Simulation of Brushless DC Motor Controller in SEM Electric Car Prototypes

Andrean Stevanus¹*, Yohanes Calvinus², Dali Santun Naga³
¹,²Electrical Engineering Department, Faculty of Engineering Universitas Tarumanagara
³Information System Department, Faculty of Information Technology Universitas Tarumanagara

*andrean.525160018@stu.untar.ac.id; andreanliu17@gmail.com

Abstract. Petroleum is a limited natural resource and if used continuously will experience scarcity and increase in price. KMHE is one of the efforts of Indonesia’s government in advancing the technology of electric vehicles and fuel vehicles in terms of more efficient use of energy. The prototype of the SEM electric car is an electric car made by UNTAR Engineering students that will be included in the upcoming KMHE. The prototype of the SEM electric car uses a BLDC motor as a drive. The BLDC motor is controlled by an electronic controller. Therefore, the BLDC motor controller simulation was designed which can be used as a reference in designing BLDC motor controllers that will be used in KMHE 2020. From the simulation results, the maximum speed of the BLDC motor is obtained by using a controller designed at 2680 rpm. The speed of an electric car of 40 km/h can be achieved by adding a proper transmission system from an electric motor to the car wheel.

1. Introduction
Petroleum is one of the most widely used energy sources at this time. Fuel oil is also one of the pillars of the Indonesia’s economy. This causes the need for fuel oil continues to increase along with the development of the Indonesian economy [1]. However, the availability of petroleum is depleting. This has prompted several countries in the world to look for alternative energy sources. Fuel vehicles as one of the biggest fossil fuel consumers will receive a large impact from these changes. For this reason, it is necessary to research and develop technology to save fossil energy and apply alternative energy sources instead [2].

One of the effort to reduce the use of fossil energy is to use electrical energy as a source of propulsion energy in vehicles. Electric vehicles have several advantages over internal combustion engine cars, including significant reductions in air pollution, gas emissions, and energy dependence on diminishing oil reserves. Electric vehicles will use electricity stored in batteries to drive electric motors, and can be recharged by generating electricity using renewable energy. The most suitable electric motor for electric vehicles is the Brushless DC (BLDC) motor, because this motor has high reliability, high power density, high efficiency, low maintenance requirements, low cost and lower weight [3].

Energy Saving Car Contest (KMHE) is an event organized by Ristekdikti which is oriented to energy efficiency of a student car designed by the application of knowledge received during college. The race is divided into two categories: Urban and Prototype. The cars in KMHE are divided into 4 classes based on the driving motor used, namely Gasoline Internal Combustion Motor (MPD), Ethanol MPD, Diesel MPD and Electric Motor. For KMHE 2020, the MORTAR Electric Team (SEM) will represent UNTAR in participating in the KMHE for the electric motorbike prototype category.

The prototype of the SEM electric car uses a 48V BLDC motor as a drive. To control a BLDC motor, an electronic controller is needed. Therefore a BLDC motor controller simulation was designed which can be used as a reference in designing BLDC motor controllers that will be used at KMHE 2020. The use of simulations can set the design flow, reduce costs and risks [4]. The simulation was made using

---

[1] [2] [3] [4]
Proteus 8 software. This software was chosen because it can perform simulations based on performance and operation of the original electronic components.

The prototype of the SEM electric car will be designed so that it can run with a maximum speed of 40 km/hour. For this reason, controllers are designed according to these needs.

2. Design

The perfect motion control system consists of three parts: the motor, drive and controller. The controller is used to provide information and calculations to get the desired motor movement. To obtain high accuracy and performance, feedback devices such as sensors, resolvers, and encoders play an important role by providing controlling information about the actual position and speed of the motor axis [5].

Detection of the position of the rotor can be done by two methods, namely with sensor and without sensor (sensorless). In the designed BLDC motor controller, the position sensor is used to detect the position of the rotor. The method of detecting the position of the rotor using sensors was chosen because it was easier to implement. The sensorless method does not use any position sensor but demands a high-performance processor, larger program code and more memory [4].

![Block Diagram of BLDC Motor Controller System](image)

**Figure 1. Block Diagram of BLDC Motor Controller System**

On Figure 1, we can see the data flow and the supply flow. The data flow define the input and output signals, while the supply flow defines the input and output power supplies.

The design tested on the simulation made with Proteus 8 software. On Figure 2 we can see that the system consists of four parts. The green part is the microcontroller, the blue part is inverter and BLDC Motor, the yellow part is step down regulator, and the orange part is gate drivers.
2.1. **Step Down Regulators**
Step down voltage regulator is used to supply voltage to the microcontroller and other supporting electronic components. The step down voltage regulator use voltage source from a 48V Li-ion battery. The component used for step down regulators are LM2596HV for 20V step down, LM7812 for 12V and LM7805 for 5V.

2.2. **Microcontroller**
Microcontroller used to provide PWM signal output to the gate driver. The duty cycle of PWM is controlled by an accelerator. Control the value of the duty cycle in this system to affect the rotation speed of the motor. Motor rotational speed is directly proportional to the applied voltage. So the change in PWM duty cycle from 0 to 100% results in a proportional change in RPM of 0% to 100%. The component used for microcontroller are Arduino Nano and 100k Ω potentiometer as accelerator.

2.3. **Gate Drivers**
Gate driver serves to increase the voltage and current from the microcontroller output signal to the MOSFET. MOSFETs need a gate voltage VGS applied above threshold voltage Vth in order to conducting current. The gate on the MOSFET forms a capacitor (gate capacitor), which must be filled or emptied each time the MOSFET is turned on or off. Because MOSFETs need a certain gate voltage to be turned on, gate capacitors must be supplied with at least the gate voltage needed to enable the MOSFET. Likewise to turn off the MOSFET, the charge on the gate capacitor must be emptied or the voltage below Vth. The component used for gate drivers are three IR2106 ICs.

2.4. **Inverter**
The inverter in this design consists of six power MOSFETs arranged so that they can provide power to each phase of the BLDC motor on a commutational basis. The commutation system on a BLDC motor must be regulated electronically because the winding of the wire on the stator must be turned on / off (on-off) or energized sequentially and regularly. Therefore, there is a need for a Hall Sensor that can provide information precisely to the controller to regulate which windings must be electrified [6]. The component used for inverter are six power MOSFET IRF2907.
3. Testing and Analysis Result

Microcontroller module design tested by comparing the output signal pattern on the Arduino Nano and Hall Sensors. Tests carried out using an oscilloscope.

| Step | Sensors (C B A) | High Side C | Low Side C | High Side B | Low Side B | High Side A | Low Side A |
|------|----------------|-------------|------------|-------------|------------|-------------|------------|
| 1    | 101            | 0           | 1          | 1           | 0          | 0           | 0          |
| 2    | 100            | 0           | 1          | 0           | 0          | 1           | 0          |
| 3    | 110            | 0           | 0          | 0           | 1          | 1           | 0          |
| 4    | 010            | 1           | 0          | 0           | 1          | 0           | 0          |
| 5    | 011            | 1           | 0          | 0           | 0          | 0           | 1          |
| 6    | 001            | 0           | 0          | 1           | 0          | 0           | 1          |

Table 1. State Table BLDC Motor Switching Signal

![Figure 3. Arduino Output and Hall Sensors Output Comparison](image)

Gate driver module design tested by measuring the gate driver output signal. The measurement result can be seen in Figure 4.

![Figure 4. Signal Measurement](image)
From Figure 4a and b, it can be seen that the signal on the high side with the low side has a different voltage level. This is because the oscilloscope takes measurements with a ground voltage reference. While the signal from the high side gate driver refers to the voltage at the source foot of the high side MOSFET. The scale used on the vertical axis of the oscilloscope is 20V. From Figure 4b, the signal on the low side voltage is 12V, while in Figure 4a, the signal on the high side is around 60V. If the source voltage is 48V, with the addition of a 12V power supply, it becomes 60V. While the VGS value received by the high side MOSFET remains 12V.

Switching on the high side MOSFET uses the bootstrapping method. Bootstrapping on MOSFET is shifting the operating point above the power supply voltage point. Bootstrapping on the gate driver circuit in the design shifts up positive and negative points at 48V. Shifting is done by using a bootstrap capacitor. In Figure 2, the bootstrap capacitors are placed on pins VB and VS. When the MOSFET low side is on and the high side is off, the 12V power supply charges the bootstrap capacitors. When the low side MOSFET is off and the high side is on, the bootstrap capacitor releases the stored charge towards the VB pin so that between VB and VS has a 12V potential difference. 48V on VS which comes from phase voltage acts as a reference voltage for the output pin HO voltage.

The testing of the controller performance done by taking a sample of motor speed. Data taken is speed measurement when the speed is stable and at maximum speed. The maximum speed is obtained by the duty cycle of the PWM signal 100%. The BLDC motor rpm indicator on Proteus 8 cannot exceed 1000 rpm, whereas on the datasheet of the BLDC motor used, the speed can reach 3700 rpm. Therefore, measuring the speed of a BLDC motor is done by setting the load on a BLDC motor by 65%, because the maximum speed produced reaches 1000 rpm which is 938 rpm. Testing is carried out with a load of 65% to 100%. The result can be seen in Figure 5.

![Torque vs Speed](image)

**Figure 5. Correlation Between BLDC Motor Torque and Rotational Speed**

From Figure 3, we can see that the test result reveal that motor torque and the rotational speed is directly proportional. Linearity between torque and rotational speed can be seen from motor power equation:

\[
P = \text{motor speed} \times \text{motor torque}
\]

where power in watt, motor speed in rad/s unit and motor torque in Nm unit.

By using the gradient in Figure, we can predict the Gradients are calculated using a linear equation

\[
y_2 - y_1 = m \times (x_2 - x_1)
\]

where m is gradient, x1 and y1 is point 1 coordinate and x2 and y2 is point 2 coordinate in Cartesian coordinate system.

By taking the first point and the last point of the graph, we can calculate the gradient:

\[
m = (y_2 - y_1) \times (x_2 - x_1)^{-1}
\]
\( m = (938 - 0) \times (65 - 100) = -26.8 \)

From the gradient obtained, we can find the maximum speed of the BLDC motor. If it is assumed that the maximum speed is obtained with a load of 0% (no load), then:

\[
y_2 = m \times (x_2 - x_1) + y_1
\]

\[
y_2 = (-26.8) \times (0 - 100) + 0 = 2680 \text{ rpm}
\]

In the prototype of an electric car that was designed, the speed is set 40km / hour. With a simple calculation, the rpm needed to get the translation speed of 40km / hour. The radius of the wheel used are 33cm.

The translation speed of 40km / hour needs to be changed to rotational speed using the formula:

\[
\omega_{\text{motor}} = \frac{v \times (r)}{1}
\]

\[v = 40 \text{ km/hour} = 11.11 \text{ m/s}
\]

\[
\omega_{\text{motor}} = \frac{11.11 \times (0.33)}{1} = 33.67 \text{ rad/s}
\]

\[
1 \text{ rad/s} = 60/2\pi \text{ rpm} = 9.549 \text{ rpm}
\]

\[
\omega_{\text{motor}} = 33.67 \times 9.549 = 321.514 \text{ rpm}
\]

4. Conclusion

From the analysis we can take conclusion that the designed microcontroller and gate drivers work according to the desired performance. Also, we can take conclusion from the speed measurement and calculation that the BLDC Motor Controller can drive the 48V BLDC Motor with the maximum no load speed 2680 rpm. To adjust with the electric car speed, which is 321.514 rpm, we can add a proper transmission system between the motor and car wheel.

5. References

[1] Setiono L 2016 Perancangan Mekanika dan Realisasi Kontrol Mobil Listrik e-Proceeding of Engineering, 3 4669-75

[2] Ristekdikti 2019 Regulasi Teknis Kontes Mobil Hemat Energi 2019

[3] Sujanarko B 2014 BLDC Motor Control for Electric Vehicle Based On Digital Circuit and Proportional Integral Controller (2014) Int. Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering 3 11674-81

[4] Satar M N A and Ishak D 2011 Application of Proteus VSM in Modelling Brushless DC Motor Drives Int. Conf. on Mechatronics 1-7

[5] Nabil H 2018 Position Estimation and Control of BLDC motor Based on Hall effect sensor and Angular Magnetic Encoder IC Int. Journal of Engineering and Applied Sciences 5 48-53

[6] Ikbar M and Zulwisli 2019 Perancangan Inverter MSTS dengan Monitoring Kecepatan Menggunakan Sensor Hall Berbasis Arduino Jurnal Vokasional Teknik Elektronika dan Informatika 7 51-8

[7] Fathoni K and Utomo A B 2019 Perancangan Kendali Optimal pada Motor Arus Searah Tanpa Sikat melalui Metode LQRI ELKOMIKA VII 377-91

Strite S and Morkoc H 1992 J. Vac. Sci. Technol. B 10 1237