International Journal of Frontier Technology and Engineering (IJFTE)
Vol. 03, No. 01, December 2024, pp. 69-76

The Effect of Throttle Signal Output Voltage Variation and Load on Current Consumption

Sahwala Dwi Rangga Wardana[1] and Zakiyah Amalia[1]

[1] *Department of Mechanical Engineering, Politeknik Negeri Malang, Malang, Indonesia*

Corresponding Author: Zakiyah Amalia, zakiyah_amalia@polinema.ac.id

Received Date: 01-10-2024 Revised Date: 14-11-2024 Accepted Date: 07-12-2024

Abstract

Many electric bike users who had never driven an electric vehicle were unaware of the characteristics of BLDC motors. Users often feel uncomfortable when riding electric bikes due to the different acceleration characteristics compared to motorcycles. Furthermore, users were unaware that the BLDC motors could spin at high speeds and consume varying amounts of current depending on the load carried by the electric bike. This lack of knowledge resulted in users being unable to operate the electric bike optimally. Therefore, this study aimed to prove the effect of throttle variation and load on current consumption and motor speed of the BLDC motor. The method used in this research was an experimental method by varying the load to 60 kg, 70 kg, and 80 kg and using three different levels of throttle output voltage. Each treatment was repeated three times. Current consumption and rotational speed were recorded using a data logger and processed using ANOVA in the Minitab software. The results of this research showed that as load increased, current consumption increased and rotational speed decreased. Additionally, as the changes in throttle output signal voltage increased, current consumption and rotational speed decreased. The highest current consumption was 3.5309 A when the vehicle was loaded with 80 kg and used mode 1. The lowest current consumption was 1.4403 A when the vehicle was loaded with 60 kg and used mode 3.

Keywords : Electric Bike, BLDC Motor, ANOVA

1 Introduction

The Indonesian government is committed to addressing global climate change through Presidential Regulation Number 55 of 2019 on Accelerating the Use of Battery Electric Vehicles (BEVs) for Road Transportation, aiming to enhance energy efficiency, air quality, and reduce greenhouse gas emissions. The regulation also encourages universities to conduct research, development, and innovation to achieve technological mastery and readiness for vehicle production in Indonesia. According to research by Deloitte and Foundry, the number of electric motorcycles in Indonesia increased from 25,782 vehicles in 2022 to 62,815 units in September 2023, attributed to incentives provided under Presidential Regulation Number 55 of 2019 as part of the central and local governments' efforts to achieve a target of 13.5 million electric motorcycles by 2030.

Electric motorcycles utilize controllers to regulate the speed and direction of BLDC motors, with MOSFETs or IGBTs controlling the voltage activated by a microcontroller through PWM signals whose duty cycle can be varied to alter voltage, current and affect motor speed and torque [1], [2], [3]. The microcontroller receives input from the throttle directly controlled by the rider, translating throttle signals linearly through the controller to manage the motor [4], [5], [6], [7]. Many electric motorcycle users, especially inexperienced ones, complain about difficult-to-control acceleration due to the instantaneous high-tunnel characteristics of BLDC motors. Although typically seen as an advantage because the throttle lever provides maximum power immediately upon activation, in this context it becomes a drawback that reduces rider comfort. Electric motorcycles are battery-powered vehicles powered by electric motors that derive energy from their internal batteries. Key components include batteries (common types being Lithium-Ion, Lithium Polymer, Lead Acid, and Nickel- Metal Hybrid), BLDC motors (Brushless DC), and BLDC controllers. Batteries function as chemical energy storage units, each type having different characteristics in terms of cost, lifespan, power density, and maintenance requirements [8], [9], [10], [11], [12]. Battery Management Systems (BMS) regulate batteries to ensure safe, efficient and reliable operation by managing voltage, protecting against overcharging, and balancing battery cells to extend useful life [13], [14], [15]. BLDC motors operate silently and require less maintenance compared to conventional motors. They require controllers to convert the DC current from the battery into the AC current supplied to the motor, with waveform shapes such as sinusoidal, square, or modified sinusoidal as desired by users[2], [3]. The research outlined aims to develop a throttle curve manipulation device to control BLDC motor speed using a microcontroller, which will be tested to assess its impact on BLDC motor current consumption.

2 Method

This research used an experimental method of varying the throttle curve, which will be manipulated using mathematical formulas in the microcontroller program code. Current consumption will be the dependent variable, while the magnitude of changes in throttle output voltage and load will be the independent variables. The objective of this research is to prove the effect of the independent variables on the dependent variable mentioned above. Current will be measured in real-time using the datalogger feature available on the BLDC controller. The entire research process is conducted at the Automotive Workshop, Department of Mechanical Engineering, State Polytechnic of Malang.

2.1 Electric Motorcycle

An electric motorcycle is a type of battery-based electric vehicle powered by an electric motor that receives its power supply from the vehicle's own battery. An electric motorcycle, as shown in Figure 1, is considered a solution to address the increasingly concerning issue of exhaust emissions from vehicles with internal combustion engines. The specifications of the electric motorcycle used in this research are listed in Table 1.

Figure 1: Electric Motorcycle

Table 1: Vehicle Specifications

Specifications	
BLDC Brand	Tiger
BLDC Motor Power	48 Volt 350 Watt
Battery	48 Volt 6 Ah Li-Po
Controller	Flipsky 75100
Rim Size	10 Inch
MCB	20 A

2.2 Construction of the Throttle Curve Manipulator Device

The schematic was created on the EasyEDA Web platform. This process connects the pins of various components to one another so that the device can function as intended. Adjust the pins according to the requirements and refer to each component's datasheet to ensure their functions. As seen in the schematic in Figure 2, an Arduino Nano is used as the main microcontroller. The Arduino reads the potentiometer used as input and then converts the reading into a PWM signal output. The potentiometer reading is performed by the ADS1115 connected to the Arduino; this additional module aims to increase the default 10-bit ADC resolution of the Arduino to 16 bits. The PWM signal is processed by an Op-Amp, which acts as a buffer. The Op-Amp converts the PWM signal into an analogue voltage that can be accepted by the BLDC controller. A 3-position button is used as input to select the output voltage variation mode on the microcontroller. There is also a 16x2 I2C LCD used to display the current mode and the potentiometer position. All components are powered by a 7-9 Volt header, which is then stepped down to 5 Volts using a step-down converter.

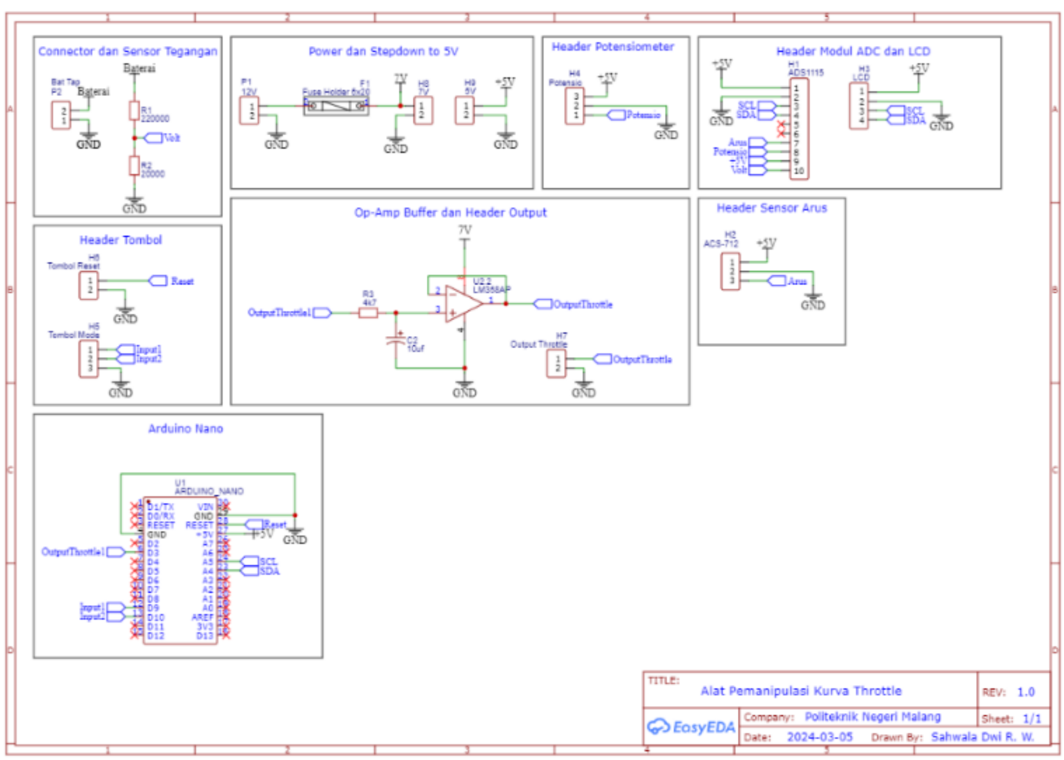

Figure 2: Device Schematic

After completing the schematic, the next step is to convert it into a PCB layout, as shown in Figure 3. Use the "Convert Schematic to PCB" menu in EasyEDA. After doing this, a new page will open that shows a blank canvas where components can be placed, and traces can be created to connect the component pins according to the schematic. Place the components close to each other according to their respective blocks. Connect all components based on the schematic while paying attention to the width and spacing of the tracks, arranging them to avoid overlapping paths. Using the available layers, such as the top layer and bottom layer, to prevent overlapping trace. The result can be seen in figure 3.

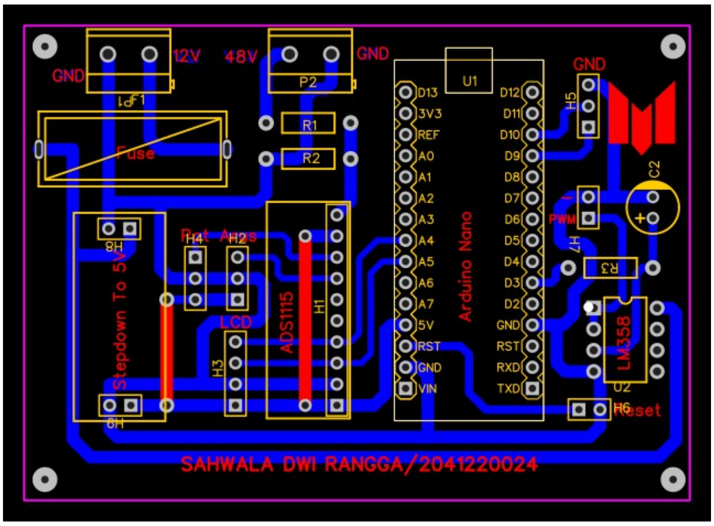

Figure 3: PCB Layout

2.3 Experimental Setup

Figure 4 shows the setup of the research equipment. The potentiometer on the throttle output modification tool is used as a replacement for the throttle because the potentiometer allows for easy adjustment and maintenance of the rotation angle during the research. The potentiometer will generate a signal that will be read by the Arduino, which will then modify the signal according to the predetermined formula. The Arduino will then send the signal to the Op-Amp, which will pass it on to the BLDC controller to drive the BLDC motor. The current consumption and rotational speed of the BLDC motor will be recorded and stored using the datalogger feature on the BLDC controller, controlled via an Android phone.

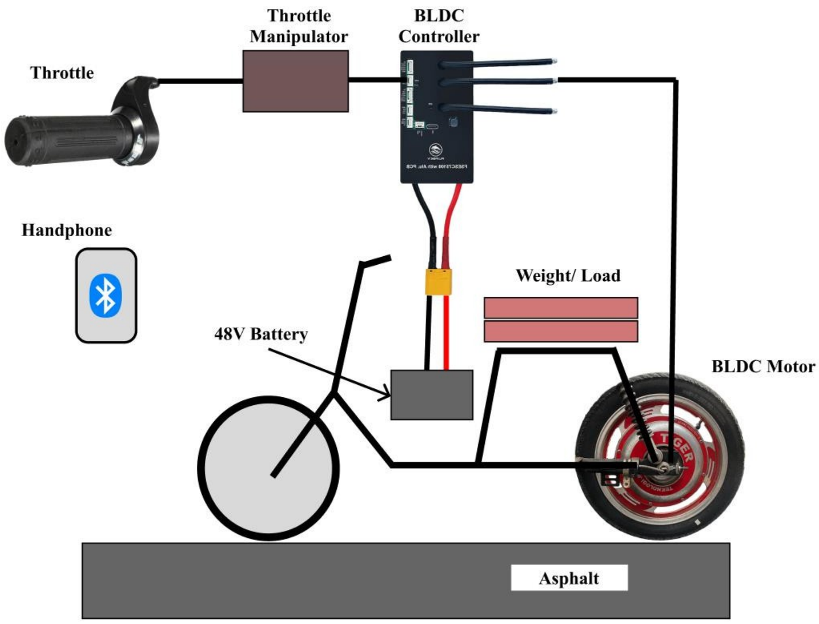

Figure 4: Experimental Setup

2.3.1 Data Collection Process

The data collected during this process include the output voltage of the Op-Amp, which is used as the input for the BLDC controller. The data obtained will be compared with the mathematical values to determine the device error. Current consumption will also be recorded during the testing process and automatically stored using the datalogger. The tests will be conducted in 3 repetitions with 9 different combinations of independent variables.

3 Results and Discussion

3.1 Result of Device Accuracy

The output voltage produced must match the calculated values. Measure the output voltage using a multimeter and compare it with the calculated voltage. Table 2 shows the test results for the Throttle output mode 1, Table 3 shows the test results for the Throttle output mode 2, and Table 4 shows the Test Results for Throttle Output Mode 3, along with the error. It can be seen in each table that the error values are quite low, ranging from 0.526% to 0.656%.

Table 2: Test Result of Throttle Mode 1 Output

Potentiometer Position (%)	Output Voltage Mode 1 Calculated	Output Voltage Mode 1 Measured	Error (%)
0	0.800	0.798	0.250
10	0.937	0.936	0.090
20	1.089	1.093	0.378
30	1.259	1.271	0.967
40	1.450	1.448	0.138
50	1.667	1.685	1.100
60	1.914	1.921	0.351
70	2.200	2.217	0.773
80	2.533	2.552	0.737
90	2.927	2.947	0.674
100	3.400	3.420	0.588
Error Average			0.546

Table 3: Test Result of Throttle Mode 2 Output

Potentiometer Position (%)	Output Voltage Mode 2 Calculated	Output Voltage Mode 2 Measured	Error (%)
0	0.800	0.799	0.125
10	0.893	0.896	0.352
20	1.000	1.013	1.300
30	1.125	1.133	0.711
40	1.273	1.271	0.136
50	1.450	1.472	1.517
60	1.667	1.685	1.100
70	1.938	1.941	0.181
80	2.286	2.296	0.450
90	2.750	2.769	0.691
100	3.400	3.420	0.588
Error Average			0.656

Table 4: Test Result of Throttle Mode 3 Output

Potentiometer Position (%)	Output Voltage Mode 3 Calculated	Output Voltage Mode 3 Measured	Error (%)
0	0.800	0.798	0.250
10	0.870	0.877	0.773
20	0.953	0.955	0.216
30	1.052	1.054	0.227
40	1.171	1.172	0.049
50	1.320	1.331	0.833
60	1.509	1.527	1.187
70	1.758	1.764	0.347
80	2.100	2.119	0.905
90	2.600	2.612	0.462
100	3.400	3.420	0.588
	Error Average		0.525

3.2 Result of Current Consumption

By examining the graph and Table 5 as well as Figure 5, we can observe that as the load increases, the current consumption also increases. In the same mode (Mode 1), the average current consumption for a 60 kg load is 2.93 A, for a 70 kg load it is 3.05 A, and for an 80 kg load it is 3.48 A. In Mode 2, the average current consumption for a 60 kg load is 1.89 A, for a 70 kg load is 2.12 A, and for an 80 kg load it is 2.37 A. The average current consumption in Mode 3 for a 60 kg load is 1.46 A, for a 70 kg load is 1.53 A, and for an 80 kg load it is 1.62 A. The mode used also affects current consumption; with the same load, Mode 1 consumes the most current compared to Mode 2, while Mode 3 consumes the least current compared to the other modes.

Table 5: Test Result

Load (kg)	Output Throttle Mode (c)	Current (Replication 1)	Current (Replication 2)	Current (Replication 3)	Average
	1	3.0164835	2.88621622	2.8854286	2.929376
60	2	1.9340708	1.88216216	1.8407377	1.885657
	3	1.4403012	1.49507353	1.4446753	1.460017
	1	3.0780702	3.08507463	2.9956164	3.05292
70	2	2.1160714	2.07528302	2.1618557	2.117737
	3	1.566506	1.50083333	1.51	1.52578
	1	3.5308955	3.46913793	3.4497753	3.48327
80	2	2.5231858	2.32135593	2.3213559	2.388633
	3	1.5976378	1.652	1.6182979	1.622645

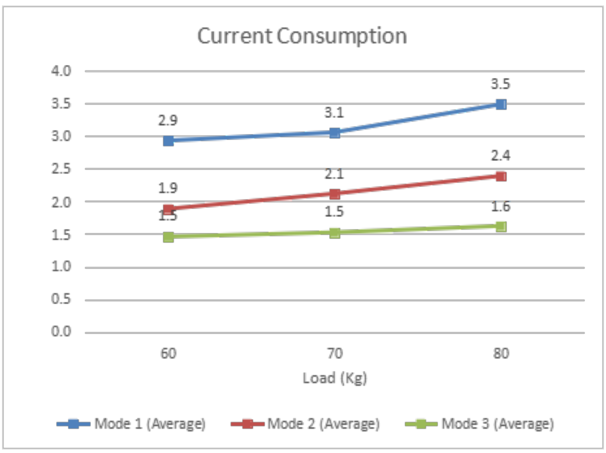

Figure 5: Current Consumption Graph

From the data presented in Table 5 and Figure 5, we can see that changes in load and mode affect current consumption. The impact of these changes on current consumption can be explained using the following formula.

$$Power(P) = Voltage(V)xAmpere(I) \tag{1}$$

but,

$$Power(P) = \frac{Work(W)}{Time(t)} \tag{2}$$

$$Work(W) = Force(F)xDisplacement(s) \tag{3}$$

$$Force(F) = Mass(M)xAcceleration(a) \tag{4}$$

Therefore, as the mass or load increases, the required power also increases. Greater power demand translates to higher current consumption. Meanwhile, changes in mode correlate with the duty cycle value on the BLDC controller. The duty cycle is controlled directly by the throttle, so a smaller throttle position results in lower current consumption. This result is consistent with research conducted by another scientist. They stated that the higher the load applied to the electric bicycle, the more the current consumption will increase. Furthermore, the higher the duty cycle sent to the controller, the higher the current consumption [16], [17].

4 Conclusion

Changes in load magnitude affect the current consumption of the BLDC motor. As the load increases, the current consumption also increases. This is based on test results showing that in Mode 1, a 60 kg load averages a current consumption of 2.93 A, while an 80 kg load averages 3.48 A. Variations in the throttle output voltage mode affect the current consumption of the BLDC motor. This is based on test results showing that at a load of 60 kg, Mode 1 averages a current consumption of 2.93 A, while Mode 3 averages 1.46 A. Higher changes in the throttle output voltage led to lower current consumption. Based on this result, we can conclude that both independent variables, the load and throttle output voltage variation mode, affect the current consumption of the BLDC motor. This is evidenced by changes in current consumption when both independent variables are varied.

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