Design and Construction of Speed Control System of Brushless Direct Current Motor 350 Watt Type 120 and 60 Degrees on Prototype Electric Vehicles Using Configuration Six-Step Commutation

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Abstract - In the world of electric cars, the motor speed control system plays an important role in the design of an electric car. A vehicle will run if the control or control of a drive in the form of a motor runs stably and has little energy consumption. One way to achieve this stability is by understanding the commutation accuracy of each motor used. The purpose of this final project is to design a brushless direct current motor speed control system of type 120 and 60 degrees using the Six-Step Commutation configuration.

Keywords: *Brushless Direct Current, Motor Control System, Six-Step Commutation.*

I. INTRODUCTION

With the development of technology in the world of vehicles, creativity and innovation continue to be carried out for the development of vehicles, especially electric cars. This electric car itself is the car of the future with Zero Emission or the absence of exhaust gases and has an effect on a pollution-free environment. And technological advances in most equipment will not be separated from the use of motors. There are various types of motors currently available, one of which is the Brushless Direct Current motor which has many advantages over the Direct Curent motor. One of the advantages of this Brushless Direct Current motor is that it has higher efficiency and long operating time. Brushless DC motor (BLDC) is one type of synchronous motor that is increasingly being used in many applications because of its efficiency, maintenance free and good power to weight ratio. However, the operation of the BLDC motor requires a rotor position sensor.

The Six-Step Commutation method is a hall sensor reading method on a Brushless Direct Current motor. This method determines the timing of the correct and appropriate reading on the hall sensor. Hall sensor is a sensor used to detect magnetic fields. The working principle of the hall sensor on a Brushless Direct Current motor is that when the south or north magnetic pole approaches the hall sensor. it will produce a HIGH or LOW signal. With the three hall sensors, six different combinations will be obtained. To adjust the speed of the vehicle by using PWM (Pulse Width Modulation) by changing the reference voltage by a potentiometer, so that the motor can rotate with an adjustable rpm.

So it is hoped that in this study it can regulate the speed of the Brushless Direct Current motor properly under load conditions and see the effect of parameter changes on the output of the Prototype type electric vehicle.

II. METHOD

In this study, it is explained about the steps in data collection and processing. The first step is to prepare the tools and materials used for research. After that, designing the Hardware and Software for the Brushless Direct Current motor control system.

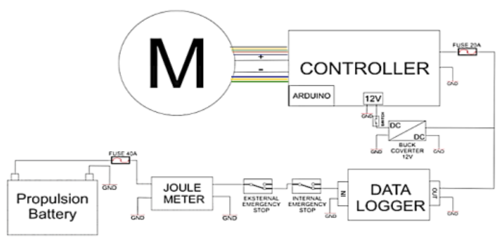

Figure 1. Electrical diagram Charging

After doing the design using Eagle Software and Arduino IDE, the next step is to determine the hall sensor pattern on each Brushlees Direct Current motor used.

In this study, the hardware design used is a series of inverters and a series of Mosfet Drivers and Microcontrollers as the brains of the commutation programming that will be carried out.

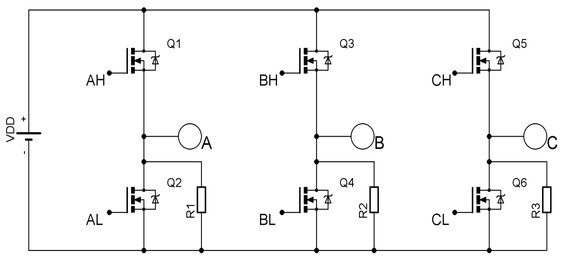

Figure 2. Inverter Circuit

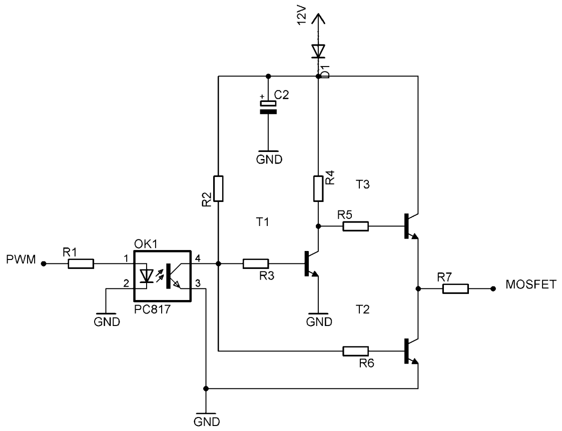

Figure 3. Mosfet Driver Circuit

The method used is a general method that is widely used in conventional Brushless Direct Current electric motors. The Six Step Commutation configuration is a configuration or steps used to make a Brushless Direct Current motor run or rotate and with the Pulse Width Modulation technique to adjust the desired motor speed according to the needs of the research to be carried out. So it has a hall sensor reading accuracy and has a small energyconsumption.

III. RESULT AND DISCUSSION

Results of Determination of Sensor Hall Pattern

In this test, it is done by looking at the output issued to the motor in the form of the output from the hall sensor. This test is done by turning the motor and seeing the hall sensor output on the serial screen on the Arduino program. There are six hall sensor patterns in each motor, each with a different hall pattern. This difference is due to the different placement of the hall sensor.

Table 1. Hall Sensor Pattern 120 Degree

Pola Ke	U	V	W	Biner
1	0	1	0	2
2	1	1	0	6
3	1	0	0	4
4	1	0	1	5
5	0	0	1	1
6	0	1	1	3

Table 2. Hall Sensor Pattern 60 Degree

Pola Ke	U	V	W	Biner
1	0	1	1	3
2	1	1	1	7
3	1	1	0	6
4	1	0	0	4
5	0	0	0	0
6	0	0	1	1

Determination of Six Step Commutation Pattern

The commutation pattern used is the six step commutation pattern, the determination of this pattern can be done by serializing an existing program and having a phase change output or a change made by the MOSFET. The following is the commutation data of the 120 and 60 degree motors.

Speed controllers or controls have commutations where the initial concept is based on the change or shift of the phase outputs which are positive, negative and float or zero. The basic concept is in the form of the following circuit drawing.

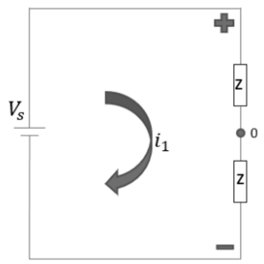

Figure 4. Network Illustration

This picture is an illustration of the flow of electricity at positive, negative and zero values. So from the figure it can be written mathematically where:

$$i_1 = \frac{V_S}{Z+Z} = \frac{1}{2}.\frac{V_S}{Z} \qquad (1)$$

There are 6 steps or what is called a six-step commutation configuration, which has a total of 6 times the phase value transfer steps on the motor so that the motor has a rotation, from the attraction caused by the magnet so that it has the desired rotation with a smooth sound and has a small curren

Results of the Six Step Commutation Motor Pattern

The test is carried out using a replacement switch, where there are six mosfet that are paired with each other. In this pattern, six MOSFETs are used alternately according to the switch pairs that have been determined through the program.

Table 3. Switch commutation mosfet

Switch	Q1	Q2	Q3	Q4	Q5	Q6
Switch	Q6	Q5	Q4	Q3	Q2	Q1
Waktu	0°-60°	60°-120°	120°-180°	180°-240°	240°-300°	300°-360°

This pattern is appropriate for use in the Brushless Direct Current motor speed control system. One of these patterns will be used on both 120 degree and 60 degree motors. The difference lies in the initialization of the binary results on each motor.

Static Test

This static test aims to determine the difference in current and power obtained from testing the controller or control system for two motors with different angles with the same wattage. At this stage, a no-load test was carried out for 5 minutes of free rotation.

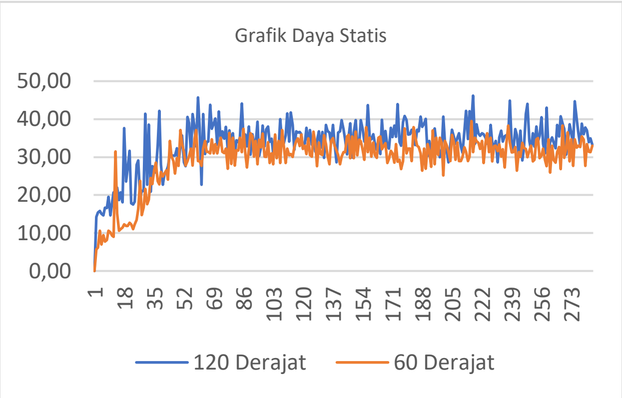

Figure 5. Satisfaction Graph

From the test graph, the control system uses an angle of 120° with a power value that is always unstable at unit time. The instability of the power value is due to changes in the load on the BLDC motor which makes the motor response unstable. This change causes the BLDC motor to use a controller. Where the controller is used to improve the motor response when there is a change in load.

Result of motor static power 120 degrees

$$f(c) = \frac{1}{b-a}\int_a^b f(x).dx$$

$$f(c) = \frac{1}{281-1}\int_1^{281} (0{,}0388\text{x} + 28{,}003)\,dx$$

$$f(c) = \frac{1}{280}\left[\frac{0{,}0388x^2}{2} + 28{,}003x\right]_1^{281}$$

$$f(c) = \frac{1}{280}[0{,}0194x^2 + 28{,}003x]_1^{281}$$

$$f(c) = \frac{1}{280}[(0{,}0194.281^2 + 28{,}003.281) - (0{,}0194.1^2 + 28{,}003.1)]$$

$$f(c) = \frac{1}{280}[(1531{,}843 + 7868{,}843) - (0{,}0194 + 28{,}003)]$$

$$f(c) = \frac{1}{280}[(9400{,}686) - (28{,}0224)]$$

$$f(c) = \frac{1}{280}[9372{,}663]$$

$$f(c) = 33{,}4738\ \ Watt$$

Result of motor static power 60 degrees

$$f(c) = \frac{1}{b-a}\int_a^b f(x).dx$$

$$f(c) = \frac{1}{281-1}\int_1^{281} (0{,}0463\text{x} + 22{,}939)\,dx$$

$$f(c) = \frac{1}{280}\left[\frac{0{,}0463x^2}{2} + 22{,}939x\right]_1^{281}$$

$$f(c) = \frac{1}{280}[0{,}02315x^2 + 22{,}939x]_1^{281}$$

$$f(c) = \frac{1}{280}[(0{,}02315.281^2 + 22{,}939.281) - (0{,}02315.1^2 + 22{,}939.1)]$$

$$f(c) = \frac{1}{280}[(1827{,}947 + 6445{,}859) - (0{,}02315 + 22{,}939)]$$

$$f(c) = \frac{1}{280}[(8273{,}806) - (22{,}962)]$$

$$f(c) = \frac{1}{280}[8250{,}844]$$

$$f(c) = 29{,}4673\ \ Watt$$

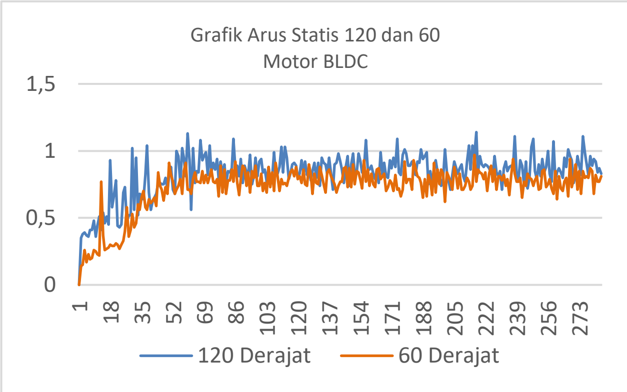

Figure 6. static flow chart

From the graph above, the results of the current are not much different between motors with an angle of 60 or 120. As explained above, what affects the current so that it looks slightly different is not the influence of the control system and also not the influence of commutation, but the motor used is different It's just that this study focuses on the commutation that exists in each motor where the 60 degree motor is rarely used anymore due to changes in commutation when we move the hall cable connected to the control or control system.

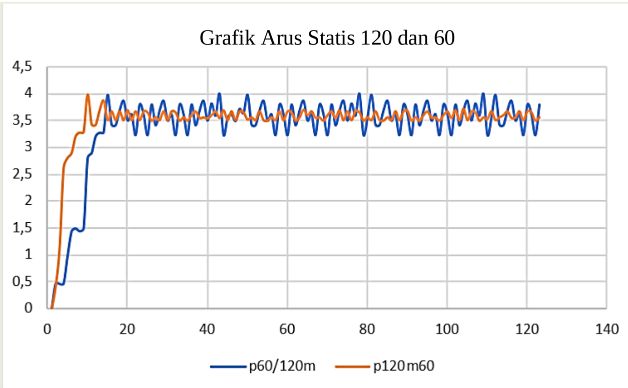

Figure 7. static flow chart

More specifically, below are the results of research that should never be tried, namely entering different commutations into each motor. This aims to determine the basic concept of commutation or Six-Step Commutation configuration used in BLDC motors in general.

This discrepancy study is for comparison purposes only and is not allowed to be attempted. From the graph above, replacement or alteration of the commutation will experience a very drastic increase in current which is fatal to the motor and its control system. This result can occur because of the inappropriate commutation of the 60 degree motor, which has hall sensor logic 1 1 1 and 0 0 0 which is not owned by the 120 degree motor and vice versa. However, a 60 degree motor can lower the amperage a little because the 60 degree motor commutation has all the hall sensor logic states that a 120 degree motor has. This has no effect and should not be done because the current is very high when it is static when it is dynamic. The following is the result of energy consumption Ah of 0.104 and Wh of 4 on the orange graph and Ah of 0.109 and Wh of 4.2.

Controlling with different commutation on one motor is not recommended because it does not match the specifications with the commutation on the BLDC motor. If this is done, what is obtained is a very high speed of course the current is high and the energy consumption is increasing.

Dynamic Test

Dynamic Testing is a test that uses a certain load which aims to determine the torque and rpm if there is a load so that it aims to determine the intended result. This test weighs about 90 kg, namely the total load of the vehicle and the mass of the driver. The distance covered is 360 m/lap, and 3 laps are carried out. From this test, the average speed obtained is 124.98 RPM. Speed with a value like this will get different power values when going uphill, downhill and when turning on the test track.

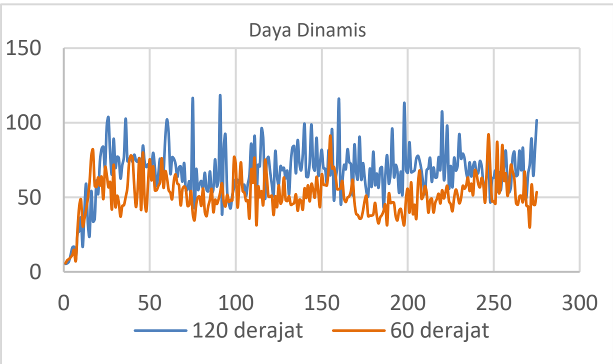

Figure 8. Dynamic Power Graph

The average current value obtained on a 120 degree motor is 1.7 Ampere and on a 60 degree motor it is 1.3 Ampere. After that, at the time of testing, a measuring instrument in the form of a joule meter was added which obtained Wh values of 3.9 and 3.6. The distance covered is 1.08 km. So it can be concluded that the efficiency equation is:

$$Jarak\ Tempuh(120°) = \frac{Panjang\ Lintasan(km)}{\text{Energi (kWh)}}$$

$$Jarak\ Tempuh(120°) = \frac{1{,}08}{0{,}0039}$$

$$Jarak\ Tempuh(120°) = 276{,}923\ \text{km/kWh}$$

$$Jarak\ Tempuh(60°) = \frac{Panjang\ Lintasan(km)}{\text{Energi (kWh)}}$$

$$Jarak\ Tempuh(60°) = \frac{1{,}08}{0{,}0036}$$

$$Jarak\ Tempuh(60°) = 300\ \text{km/kWh}$$

The difference in mileage results is not driven by the difference in commutation, even though using the same controller. However, each BLDC motor has different characteristics.

IV. CONCLUSION

From the results of the study entitled "Design of a Brushless Direct Current Motor Speed Control System 350Watt Type 120 And 60 Degrees in Prototype Electric Vehicles Using Six-Step Commutation Configuration" it can be concluded as follows:

1. The use of commutation must be in accordance with the angle of each BLDC motor according to its specifications.
2. The results of the hardware and software design on this control system correspond to each motor based on the hall sensor commutation input.
3. The performance of the speed control system on a 120 and 60 degree motor angle has almost similar results where the distance traveled on a 120 degree motor is 276,923Km/kwh and on a 60 degree motor it is 300km/kwh based on the data that has been taken.
4. At angles of 120 and 60 degrees, the same (change mosfet switch) is used and the difference lies in calling the binary value on the hall sensor which corresponds to the value serialized in the program where at 120 degrees the calling order is 264513 and at 60 degrees has the order of 376401 .
5. Changing the program that does not match the original commutation of the motor results in a high current surge of 0-4 A compared to the appropriate one of 0-1 A resulting in large energy consumption.

V. SUGGESTION

Changing the commutation is not recommended because it has a large current value so that it has an impact on the control system and increases energy consumption. However, if it is only limited to knowing the concept of the Six-Step Commutation configuration, there is no problem with paying attention to the existing SOPs and only static testing is carried out. The use of a better type of sensor and has more accuracy to improve stability so that readings on the load are more accurate.

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