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DESIGN OF SOLAR ELECTRIC BICYCLE BASED ON *PULSE WIDTH MODULATION* ON *THROTTLE* AS DC MOTOR SPEED REGULATOR

Singgi Fadly, Chairul Gagarin Irianto, Syah Alam

Jurusan Magister Teknik Elektro, Universitas Trisakti Jakarta Barat, Indonesia

*Email: *162012200003@std.trisakti.ac.id*

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ABSTRACT

Electric bicycles are designed to use renewable energy to support government efforts to reduce carbon emissions. The problem in every region or city regarding fuel-powered vehicles certainly increases air pollution. Generally, electric bicycle is designed to be a solution and are used in everyday life to carry out daily activities by requiring bicycle gas throttle control which can help the driver or person control the speed of the electric bicycle. In this study, designing a solar electric bicycle as environmentally friendly energy based on PWM signals to determine the duty cycle value or work cycle with an optimized PWM value can influence the system speed (km/hour) in Revolutions Per Minute (RPM) to determine the performance of the DC motor. The electric bicycle uses 30Wp solar power, two 12V 7.5 Ah batteries connected in series, and a 24V 250W DC brushless motor. Based on the design results with a total electric bicycle weight of 37kg plus driver variations of 55kg, 65kg, 75kg and 85kg, the total controller power value is 163.44 watts. The duty cycle test results were 25%, 50%, 75% and 98% with 249.9 being the maximum PWM value and 9.8 Vout resulting in a maximum speed of an electric bicycle of 2648 RPM or equivalent to the speed of an 18-speed electric bicycle. 28 km/h. In this case, the electric bicycle is in suitable condition to be used to carry out daily activities by utilizing clean, cheap and effective energy.

INTRODUCTION

The development of electric engine technology is increasingly rapid, and vehicle innovations have emerged in reducing carbon emission consumption in every region or city. This problem has become serious for the government and even in the world. One of the efforts to overcome this is to use alternative energy, namely solar heat or solar panels that can convert sunlight into electrical energy. Pedaling a bicycle using pedals generated from human power results in fatigue, so it is used for users of the nearest distance, while bicycles that are combined with electricity assisted by batteries as an energy source and DC motors can reach longer distances by minimizing human labor.

PWM *control* is a way of manipulating the width of a signal expressed by pulses in a period to obtain different average voltages. The use of *electric bicycle gas* throttle on *PWM* signals could process the speed of the motor and prevent excessive power consumption in electronic circuits. The voltage supplied at a specific time interval is the reason PWM *can* process the speed of the motor. The speed of the motor and the terminal voltage have a direct proportional relationship, this certainly has a purpose, the lower the voltage, the slower the motor speed, the more value in regulating the speed of the DC motor with *the PWM method*, which is easy, not complicated and economical in its implementation [1]. This *PWM* plays an important role in improving the driving performance of DC motors [2]. The main source of DC motors is a direct current voltage source that has two terminals to drive it [3]. In this DC motor, it is the core of the engine or the main drive on electric bicycles [4].

Because this study uses *a throttle control* that can regulate the speed of the DC motor to determine the *duty cycle* or speed of the electric bicycle in the form of *a PWM* signal to RPM.

The specification of the electric bicycle uses a monocrystalline type of solar panel which is an energy-saving panel of 30 Wp capable of producing a maximum output power of 30 Watts [5]. Therefore, efforts to create affordable and environmentally friendly power sources such as solar power plants are still being carried out because the process of converting solar radiation into light-capturing materials is carried out by solar panel systems [6]. The type of electric motor consists of a *250-Watt* Brushless Direct Current *(*BLDC), *a 30A solar charge controller* (SCC) as a regulator for the storage and discharging of electrical energy to the battery [7], two 12V 7.5 Ah batteries are assembled in series connected to a load controlled using an electric bicycle gas *throttle*. Mechanical design in general can be seen in Figure 1.

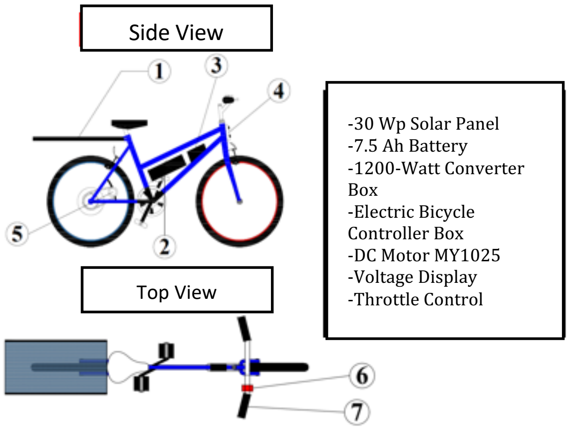


Figure 1. Mechanical design of PWM-based solar electric bicycle on *throttle*

The use of electric bicycles has been carried out by previous researchers [8], the result is the application of BLDC motor speed control installed on the bicycle pedal called *pedal assist* which functions on the control mechanism of the electric bicycle by pedaling the bicycle then paired with a T1368 torque sensor on the pedal to be able to control the torque or speed of the bicycle, but control the electric bicycle with a pedaling model and Reliably using the torque sensor in controlling it is still considered not good, because it still uses a manual system and the sensor used at any time can experience *errors in* torque readings so that electric bicycles have problems controlling speed and can be dangerous for the driver.

Based on this background, this study aims to control the speed of electric bicycles using gas *throttles* so that it is easy to adjust the speed according to the driver's wishes. Then realize an electric bicycle and measure the signal presentation in the *low* and *high* signal periods or *varying duty cycles* using an oscilloscope by measuring the power of the electric bicycle controller and can measure *Revolution Per Minute* (*RPM*) using a digital tachometer as a DC motor *performance* test.

Previous research on electric bicycles has primarily focused on the application of BLDC motor speed control through mechanisms like pedal assist and torque sensors. (Suhadha et al., 2021) explored the use of torque sensors for controlling bicycle speed but identified limitations in manual systems and sensor errors. Similarly, (Ulum et al., 2021) designed a 250-watt electric bicycle and found challenges in power consumption efficiency. These earlier studies provided a foundation for understanding motor control in electric bicycles but lacked comprehensive solutions for efficient speed regulation.

Recent studies, such as those by (Saputra et al., 2020) and (Mohanraj et al., 2022)have advanced the understanding of motor control, particularly with the introduction of Pulse Width Modulation (PWM) as a method for speed regulation. Saputra et al. demonstrated PWM's effectiveness in controlling DC motor speed while minimizing power losses, while Mohanraj et al. reviewed advanced control techniques for BLDC motors. These studies have established PWM as a reliable and efficient method for speed control in electric vehicles, including electric bicycles.

Building on these findings, our research integrates PWM-based throttle control to enhance the performance of solar-powered electric bicycles. This approach aims to provide a more refined and energy-efficient solution for controlling electric bicycle speed, contributing to both the existing literature and practical advancements in renewable energy-powered transportation systems. Future research could further explore the impact of solar power integration on the overall performance of electric bicycles, focusing on improvements in energy storage and efficiency.

METHOD

System Planning

This research method performs the stages of assembly, tool realization, test results of PWM signal variation to *RPM* under normal conditions without the load of the rider or driver, while the power analysis of the electric bicycle *driver* controller generated in the form of load and without the load of the driver (person) can be tested as shown in Figure 2.

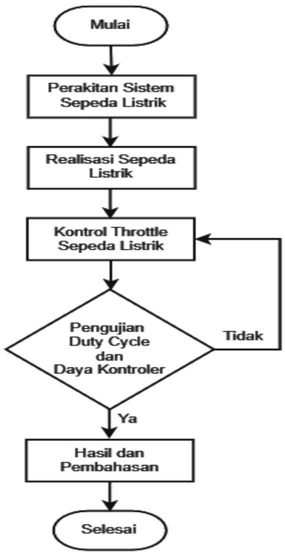


Figure 2. ***Flowchart*** **Research**

System Block Diagram

The stages of the solar electric bicycle design system based on *Pulse Width Modulation* (*PWM*) on the *throttle* as a DC motor speed regulator in which there are 30Wp solar panel components that produce electrical energy where solar cells can directly convert sunlight radiation into electrical energy [9], *solar charge controller* (*SCC*) 30A as a regulator for the storage and use of electrical energy to the battery, two pieces of 12V 7.5 Ah batteries are installed in series, then the electric bicycle driver controller gets a voltage of 24VDC generated from the battery to control the speed of the DC motor on the driver where there is a *gas throttle* on the bicycle handlebars to be passed on to the DC-DC converter as a direct voltage (DC) power supply device generated through input DC voltage conversion to form a lower or higher output DC voltage [10], the converter uses *a 1200W 20A* boost converter type with an *input* voltage of 8-60V and *an output* voltage of 12-83V to improve the performance or *performance of* the DC motor. DC motors require a unidirectional voltage supply on the field coil to be converted into mechanical energy, in General Electric bicycles are driven by electric motors [11]. The system block diagram is shown in Figure 3.

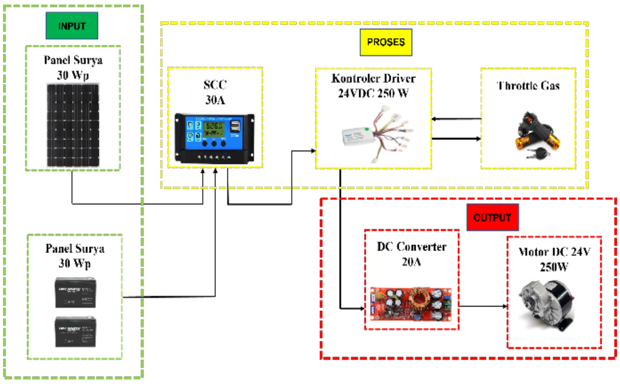


Figure 3. System Block Diagram

Based on Figure 3, *the input components* consist of a solar panel and a battery. The process components include SCC, driver controller and *gas throttle* while *the output* component has a DC converter to maintain the voltage results at the *driver* controller so that the voltage supplied to the DC motor and the DC motor is safe to use.

Realization of Electric Bicycles

Overall, the mechanical design or design and assembly of the system that has been made can be realized into a unit, namely an electric bicycle. The frame of a bicycle is generally made of lightweight aluminum on two wheels and is easy to place anywhere. Bicycle pedals function as a driver's choice to pedal the bicycle manually using human power, this helps the driver at any time the electric power produced can run out during the trip and helps the driver reach his destination. The realization of electric bicycles can be shown in Figure 4.

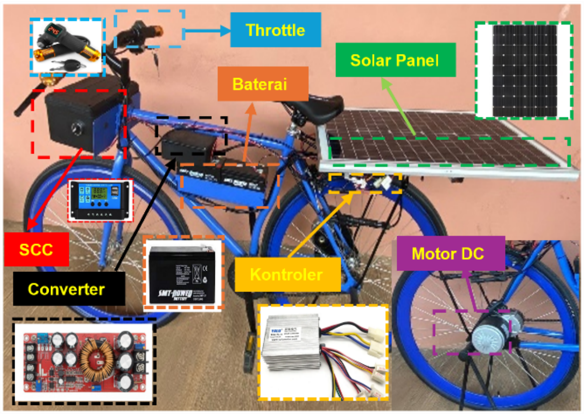


Figure 4. Realization of Electric Bicycles

Based on the realization results shown in Figure 4, that electric bicycles have a *throttle* on the handlebars of the bicycle in the position of the driver's hand on the right. The front of the bike has a black box in which there is an SCC. In the middle of the bicycle stores the battery and DC converter and the rear of the bicycle is paired with a solar panel positioned in a horizontal line and under the solar panel there is *a bicycle driver* controller that can be connected to the *driver's throttle*, battery and DC motor, while the DC motor is attached to the rear wheel of the bicycle which is connected to a mechanic with a freewheel type of gear In the mechanism the rear wheel is not locked off with pedal rotation [12].

***Throttle* Electric Bike**

Electric bikes require speed control of the speed of the bike, i.e. *gas throttle*, the gas *throttle* mounted on the handlebars is used instead of a potentiometer to adjust the width of the pulse on the *PWM* equipped with a voltage indicator and an ignition key to turn the power on or off. When the gas *throttle* is pulled the *electronic speed control* will be activated [13], so that the DC motor drives the rear wheel of the bike. *The electric bike gas throttle* shown in Figure 5.

Figure 5. *Throttle* Gas Bicycle

***Pulse Width Modulation* (*PWM*)**

Pulse Width Modulation is a modulation technique that changes the signal width (*Pulse Width*) with a fixed frequency and amplitude value. High and low *PWM* signals are called *PWM duty cycles*. The signal condition that is in *the ON* condition is called 100% *duty cycle* while the *signal condition OFF* is called 0% *duty cycle*, the PWM signal is shown in Figure 6.

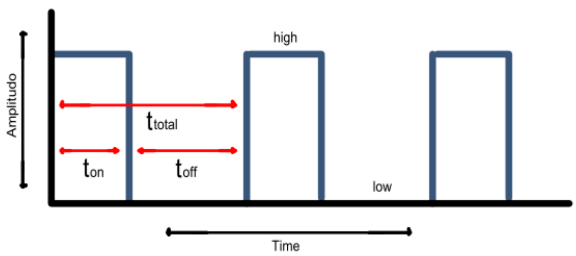


Figure 6. PWM Signal

Ton is the time when the *output voltage* is in the high position (*high* or 1) and T*off* is the time when the *output* voltage is in the low position (*low* or 0). T total is the time of one cycle or the sum between T*on* and T*off* or commonly referred to as the term period of one wave [14], while the *PWM* value in this system uses 8 bits (256) which means that each PWM value is referenced with the numbers 0 to 255 [15], then the maximum value of PWM is 255 as can be shown in the equation formula (1) to (4) as follows:

$$Ttotal = Ton + Toff \qquad (1)$$

The working cycle of a wave is defined by the following equation:

$$D = \frac{Ton}{Ton+Toff} + \frac{Ton}{Ttotal} \qquad (2)$$

The output *voltage* can vary with *the duty cycle* in the following equation:

$$Vout = D\ x\ Vin = \frac{Ton}{Ton+Toff} \qquad (3)$$

Hasl PWM is obtained based on the work cycle with max PWM, as follows:

$$PWM = Duty\ Cyle\ x\ Max\ PWM \qquad (4)$$

Motor DC 24VDC 250W

The types of motorcycles used in electric bicycles are *Direct Current* (DC) with type *brushless* [16]. A DC motor is an electromechanical device that converts electrical energy into mechanical energy with direct current as a supplier of electrical energy. DC motors are the starting propulsion on electric bicycles.

Figure 7. Motor DC 24VDC 250W

RESULTS AND DISCUSSION

The results of the design of a solar electric bicycle based on *Pulse Witdh modulation* (*PWM*) on the *throttle* as a DC motor speed regulator were analyzed as follows:

Load Rate *Driver* Controller Power Measurement

The power test of the no-load motor controller is carried out to determine the voltage, current and normal power in the components of the electric bicycle is needed with a battery test scenario in full condition generated from a solar panel of 24.5V 7.5Ah with a 100% gas throttle pull, so that the performance of the electric motor works optimally. As for the test of the electric bicycle controller measured on the connected cable socket part, it is shown in Figure 8.

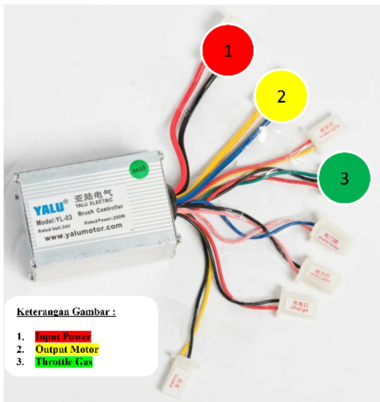


Figure 8. Controller Parts *Driver* 24V 240W

Based on Figure 8, the electric bicycle *driver* controller used is connected into three parts, namely the input voltage obtained from the battery, the output voltage to provide electrical energy to the DC motor and the *gas throttle* to regulate the speed of the motor which is intended to be the measurement results obtained in Table 1, with the power formula used to calculate the electrical power in an electrical circuit with Equation (5), as follows [17]:

$$P = V \, x \, I \qquad (5)$$

Where:

P : Power (Watts)
V : Voltage (Volts)
I : Arus (Ampare)

Table 1. Results of Driver Controller Power Measurement Without Load Rate

No Load

It	**Measurement Controls Driver**	***Throttle* Gas**	**Tegangan (Volts)**	**Current (Ampere)**	**Power (Watt)**
1	*Input* Power (Battery)	100%	24,5	1,75	42,8
2	*Output* (Motor DC)		22,7	1,80	40,8

In the table above, *the input* of the *driver* controller is obtained from the battery and *the output* voltage produced from the controller is connected to the DC motor with the maximum *throttle* speed, besides that it can be seen that the *input* voltage has a large difference in value from *the output* voltage, the difference in results is caused by the *driver* components which results in losses, so that the voltage obtained from the motor *driver* is reduced [18]. So the power produced at the *input* is greater than the *output*, this can provide power efficiency on the electric bike.

Measurement of Driver Controller Power *with* Load Rate

This test aims to determine the power of the electric bicycle controller with the presented load. Testing electric bicycles weighing 37kg and weighing people or drivers of 55kg, 65kg, 75kg and 85kg was carried out along flat roads without hills (uphill) at maximum speed. The measurement of the DC motor that is the wheel load to find out, the voltage, current, power and speed (km/h) generated are shown in Table 2.

Table 2. Measurement of Driver Controller Power with Load Rate

With Load

No	**Bike Weight (Kg)**	**Weight of people (Kg)**	**Tegangan Motor DC (Was)**	**Current Motor DC (Ampere)**	**Power Motor DC (Watts)**	**Speed Bicycle (Km/Jam)**
1	37	55	22,7	5,3	120,31	28

2	37	65	22,7	5,8	131,66	26
3	37	75	22,7	6,4	145,28	22
4	37	85	22,7	7,2	163,44	18

Results of the power graph of the driver controller with the load rate

The power of the electric bicycle controller is measured using a multimeter and a tamper with Persaman (5). The power of the electric bike is obtained based on the load of the driver (person) shown in Figure 9.

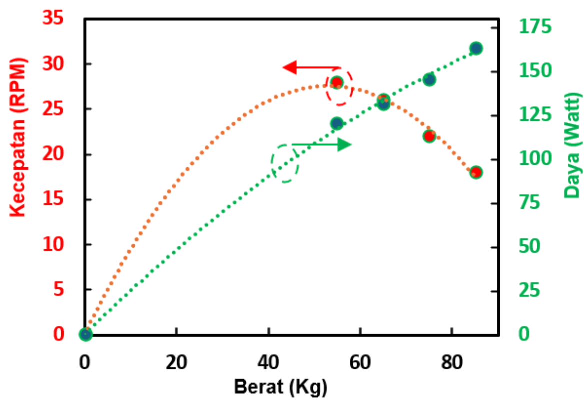
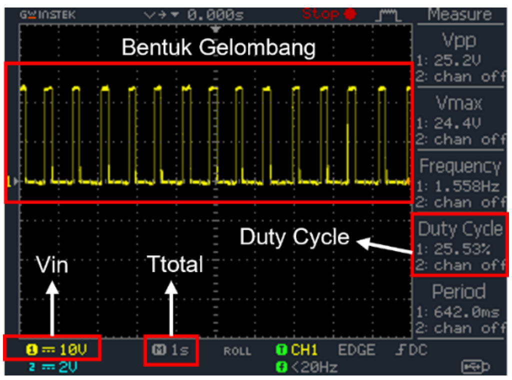


Figure 9. Electric Bike Controller Power Chart Results

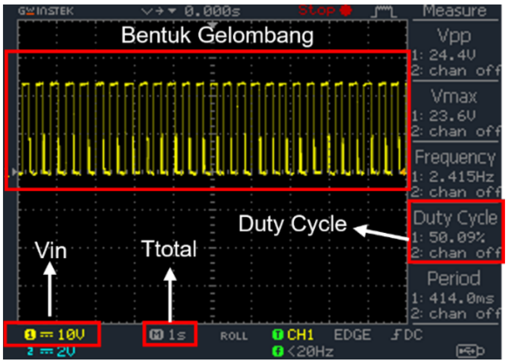
The results of the graph above show that the driver's load affects the speed rate of the electric bike, that the heavier the load generated on the driver (person), the greater the power generated by the load of the DC motor.

PWM Work Cycle Test Results

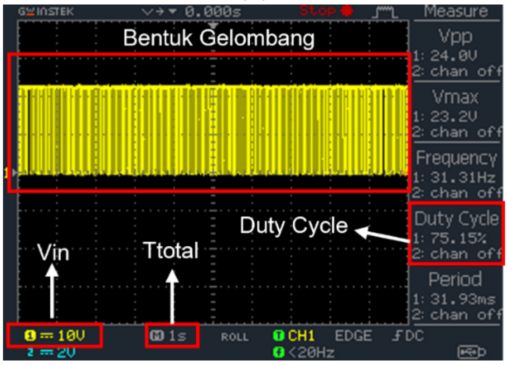
The results of *the PWM work cycle test* were carried out with values of 25%, 50%, 75% and 98% under normal conditions without the load of the driver (person) using measurements with an oscilloscope which can be seen in Figure 10.



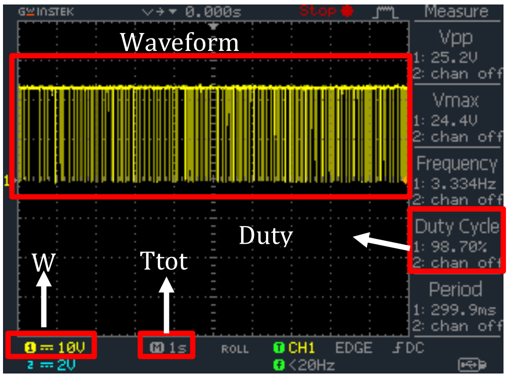
(a)



(b)



(c)



(d)

Figure 10. The duty cycle (*Duty Cyle*) PWM (a) 25% (b) 50% (c) 75% (d) 98%

The results shown in Figure 10 have the purpose of data analysis based on Equations (1) to (4), namely the work cycle that determines the *PWM* value to be used to find the *output* value and the value to be searched such as Ton, Toff, *PWM*, and Vout or can be seen in Tables 3 and 4.

Table 3. Value *Input* What has been determined

Duty Cycle	Ttotal (ms)	Max PWM	Vin (Was)
25%	1000	255	10
50%			
75%			
98%			

Table 4. Value *Output* What you get

Duty Cycle	Ton(ms)	Toff(ms)	PWM	V(*Out*)
25%	250	750	63,75	2,5
50%	500	500	127,5	5
75%	750	250	191,25	7,5
98%	980	20	249,9	9,8

In Table 4, it shows that the data generated by *Duty cycle*, *PWM*, V*out* is greater the value produced is the same as the result of the driver adjusting the *gas throttle* of the electric bicycle, if the driver increases the *gas throttle* value, the output voltage will be greater and the speed of the bicycle will increase. In addition, the graph data based on Table 4 is shown in Figures 11 and 12.

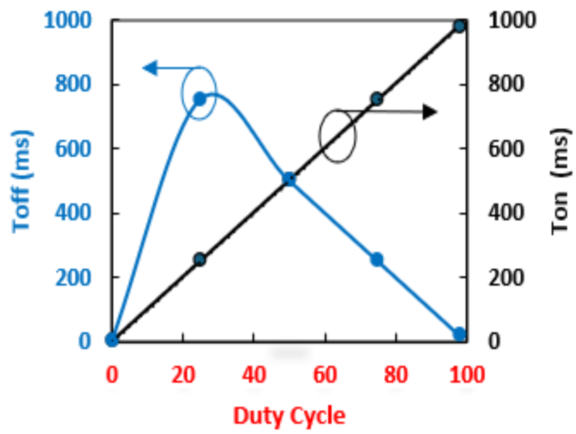


Figure 11. Graph Results *Duty Cycle* Against T*on*(ms) dan T*off*(ms)

Based on the results of the graph in Figure 11, it shows that the T*off* (ms) result decreases while the larger the duty *cycle* value produced, the more the T *on* value increases.

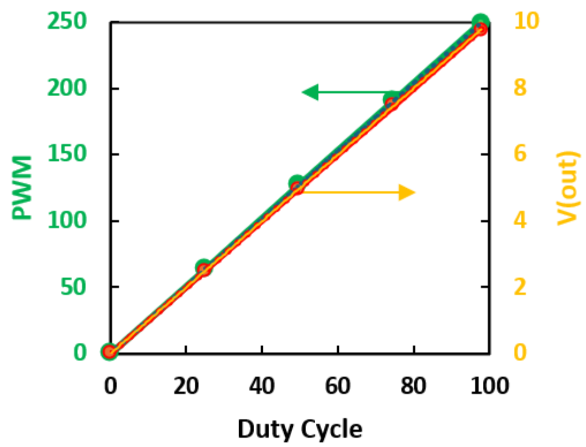


Figure 12. Graph Results *Duty Cycle* Against *PWM* and V*out*

Based on the results of the graph in Figure 12, showing that the results of *the duty cycle*, *PWM* and V*out* have increased values together, meaning that the greater the *value of the duty cycle* and *PWM*, the greater the V *out* value or *output* voltage produced and can vary depending on the condition of the *duty cycle* value which is controlled by the driver in regulating the speed of the electric bike.

PWM Test Results Against RPM

The PWM *test part* is carried out by measuring the speed of the DC motor using a tachometer manually, the data from the measurement results is carried out with the PWM results obtained against the Revolution Per Minute (RPM) with the understanding of the number of revolutions or rotation of a shaft in one minute [19]. The rotational speed of the electric bicycle wheel produced without the load of the driver (person) under normal circumstances shows *the performance* of the 250-Watt DC motor shown in Table 4.

Table 5. PWM Test Results against RPM

Duty Cycle	PWM	RPM
25%	63,75	957
50%	127,5	1650
75%	191,25	2089
98%	249,9	2648

Based on Figure 13, the graph results show that the larger the *duty cycle value*, the *greater* the RPM produced, meaning that it can follow the increase value produced linearly.

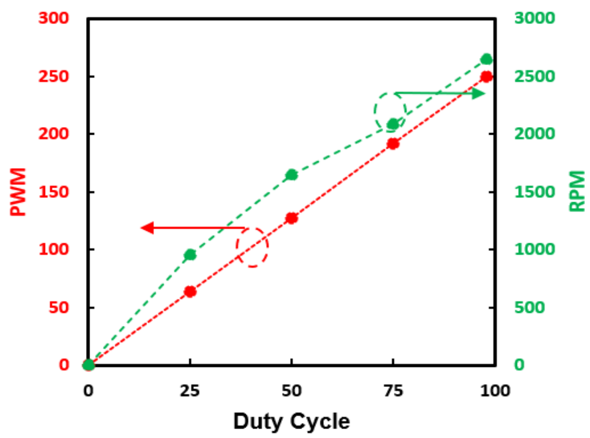


Figure 13. PWM Graph Results Against RPM

CONCLUSION

The conclusion from the results of the research that has been carried out is that design, measurement and testing are able to function properly. After measuring and testing *the performance of* the DC motor, it produces the power of the electric bicycle controller without load and the driver's load, where the weight of the bicycle alone produces 37kg plus the weight of the driver (person) variation of 55kg, 65kg, 75kg and 85 kg, with a minimum of 40 watts of electrical power and a maximum of 163 Watts, the power of the *driver* controller This shows that if the heavier the load generated on the driver (person), the greater the electrical power generated on the bicycle controller, then *the duty cycle* (work cycle) obtained from the measurement results using an oscilloscope of 25% to 98% get a maximum increase in Ton of 250-980ms, while the Toff result of 750-20ms gets a decrease in value and a maximum PWM value which was achieved of 249.9 following the results of 2648 rotations per minute with a maximum Vout of 9.8V, from the data obtained, of course, the performance of the 250 Watt DC motor worked well. For suggestions in the research that has been carried out by the researcher, there are suggestions that can be added, namely being able to calculate the power every hour produced from solar power in influencing the performance of the DC motor or the speed of the bicycle produced and can try to measure the work cycle (*duty cycle*) using an oscilloscope with the weight test of the driver (person) in order to get the results of increasing the data in the testing stage.

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