacitors, I will determine the number of capacitors needed in parallel to achieve the desired voltage through the following calculations:

Calculation for Parallel Capacitor Configuration

To maintain the required voltage, I can calculate the necessary number of capacitors to be connected in parallel, considering the total capacitance needed. Here is the step-by-step process:

① Determine Total Required Capacitance: Calculate the total capacitance value required by the design.

② Capacitance of Selected Capacitor: Note the capacitance value of the selected capacitor from Farnell.

③ Calculate Number of Capacitors Needed: Use the formula for capacitors in parallel.

$$C_{theory} = \frac{1}{2*\pi*f*Z_{cESR}} = \frac{1}{2*\pi*10000*1.199*10^{-3}} = 13.27mF$$

$$n_{capacitor} = \frac{C_{theory}}{C_{selection}} = \frac{13.27}{8.2} = 1.618 = 2 \ capacitors$$

④ It is important to consider that the normalized model of capacitors typically includes a resistance known as equivalent series resistance (ESR). This represents the heating of the capacitor due to thermal dissipation. The ESR value is provided by the manufacturer in the datasheet as 42.8mΩ. Therefore, reflecting a bus with two capacitors connected in parallel, I will calculate the capacitor value and the ESR value to be entered into PSIM as follows:

$$\frac{ESR}{n_{capacitor}} = \frac{42.8}{2} = 21.4m\Omega$$

$$C_{real} = n_{capacitor} * C_{selection} = 2*8.2 = 16.4mF$$

Finally, if put the values obtained in this way back into the PSIM circuit diagram and run the simulation:

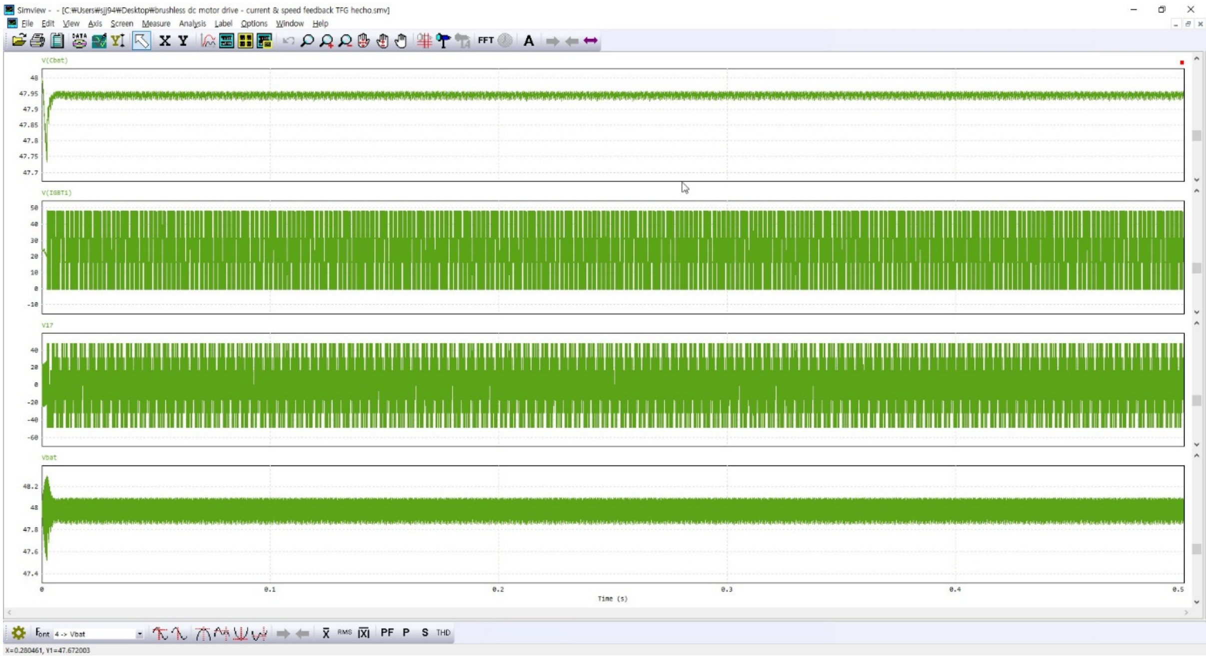


Figure 73.V(Cbat), V(IGBT1), V17, Vbat value graphs (obtained from PSIM)

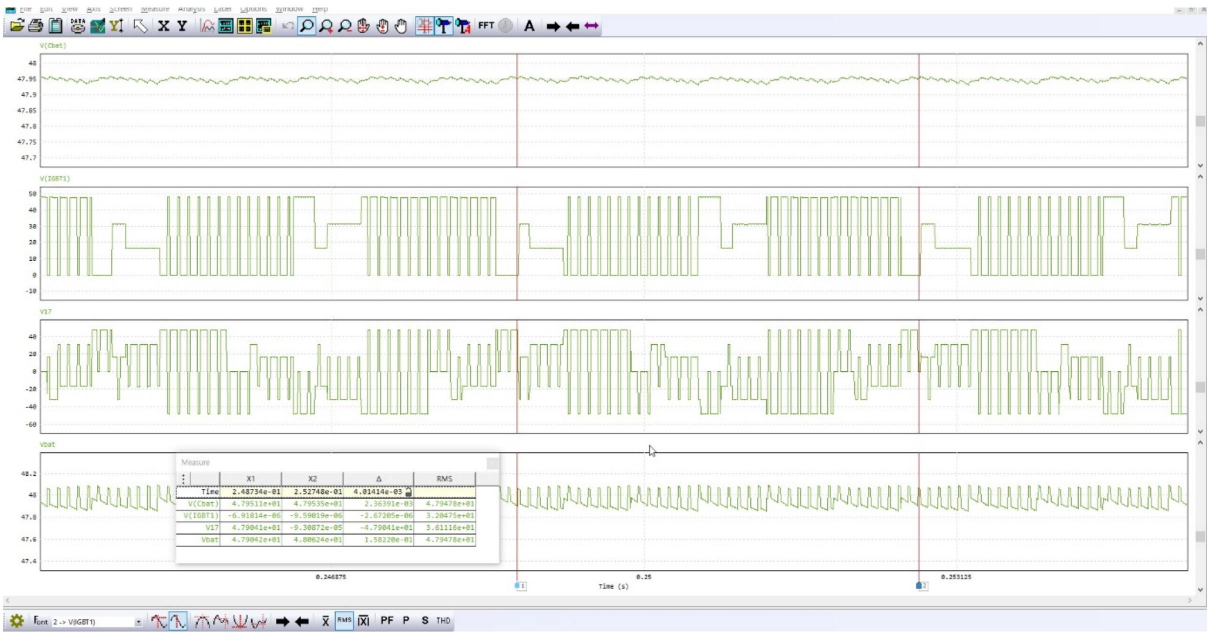


Figure 74. V(Cbat), V(IGBT1), V17 value graphs (obtained from PSIM)

Measure

	X1	X2	Δ	RMS
Time	2.48734e-01	2.52748e-01	4.01414e-03	
V(Cbat)	4.79511e+01	4.79535e+01	2.36391e-03	4.79478e+01
V(IGBT1)	-6.91814e-06	-9.59019e-06	-2.67205e-06	3.20475e+01
V17	4.79041e+01	-9.30872e-05	-4.79041e+01	3.61116e+01
Vbat	4.79042e+01	4.80624e+01	1.58220e-01	4.79478e+01

Figure 75. V(Cbat), V(IGBT1), V17, Vbat Table (obtained from PSIM)

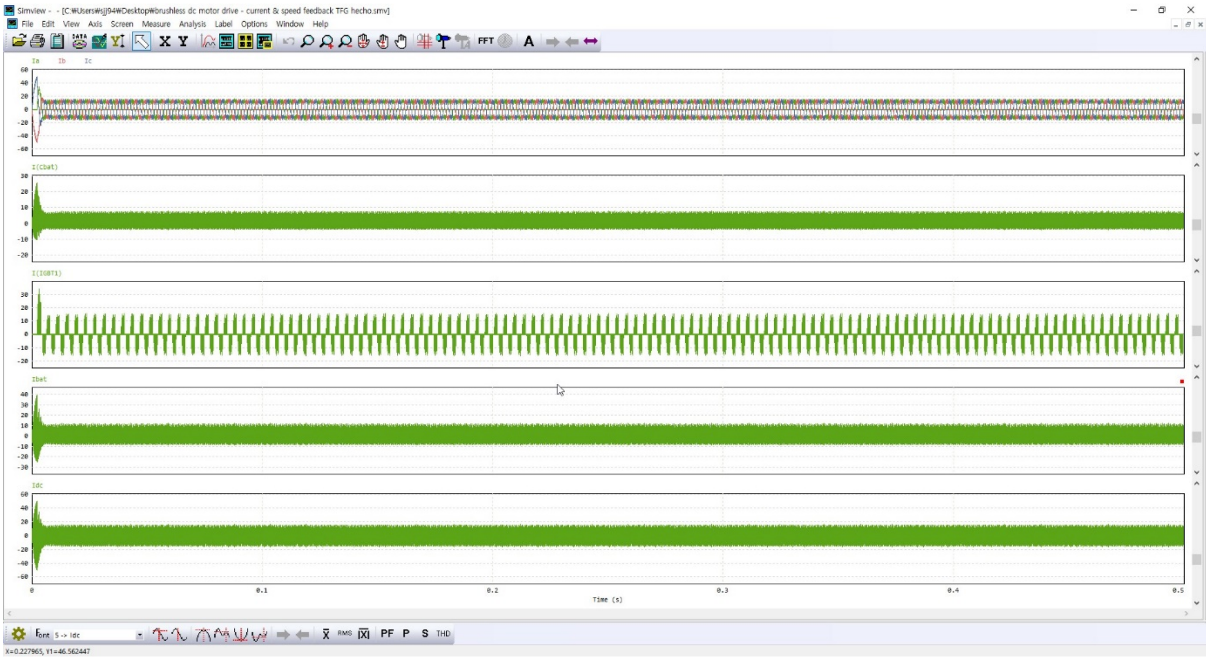


Figure 76. Ia, Ib, Ic, Ibat, Idc, I(IGBT1), I(Cbat) values graph (obtained from PSIM)

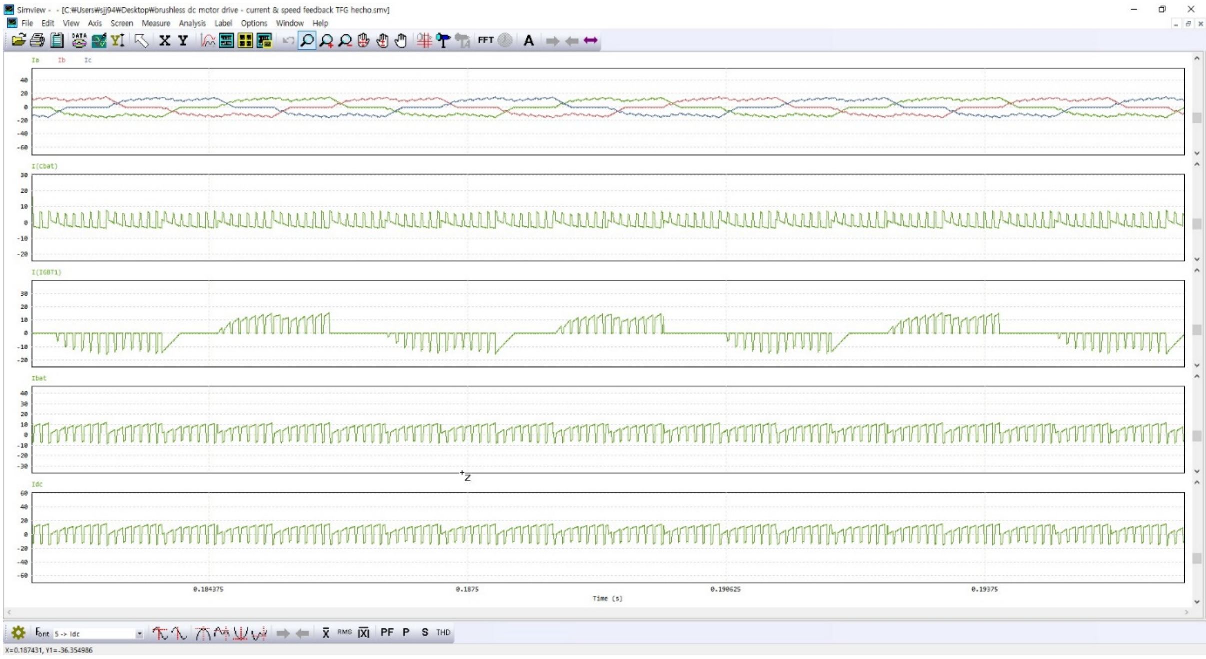


Figure 77.Ia, Ib, Ic, Ibat, Idc, I(IGBT1), I(Cbat) values graph (obtained from PSIM)

Measure

	X1	X2	Δ	RMS
Time	1.88552e-01	1.92567e-01	4.01443e-03	
Ia	1.24418e-01	-1.45306e-06	-1.24420e-01	9.53743e+00
Ib	-1.35716e+01	-1.27394e+01	8.32173e-01	9.66319e+00
Ic	1.34472e+01	1.27394e+01	-7.07753e-01	9.50220e+00
I(Cbat)	6.65886e+00	-2.90301e+00	-9.56188e+00	3.58767e+00
I(IGBT1)	0.00000e+00	0.00000e+00	0.00000e+00	6.68254e+00
Ibat	-7.25281e+00	-1.05418e+00	6.19863e+00	7.73547e+00
Idc	-1.41990e+01	-4.25496e+00	9.94400e+00	1.08879e+01

Figure 78.Ia, Ib, Ic, Ibat, Idc, I(IGBT1), I(Cbat) Table (obtained from PSIM)

In this way, I have completed the selection of the appropriate transistor and capacitor for this design. The market offers a wide variety of transistors and capacitors, each with its unique resistance values and capacitance (C) values, among other characteristics. Therefore, if we experiment with different components, the graph values may vary slightly.

7. Conclusion

This completes the design of the motor and battery used in the electric scooter, as well as the components for voltage conversion. The market for electric scooters is expanding, and due to eco-friendly policies, it is becoming difficult to find a substitute that is as convenient for short-distance travel as electric scooters. Consequently, numerous electric scooters are being developed and produced, and various manufacturing and sharing companies are emerging.

Of course, this new mode of transportation is somewhat different from the conventional ones we are accustomed to, leading many to raise concerns about the risks and safety issues of electric scooters. However, this is because clear safety laws and guidelines for the use of electric scooters have not yet been fully established. Therefore, over time, as clear standards for electric scooter operation are developed and they become more integrated into our daily lives, there is no doubt that they can replace existing modes of transportation.

With this future vision in mind, I approached this design, prioritizing efficiency, practicality, convenience, and portability. There is indeed a wide variety of motors and batteries available in the market. As previously mentioned, an electric scooter can be designed based on a DC motor, and it can also be made using a lithium polymer battery. If a lithium polymer battery is used, the size of the scooter can be further reduced, and it can be customized into various shapes.

However, we must consider the pros and cons, cost, and market availability of each component. Therefore, in this design, I used the commonly used BLDC motor and lithium-ion battery. While this paper focuses on one method, various designs using different methods and components are possible, requiring extensive research and experimentation. This paper prioritized efficiency and convenience, leading to the results presented.

Bibliographic references

1. a man who makes money. (2020, December 24). Summary of secondary battery types and technologies. Retrieved July 18, 2024, from a man who makes money website: https://rollingcoin.tistory.com/32
2. Alemanno, A., Ronchi, F., Rossi, C., Pagliuca, J., Fioravanti, M., & Florian, C. (2023). Design of a 350 kW DC/DC Converter in 1200-V SiC Module Technology for Automotive Component Testing. *Energies*, *16*(5), 2341. https://doi.org/10.3390/en16052341
3. 알고보면재밌어. (2023, November 18). #19. 커패시터(Capacitor)의 종류. Retrieved July 21, 2024, from 회로 설계 : 기초부터 실무까지! website: https://analog-circuit-design.tistory.com/entry/19-%EC%BB%A4%ED%8C%A8%EC%8B%9C%ED%84%B0Capacitor%EC%9D%98-%EC%A2%85%EB%A5%98
4. AliExpress. (2024). Chamrider 36V Battery 10AH ebike battery 25A BMS 48V battery 30A 18650 Lithium Battery Pack For Electric bike Electric Scooter - AliExpress 18. Retrieved July 19, 2024, from aliexpress. website: https://es.aliexpress.com/item/1005006824684018.html?channel=facebook&fbclid=IwZXh0bgNhZW0CMTEAAR085N6CKWZ27kQ90_xB6i3VxaA__BjCj7XnSfvQDIwbzya7rKiQsZ00mPw_aem_ZSfZCab3wgazHfqkdeRY9g
5. Badar, J., Akhter, F., Munir, H. M., Bukhari, S. S. H., & Ro, J. (2021, August 25). Efficient Real-Time Controller Design Test Bench for Power Converter Application.

Retrieved July 21, 2024, from IEEE Xplore website: https://ieeexplore.ieee.org/document/9522104

6. 박승민. (2022, August 10). 반도체의 기초, MOSFET 의 모든 것. Retrieved July 21, 2024, from SK 채용 공식 블로그 website: https://www.skcareersjournal.com/2689
7. BTong. (2024, January 19). BTong : 네이버 블로그. Retrieved July 21, 2024, from blog.naver.com website: https://blog.naver.com/jush0117/223327288575
8. cutoffon00. (2024, July 18). brushless motor. Retrieved July 18, 2024, from 나무위키 website: https://namu.wiki/w/%EB%B8%8C%EB%9F%AC%EC%8B%9C%EB%A6%AC%EC%8A%A4%20%EB%AA%A8%ED%84%B0
9. d0mo0vnshp. (2024). 8V 20ah lifepo4 battery 32650 lifepo4 cells With 50A BMS for 2000w scooter electric vehicles c. Retrieved July 19, 2024, from Shopee.ph website: https://shopee.ph/%E2%99%A848V-20ah-lifepo4-battery-32650-lifepo4-cells-With-50A-BMS-for-2000w-scooter-electric-vehicles-c-%E2%9D%88%E2%93%9B-i.1267150652.26804653771?sp_atk=ca7e9360-0ae2-4ee3-8011-c4d444b31be2&xptdk=ca7e9360-0ae2-4ee3-8011-c4d444b31be2
10. Daniel, Z. (2024). 브러시리스 DC 모터 대 브러시 DC 모터. Retrieved July 21, 2024, from Stepperonline website: https://www.omc-stepperonline.com/ko/support/brushless-dc-motor-vs-brushed-dc-motor-ko
11. Electronics Maddy. (2020, September 12). Design and Simulation of Buck Boost Converter in PSIM | POWERSIM. Retrieved July 21, 2024, from YouTube website: https://www.youtube.com/watch?app=desktop&v=-PqUuUhMtMc

12. García Ortega, A. (2022). Diseño de los convertidores electrónicos de la cadena de tracción de un kart eléctrico de 20 kW con dos motores BLDC independientes en el eje trasero. *Riunet.upv.es*, 1–103. Retrieved from https://riunet.upv.es/handle/10251/187151

13. 후인. (2020, December 23). 콘덴서(캐패시터) 정의, 구조,기능과 역할 정리. Retrieved July 21, 2024, from 네이버 블로그 | 후인의 직장인으로 살아가는 이야기 website: https://m.blog.naver.com/huinhuin/222182363568

14. Kang, M. G. (2013). A Comparison of DC-DC Buck Converter Controller. *Journal of the Institute of Electronics and Information Engineers*, *50*(7), 281–285. https://doi.org/10.5573/ieek.2013.50.7.281

15. KEDT. (2023, June 9). Comparison of characteristics of lithium-ion battery and lead-acid battery. Retrieved July 18, 2024, from Comparison of characteristics of lithium-ion battery and lead-acid battery website: https://k-editor.tistory.com/entry/%EB%A6%AC%ED%8A%AC%EC%9D%B4%EC%98%A8-%EB%B0%B0%ED%84%B0%EB%A6%AC-%EB%82%A9%EC%82%B0-%EB%B0%B0%ED%84%B0%EB%A6%AC-%ED%8A%B9%EC%A7%95-%EB%B9%84%EA%B5%90

16. KEMET. (2024). KEMET ALC80D822EH100. In *Farnell*. Retrieved from https://search.kemet.com/component-documentation/download/specsheet/ALC80D822EH100

17. KUNRAY. (2024). KUNRAY 8inch E-Scooter Hub Motor 36V 48V 350W 500W Brushless Motor with LCD Display Scooter Rear Wheel Motor Drum Brake. Retrieved July 19, 2024, from Kunray Electric website:

https://cnkunray.com/products/kunray-8inch-scooter-hub-motor-36v-48v-350w-500w-brushless-motor-with-lcd-display-scooter-rear-wheel-motor-drum-brake?VariantsId=10974

18. lagrange0115. (2020, September 30). Lead acid battery principle (lead acid battery). Retrieved July 18, 2024, from blog.naver.com website: https://blog.naver.com/lagrange0115/222103678020
19. Lee, J. (2016, April 1). 7 basic knowledge of "DC-DC converter" of microcomputer board. Retrieved July 18, 2024, from magazine.hellot.net website: http://magazine.hellot.net/magz/article/articleDetail.do?flag=all&showType=showType1&articleId=ARTI_000000000041286&articleAllListSortType=sort_1&page=1&selectYearMonth=201604&subCtgId
20. Lee, K. (2008). PSIM 을 이용한 BLDC 전동기 제어 시뮬레이션. Retrieved July 21, 2024, from Riss.kr website: https://www.riss.kr/search/detail/DetailView.do?p_mat_type=1a0202e37d52c72d&control_no=a33d3485780e48e5ffe0bdc3ef48d419&keyword=BLDC%20PSIM
21. lovejng. (2014, June 16). 캐패시터(콘덴서)에 대하여 - 종류. Retrieved July 21, 2024, from blog.naver.com website: https://blog.naver.com/lovejng/220031774972
22. nelso. (2024). 48V to 36V 10A 360W DC to DC Converter. Retrieved July 19, 2024, from 48V to 36V 10A 360W DC to DC Converter website: https://www.nelsotech.com/products/power-supply/dc-to-dc.php?model=DLS-4836DC
23. NEVSEMI. (2023, October 24). Difference Between BJT, MOSFET and IGBT: BJT vs MOSFET vs IGBT - Nevsemi Electronics. Retrieved July 21, 2024, from

www.nevsemi.com website: https://www.nevsemi.com/blog/difference-between-bjt-mosfet-and-igbt-bjt-vs-mosfet-vs-igbt

24. Official Store, V. (2024). 48V to 36V DC power converter 40~60V to 36V car modification step-down power module transformer - AliExpress. Retrieved July 19, 2024, from aliexpress. website: https://www.aliexpress.us/item/1005002387963723.html?channel=facebook&fbclid=IwZXh0bgNhZW0CMTEAAR0KXNKzxcxvxbWas2Bl2ibpIKj6tDxplKRn-4UHdBo6XufWoLdO9JUMJcc_aem_tD0hM_tKDwMyQvuI-fFoaw
25. Paynoh. (2020, April 3). MC Magnet Industry (paynoh): Naver Blog. Retrieved July 18, 2024, from blog.naver.com website: https://blog.naver.com/paynoh/221888262974
26. pocket magazine. (2022, October 6). Pros and cons of electric kickboard front and rear wheels. Is there a big difference just because the driving method is different? - Enuri shopping knowledge Enuri TV. Retrieved July 18, 2024, from m.enuri.com website: https://m.enuri.com/knowcom/detail.jsp?kbno=2698354&bbsname=enuritv
27. SANG, Y. (2020). 메카넘 휠과 BLDC 모터를 이용한 전동휠체어의 유연한 제어에 관한 연구 = A Study on Flexible Control of Electric Wheelchair Using Mecanum Wheels and BLDC Motors. Retrieved July 21, 2024, from Riss.kr website: https://www.riss.kr/search/detail/DetailView.do?p_mat_type=be54d9b8bc7cdb09&control_no=3d2398d2bd98138affe0bdc3ef48d419&keyword=BLDC%20%EB%AA%A8%ED%84%B0
28. Sayed, K., El-Zohri, H. H., Ahmed, A., & Khamies, M. (2024). Application of Tilt Integral Derivative for Efficient Speed Control and Operation of BLDC Motor Drive

for Electric Vehicles. *Fractal and Fractional*, *8*(1), 61. https://doi.org/10.3390/fractalfract8010061

29. Scooter City. (2024). 500W Zipper Electric Scooters For Kids. Retrieved July 19, 2024, from www.scootercity.co.uk website: https://www.scootercity.co.uk/500w-zipper-electric-micro-scooter.html
30. Shopee. (2024). New 32650 Lifepo4 Battery Pack 16S 2P 48v 11Ah. Retrieved July 19, 2024, from Shopee.ph website: https://shopee.ph/New-32650-Lifepo4-Battery-Pack-16S-2P-48v-11Ah-i.67945311.8645618419
31. STMicroelectronics. (2024). N-CHANNEL 100V 0.028 OHM 40A D2PAK LOW GATE CHARGE STripFET MOSFET. Retrieved July 21, 2024, from STMicroelectronics website: https://www.st.com/en/power-transistors/stb40nf10l.html#overview
32. Store, L. (2024). LiitoKala 36V 48V 60V 30Ah 21700 Lithium Battery Pack 750w 1000w 1200w Free Charger 42V 54.6V 67.2V - AliExpress. Retrieved July 19, 2024, from aliexpress. website: https://es.aliexpress.com/item/1005003580552621.html?channel=facebook&fbclid=IwZXh0bgNhZW0CMTEAAR0J37XcfgA8xiCokhrH2dB0nW1aE7R-uz7qjBpkYDAbgqjFVxFYZzr-K-8_aem_rUWlYdddPpqrARRc3zX6kw
33. Store, X. (2024). XWST 48v 60v 72v 40-90v to 36V Power Converter Step Down 90 Volts to 36 Volt 20A Buck Voltage Reducer For Golf Carts Vehicles - AliExpress 13. Retrieved July 19, 2024, from aliexpress. website: https://www.aliexpress.us/item/1005003103377128.html?channel=facebook&fbclid=IwZXh0bgNhZW0CMTEAAR2aC7fEcfH7i-L-

cRRpGxnJpaFgiSYI6tLfxRPbe1wsYAtPWJJE39csFa8_aem_3O0IZtAgvQMrthkPFp1fAg

34. Suh, J. (2023, July 3). 전동킥보드 충전기를 살때는 배터리종류, 전압, 단자타입, 극성을 꼭 확인하자! Retrieved July 17, 2024, from 네이버 블로그 | 아이맥스 전동킥보드 website: https://m.blog.naver.com/visionmobility/221743944797
35. Tao, Y. (2009). Design on Cable-reduced BLDC Motor System using DC-link communication. In *RISS* (p. 132). Retrieved from https://dcollection.jnu.ac.kr/public_resource/pdf/000000028076_20240721102831.pdf
36. VOLRAD. (2024). V-Motion High Torque Brushless DC Motor 350W. Retrieved July 19, 2024, from Volrad website: https://volrad.com.tr/en/product/v-motion-high-torque-350w/
37. WEB, T. (2023, September 27). IGBT 의 특징 : MOSFET, 바이폴라 트랜지스터와의 비교 | IGBT 란? | TechWeb. Retrieved July 21, 2024, from 로옴이 제공하는 전원 설계 기술 정보 사이트 「ROHM TechWeb」. 전원 설계에 관한 기초 지식, 기술 정보, 설계 정보 등을 게재하고 있습니다. website: https://techweb.rohm.co.kr/product/power-device/igbt/11651/

Image Reference

1. https://solumpv.com/actualidad/what-is-the-best-selling-electric-scooter/
2. https://phys.org/news/2019-07-electric-scooters-eco-friendly.html
3. https://i.pinimg.com/originals/71/15/86/7115867eb4a81417b9c5ca10d433b58e.jpg
4. https://www.weareellectric.com/mobility/the-electric-scooter-plume-allure-when-design-safety-and-sustainability-meet
5. https://xlt-scooter.com/r-d-and-designing.html
6. https://www.brushless.com/why-bldc-motor-is-used-in-electric-vehicle
7. https://www.ablic.com/en/semicon/applications/bldc-motor/what-bldc-motor/
8. https://www.amazon.de/-/en/24V36V48V-Electric-Brushed-Scooter-Conversion/dp/B074M6RLCH
9. https://www.iqsdirectory.com/articles/electric-motor/dc-motors.html
10. https://www.inomile.com/inomile/new.html?a=10
11. https://www.inomile.com/inomile/new.html?a=10
12. https://www.hellot.net/news/article.html?no=79350
13. https://electronics.howstuffworks.com/everyday-tech/question390.htm
14. https://www.shutterstock.com/es/image-photo/ev-battery-module-automotive-industry-on-2336751263
15. https://www.tycorun.com/blogs/news/what-is-a-lead-acid-battery
16. https://www.enix-power-solutions.com/lifepo4-batteries/
17. https://ul.org/research/electrochemical-safety/getting-started-electrochemical-safety/what-are-lithium-ion
18. https://www.researchgate.net/figure/Schematic-of-a-lithium-polymer-battery-based-on-GPEs_fig2_349716200

19. https://www.mouser.es/new/meanwell/mean-well-dc-dc-converters/

20. https://m.blog.naver.com/techref/222429179311

21. https://m.blog.naver.com/techref/222429179311

22. https://m.blog.naver.com/techref/222429179311

23. https://m.blog.naver.com/techref/222429179311

24. https://m.blog.naver.com/techref/222429179311

25. https://cnkunray.com/products/kunray-8inch-scooter-hub-motor-36v-48v-350w-500w-brushless-motor-with-lcd-display-scooter-rear-wheel-motor-drum-brake?VariantsId=10974

26. https://volrad.com.tr/en/product/v-motion-high-torque-350w/

27. https://cnkunray.com/products/kunray-8inch-scooter-hub-motor-36v-48v-350w-500w-brushless-motor-with-lcd-display-scooter-rear-wheel-motor-drum-brake?VariantsId=10974

28. Table comparing each Motor

29. https://www.scootercity.co.uk/500w-zipper-electric-micro-scooter.html

30. https://es.aliexpress.com/item/1005006824684018.html?spm=a2g0o.productlist.main.5.1ef427b91MTibs&algo_pvid=9b9edec3-6ff2-458e-aa04-27781d8e3eb0&algo_exp_id=9b9edec3-6ff2-458e-aa04-27781d8e3eb0-2&pdp_npi=4%40dis%21EUR%21268.83%21120.97%21%21%212080.75%21936.34%21%402103956b17211397994384950e27bf%2112000038430425927%21sea%21ES%211873791919%21&curPageLogUid=qcTzE6Rqrb8E&utparam-url=scene%3Asearch%7Cquery_from%3A

31. https://es.aliexpress.com/item/1005003580552621.html?spm=a2g0o.productlist.main.13.d6b67d1a5e8mCy&algo_pvid=fc8fdb17-fead-40e3-9a4a-1930e4f7e917&algo_exp_id=fc8fdb17-fead-40e3-9a4a-1930e4f7e917-6&pdp_npi=4%40dis%21EUR%21330.82%21221.65%21%21%21352.01%21235.85%21%402103956b17211399033847439e27a5%2112000026363295249%21sea%21ES%211873791919%21&curPageLogUid=FrXUElAV3gm1&utparam-url=scene%3Asearch%7Cquery_from%3A

32. https://www.aliexpress.us/item/33012011292.html?spm=a2g0o.productlist.main.5.14ac4624

BJEKjb&algo_pvid=364ad66d-647a-46ea-8f8b-3d350819a9d9&algo_exp_id=364ad66d-647a-46ea-8f8b-3d350819a9d9-2&pdp_npi=4%40dis%21EUR%21444.99%21355.99%21%21%21470.69%21376.55%21%402103872a17204878857982166ecd5b%2167046799872%21sea%21ES%211873791919%21&curPageLogUid=5eJEbcG9Nt5Y&utparam-url=scene%3Asearch%7Cquery_from%3A

33. Table comparing each battery

34. https://www.aliexpress.us/item/4001145642321.html?spm=a2g0o.productlist.main.45.28be63beiheOWF&algo_pvid=2d4d6e83-473a-4b66-afc9-e6cc9762482f&algo_exp_id=2d4d6e83-473a-4b66-afc9-e6cc9762482f-22&pdp_npi=4%40dis%21EUR%2112.03%2112.03%21%21%2112.73%2112.73%21%40211b801a17204894608293000e4db7%2110000014888930345%21sea%21ES%211873791919%21&curPageLogUid=ucZvMwksdWOi&utparam-url=scene%3Asearch%7Cquery_from%3A

35. https://www.aliexpress.us/item/1005002387963723.html?spm=a2g0o.productlist.main.1.674c8194nuA5Cm&algo_pvid=dbe49fd7-855f-4353-8d22-e11e326e1d04&algo_exp_id=dbe49fd7-855f-4353-8d22-e11e326e1d04-0&pdp_npi=4%40dis%21EUR%2113.80%2113.80%21%21%21106.82%21106.82%21%40210387dd17211473750146866ee9b0%2112000020469777477%21sea%21ES%211873791919%21&curPageLogUid=3cutirzqPSxC&utparam-url=scene%3Asearch%7Cquery_from%3A

36. https://www.nelsotech.com/products/power-supply/dc-to-dc.php?model=DLS-4836DC

37. Table comparing each converter

38. PSIM program home screen (Screenshot taken from PSIM Program)

39. PSIM program home screen (Screenshot taken from PSIM Program)

40. Samples that appear when click 'Open Examples...' (Screenshot taken from PSIM Program)

41. Select 'brushless dc motor drive - current and speed feedback' file for design. (Screenshot taken from PSIM Program)

42. 'brushless dc motor drive - current and speed feedback' file schematic (Screenshot taken from PSIM Program)

43. Circuit diagram with unnecessary parts removed and modulator added (Screenshot taken from PSIM Program)

44. Added a sensor to measure the resistance value entering the battery (Screenshot taken from PSIM Program)

45. Circuit diagram photo added for motor torque value and measurement (Screenshot taken from PSIM Program)

46. Photo of completed circuit diagram design (Screenshot taken from PSIM Program)

47. https://volrad.com.tr/en/product/v-motion-high-torque-350w/

48. Brushless DC Machine Parameters (Screenshot taken from PSIM Program)

49. Definition and calculation of each parameter (Screenshot taken from PSIM Program)

50. Photo of completed BLDC Parameters (Screenshot taken from PSIM Program)

51. https://es.aliexpress.com/item/1005006824684018.html?spm=a2g0o.productlist.main.5.1ef427b91MTibs&algo_pvid=9b9edec3-6ff2-458e-aa04-27781d8e3eb0&algo_exp_id=9b9edec3-6ff2-458e-aa04-27781d8e3eb0-2&pdp_npi=4%40dis%21EUR%21268.83%21120.97%21%21%212080.75%21936.34%21%402103956b17211397994384950e27bf%2112000038430425927%21sea%21ES%211873791919%21&curPageLogUid=qcTzE6Rqrb8E&utparam-url=scene%3Asearch%7Cquery_from%3A

52. https://es.aliexpress.com/item/1005006824684018.html?spm=a2g0o.productlist.main.5.1ef427b91MTibs&algo_pvid=9b9edec3-6ff2-458e-aa04-27781d8e3eb0&algo_exp_id=9b9edec3-6ff2-458e-aa04-27781d8e3eb0-2&pdp_npi=4%40dis%21EUR%21268.83%21120.97%21%21%212080.75%21936.34%21%402103956b17211397994384950e27bf%2112000038430425927%21sea%21ES%211873791919%21&curPageLogUid=qcTzE6Rqrb8E&utparam-url=scene%3Asearch%7Cquery_from%3A

53. Batteries Parameters (Screenshot taken from PSIM Program)

54. Resistance value of the battery (Screenshot taken from PSIM Program)

55. Resistance value of the condenser (Screenshot taken from PSIM Program)

56. Capacitor value (Screenshot taken from PSIM Program)

57. PWM digital controller parameters (Screenshot taken from PSIM Program)

58. PSIM Duty value (Screenshot taken from PSIM Program)

59. Torque Value (Screenshot taken from PSIM Program)

60. Run PSIM Simulation. (Screenshot taken from PSIM Program)

61. Selection Parameters. (Screenshot taken from PSIM Program)

62. Vt, Vduty, V62, V63, V64 value graphs (Screenshot taken from PSIM Program)

63. V(Cbat), V(IGBT1), V17 value graphs (Screenshot taken from PSIM Program)

64. V(Cbat), V(IGBT1), V17 value graphs (Screenshot taken from PSIM Program)

65. V(Cbat), V(IGBT1), V17 Table (Screenshot taken from PSIM Program)

66. Ia, Ib, Ic, Ibat, Idc, I(IGBT1), I(Cbat) Value Graghs (Screenshot taken from PSIM Program)

67. Ia, Ib, Ic, Ibat, Idc, I(IGBT1), I(Cbat) Value Graghs (Screenshot taken from PSIM Program)

68. Ia, Ib, Ic, Ibat, Idc, I(IGBT1), I(Cbat) Table (Screenshot taken from PSIM Program)

69. https://www.skcareersjournal.com/2689

70. https://www.skcareersjournal.com/2689

71. Data values to use

72. https://www.st.com/en/power-transistors/stb40nf10l.html

73. https://www.st.com/en/power-transistors/stb40nf10l.html

74. https://es.farnell.com/kemet/alc80d822eh100/conden-8200uf-100v-alu-elec-qc/dp/2951100

75. https://es.farnell.com/kemet/alc80d822eh100/conden-8200uf-100v-alu-elec-qc/dp/2951100

76. V(Cbat), V(IGBT1), V17, Vbat value graphs (Screenshot taken from PSIM Program)

77. V(Cbat), V(IGBT1), V17, Vbat value graphs (Screenshot taken from PSIM Program)

78. V(Cbat), V(IGBT1), V17, Vbat Table (Screenshot taken from PSIM Program)

79. Ia, Ib, Ic, Ibat, Idc, I(IGBT1), I(Cbat) values graph (Screenshot taken from PSIM Program)

80. Ia, Ib, Ic, Ibat, Idc, I(IGBT1), I(Cbat) values graph (Screenshot taken from PSIM Program)

81. Ia, Ib, Ic, Ibat, Idc, I(IGBT1), I(Cbat) Table (Screenshot taken from PSIM Program)

8. Budget

In this chapter, we will estimate the budget for the current design. In any engineering project, expenses occur in various areas, and engineers must prepare for these by estimating the budget for the product they have designed to avoid excessive spending. I will calculate the total budget by considering the software and hardware used, components involved, and labor costs.

8.1. Software

For this design, I used Word, PowerPoint, and Adobe PDF software for writing the thesis, and PSIM 2024 for the design.

Software	Price (€/year)	Use time(Year)	Spending (€)
Microsoft Office 365®	83.88	0.5	41.94
Adobe PDF	187.67	0.5	93.84
PSIM 2024	2,753.40	0.3	1,376.70
Total	-	-	**1512.48**

8.2. Hardware

I used my laptop to write the thesis, and the estimated cost is:

Hardware	Price (€)	Use time(year)	Total Price (€)
Asus Vivobook Pro 15	540.35	0.5	270.18
SteelSeries Rival 3 Wireless	34.99	0.5	17.5
Total	-	-	**287.68**

8.3. Components

The components used in this design include a BLDC Motor, Battery, MOSFET, and Capacitor.

Components	Unit	Price (€)	Total Price (€)
V-MOTION HIGH TORQUE BLDC MOTOR 350W	1	82.92	82.92
Chamrider-batería de litio para bicicleta eléctrica, paquete de 36V, 10AH, 25A, BMS, 48V, 30A, 18650	1	174.83	174.83
MOSFET (STB40NF10LT4)	1	2.4	2.4

Capacitor (KEMET ALC80D822EH100)	2	8.89	17.78
Total	-	-	**277.93**

8.4. Human resources

Human resources refer to the personnel required for the design. Each engineer's salary varies based on their experience and skills. For this design, I used the average starting salary for an engineer in Spain, which is 25,000 euros annually. This translates to earning 2,000 euros per month, and assuming a monthly working time of 165 hours, the hourly wage is 12.12 euros.

Work	Time (hour)	Price (€)
Specification Analysis	50	606.06
Design and calculations	40	484.8
Circuit diagram production	60	727.2
Total	-	**1818.06**

8.5. Total Project Cost

The total project cost is the sum of all expenses calculated above, excluding any exceptional costs.

Description	Price (€)
Software	1512.48
Hardware	287.68
Components	277.93
Human resources	1818.06
Total	**3896.15**

9. Specification Document

9.1. Objective

This specification document aims to establish the technical conditions and guarantees for the power converter designed in this thesis, which supplies power to the 500W BLDC motor of an electric scooter using a 48V battery. This document outlines the specific requirements to ensure the safety, efficiency, and reliability of the system. It provides detailed descriptions of all components and procedures involved.

9.2. Material Conditions

9.2.1. General Materials

All materials used in the prototype must be of the highest quality and meet the following criteria:

- Compliance with relevant regulations and standards.
- Possession of the characteristics specified in the technical specifications.
- Certification from appropriate authorities.

9.2.2. Electrical Cables

T he electrical cables used in the prototype must meet the following conditions:

- Conductors must be made of copper with a nominal voltage rating of 570V.
- Wiring must withstand voltages up to 1000V.
- Cable identification should follow the color code below:
- Black and brown for cables connected to the negative polarity.
- Red and blue for cables connected to the positive polarity.
- All cables must be covered with an orange protective sleeve to prevent short circuits.

9.2.3. Electronic Components

The electronic components used in the prototype must meet the following conditions:

A. MOSFET

- The selected MOSFET must withstand voltage peaks exceeding 48V, with a rated voltage of 100V.
- The current capacity must be at least 25A.

Example: STMicroelectronics STB40NF10LT4 MOSFET meets these conditions.

B. Capacitors

- Capacitors must have a minimum capacitance of 13.27mF and an ESR of 24.4mΩ.
- At least two units should be connected in parallel.

Example: KEMET ALC80D822EH100 capacitors meet these conditions.

9.2.4. Battery

- The battery must have a rated voltage of 48V and provide 500W of output power.

Example: Chamrider 36V 10AH, 25A BMS, 48V 30A lithium battery pack.

9.2.5. Motor

- The motor must be of the BLDC type and provide a rated output of 350 W.

Example: V-MOTION HIGH TORQUE BLDC MOTOR 350W.

9.3. Execution Conditions

9.3.1. Assembly

All components must be assembled in accordance with the manufacturer's technical specifications and meet the following conditions:

- All components must comply with relevant safety regulations.
- During assembly, direct and indirect contact with conductive materials not designed and selected for contact must be avoided to prevent short circuits.

9.3.2. Operating Temperature

- The battery must operate within a temperature range of -20ºC to 60ºC.
- Electronic components must not be exposed to temperatures higher than those specified.

9.3.3. Mechanical Requirements

- The prototype must not be exposed to impacts or sharp objects.
- All connection points and contact areas must be made of designed materials, and any unintentional contact with conductive objects must be avoided to prevent direct or indirect contact.
- The prototype is not designed to withstand temperatures above the specified limits and should not be subjected to fire or destructive tests.

9.4. Testing and Adjustments

9.4.1. Operational Testing

- All components must undergo operational testing according to the specific regulations of each product.

- Voltage, current, and temperature tests must be performed to ensure the proper operation of the power converter and BLDC motor.

9.4.2. Final Adjustments

- Final adjustments must be made to ensure the system meets the project requirements.
- All results from the tests and adjustments performed must be documented.

9.5. Warranty

The prototype must guarantee the protection of individuals and property while ensuring safety and efficiency. The energy values established in the project must be met as minimum values to ensure the proper performance of the system.

9.6. Documentation

All technical documents and certifications for the components used must be provided, including user manuals and technical specifications for the power converter and motor. Additionally, records of all tests and verification procedures performed during the project must be included.

ANEXO

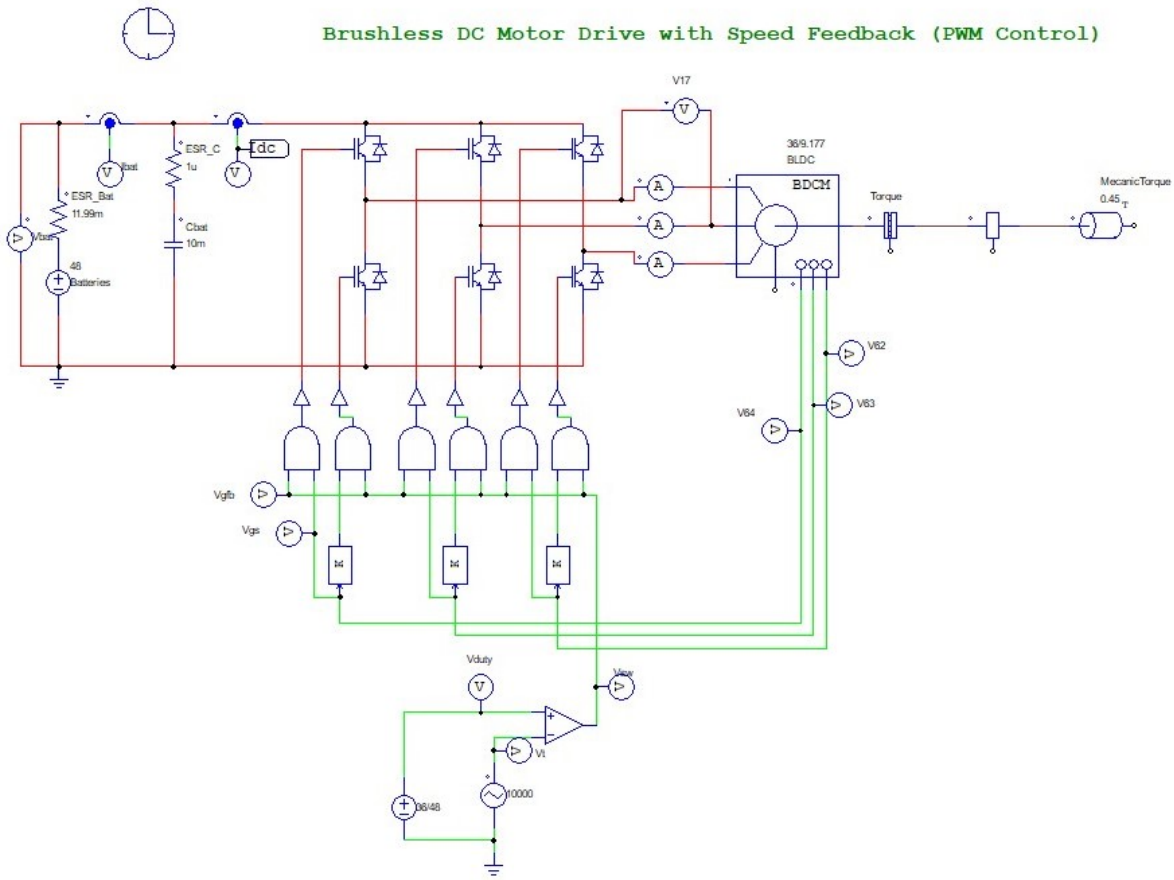


Figure 79. Completed circuit diagram (Obtained from self-made PSIM)