

# Analysis and testing of DC motor control system for electric bike

**A Parastiwi\*, P C M Al-Akbary and H K Safitri**

Department of Electronics Engineering, Politeknik Negeri Malang, Indonesia

\*parastiwi@polinema.ac.id

**Abstract.** The proposed electric bike is driven by using a 24V350WDC motor and VRLA 24V battery as a source of voltage. Input point settings are done by pressing the speed control button in the form of digital data, which is then converted to voltage by the microcontroller. The output of the microcontroller in the form of a PWM becomes input for the motor driver, where the output speed of the motor will be detected by the speed sensor. The automation used is the PI method using the Zeigler Nichols 2 tuning formula. The control method using PI had been analyzed and tested, resulting in  $K_p=3.37$  and  $K_i=0.73$ . The electric bike has been tested with different loads. The proposed electric bike was successfully controlled and able to be driven with a minimum speed of 5km/h and a maximum speed of 20km/h.

## 1. Introduction

Electric bikes are an alternative mode of transportation that can match the practicality of a motorcycle. There is a crucial changes and growing interest in cycling [1]. Electric bikes (e-bike) are generally the same as a traditional bicycle with the addition of a motor, battery and controller. The most widely used motor is a DC motor which has the advantage of better speed regulation, high dynamic response, high efficiency, long operating period, quiet operation, higher speed range [2]. DC motors are electromagnetic devices that convert electrical energy into mechanical energy. DC motors or often called direct current motors are more often used for purposes that require speed regulation.

In addition, the braking system on the e-Bike was done with a sliding pot where the shift lever is connected to the spring and gas on the handlebar in an opposite direction, so that when the gas on the handlebar is pulled and released suddenly the potentiator will return to the position of the resistance value the largest and the voltage that goes into the microcontroller is 0V which will cause the motor to stop [3]. The braking system is used to protect the DC motor so that no load is added to the motor when the brakes are pulled, this brake will be connected to the microcontroller, when the brakes are pulled it will automatically cut off the voltage flow on the DC motor, with this system break it is also expected to reduce energy discharges when braking.

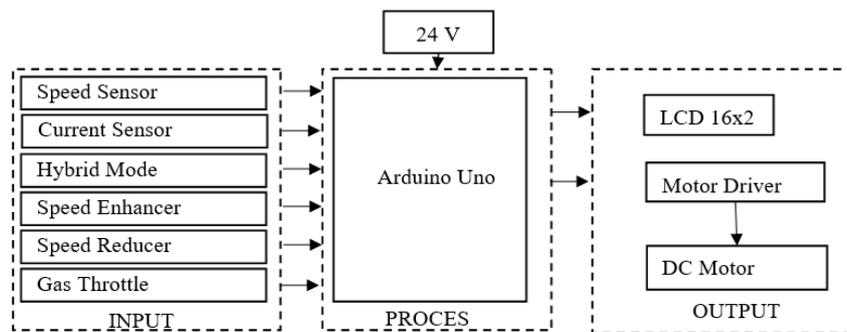
For the power source on the e-Bike DC voltage supply from the battery to the coil through a brush that touches the commutator, two segments are connected with two ends of the coil. The one-coil coil in the picture above is called the armature or commonly called the rotor. Armature is a designation for components that rotate between magnetic fields. The characteristic of a dc motor is the power needed for the torque or speed obtained which can be analyzed the working limits of the motor and the optimum working area of the motor.



In a previous study, Huda designed an e-Bike using a DC motor with a 350Watt voltage of 36V, a battery that used a type of Lithium 36V12Ah but braking was done mechanically so that the efficiency of energy usage became less [4]. Whereas Rachmadi controls the motor on the e-Bike by using Fuzzy logic has been able to be used to set the motor at a speed of 200RPM [5]. Langford states that e-Bike needs to be limited in speed to maintain the safety of the rider [6]. Whereas Salmeron's research which states that e-Bike designs that are more like traditional bicycles are more attractive to users are used as a foundation to use bicycles that are available in the market as the main material of design [7]. This paper will discuss the design analysis and testing of dc motor speed control for accelerating electric bike using the PI Method.

## 2. Electric bike design

The working principle of this Electric Bike is to use a 24V battery to provide voltage supply to circuits and components such as motors. The speed sensor installed with the rotating disk will provide an output in the form of a digital signal that corresponds to the speed of the DC motor. Input system which is a set point and functions to run the motor comes from the push button that is used to select the motor speed mode.



**Figure 1.** Proposed system block diagram.



**Figure 2.** Design and implementation of the e-bike with 350watt DC motor mounted on rear wheel.

LCD is used to display the speed on a motor with the parameters displaying the set point and present value. When the system is turned on, the motor driver starts working until it reaches the desired setpoint value with a maximum speed of 20km/h, then the Arduino as a microcontroller controls the motor speed based on the  $K_p$  and  $K_i$  values that had been entered. The proposed system block diagram of electric bike as seen in Figure 1 and the design and implementation of the proposed electric bike with motor mounted on rear wheel shown in Figure 2.

### 3. Methods

#### 3.1. Control system design

The most used controller tuning was published by Ziegler and Nichols are used to provide closed-loop responses that have one-quarter decay ratio with minimum settling time and minimum largest error. The PI controller in many cases has low computation time, easily implemented, and robust to load variation [8]. The Ziegler-Nichols method is more robust because it does not require a specific process model. In order to tune a controller using the Ziegler-Nichols method the Integral element of the PI controller are ignored. The Proportional element is used to find a  $K_c$  that will sustain oscillation. This value is considered the ultimate gain  $K_{cu}$ . The period of oscillation is the ultimate period  $P_u$ . This Ziegler-Nichols method consists of two steps which are determination of the dynamic characteristics of the control loop and estimation of the controller tuning parameters that produce a desired response for the dynamic characteristic from the first step [9]. Consequently, the application of set-point weighting and the modification of the tuning formula can be based simply on the knowledge of the normalised gain [10]. Ziegler-Nichols method are designed to give an amplitude ratio between subsequent oscillations [11].

The control system started from setting the values of  $K_p$  and  $K_i$  starting from zero which will then run the motor on an electric bike. The following step is to observe the graph display of the speed sensor and observe the motor rotation to find out whether the motorbike has been isolated or not and continues to increase the  $K_p$  value continuously to achieve isolation. If the motor has been insulated, and the graph has formed a continuation oscillation, then calculate the  $K_{cr}$  and  $P_{cr}$ . After that calculate the value of  $T_i$  using the values of  $K_{cr}$  and  $P_{cr}$ . By using the  $K_p$  and  $K_i$  values that have been obtained, then observe the motor rotation speed on the electric bike.

#### 3.2. Evaluation

The methodology used in this paper is the experimental method. The data collection carried out by systematically recording the results of the influence of relationships and differences in the changes that have been investigated. In taking the technical data used is a trial error technique and look for the optimal motor rpm that will be used to solve the problem.

### 4. Results and discussion

The control system is consisted of four elements: 1) PI controller is used to control the PWM quantity that enters the motor driver; 2) The driver is used to run dc motors on electric bikes; 3) Motor DC is used to run electric bikes; and 4) The speed sensor is used to see whether the motor's speed is like a predetermined set point, by placing the speed sensor on the motor shaft, then each change in speed will be read by the sensor.

#### 4.1. PI control design, testing, and analysis

In software design using the theory of Ziegler-Nichols to determine the value of  $K_p$ ,  $K_i$  according to the existing method, where both of these constants affect the system response. For planning the whole system testing is done using PI parameters according to the controller used in this system. The parameters tested:

- Up time (rise time/ $t_r$ ) is the time it takes for a response to rise from the percentage of 10% - 90% of the final value
- Delay time ( $t_d$ ) is the time needed for the response to reach the first half of the final value
- Peak time (peak time/Topping time  $t_p$ ) is the time it takes for the response to reach the peak of the first pass.

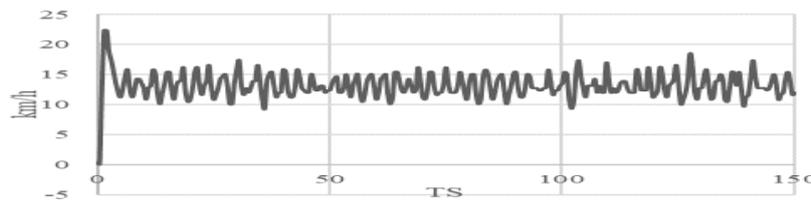
- Maximum surge (maximum overshoot/MO) is the maximum peak value of the response curve for values at steady state. The maximum surge can be expressed according to the equation below:

$$MO = \frac{y(tp) - y(\infty)}{y(\infty)}$$

- Steady State (ESS) Error is the steady state error difference of the system with a predetermined set point. To determine the steady state error, the steady state value must first be known in the system. ESS Calculation:

$$ESS = \frac{\text{Steady state} - \text{Setpoint}}{\text{Setpoint}} \times 100\%$$

The way to find the value of PI is to give a value of 0 to  $K_i$ . Then the next step is to increase the  $K_p$  value from a small value from 1 to find the value where the response system will be insulated, with the condition that the response must be stable in isolation. After getting the  $K_p$  value, then look for the  $K_{cr}$  value. Whereas for the period value on the wave is called  $K_{cr}$ . The period value on the wave is called the  $P_{cr}$ . After obtaining the  $K_{cr}$  and  $P_{cr}$  values, the values of  $K_p$  and  $K_i$  can be obtained through the Ziegler Nichols 2 formula, using formula in Figure 3.



**Figure 3.** The Graph of motor when the value of  $K_p$  is set to 7.5.

From the graph in Figure 3 shows that the test with a value of  $K_p = 7.5$  shows that the response has passed the continuation oscillation in seconds 6. In accordance with the rules of tuning PI the  $K_p$  value obtained can be used to find the value of  $T_u$ . Setting of  $K_p$  and  $K_i$  is as follows:

$$\begin{aligned} K_{cr} &= 7.5 \\ T_1 &= 6.5 \\ T_2 &= 12 \\ T_s &= T_2 - T_1 = 12 - 6.5 = 5.5 \\ P_{cr} &= 5.5 \end{aligned}$$

$$\begin{aligned} \text{Kp was calculated as } K_p &= 0.45K_{cr} \\ &= 0.45 \times 7.5 \\ &= 3.37 \end{aligned}$$

$$\begin{aligned} \text{Ti was calculated as } T_i &= \frac{1}{1.2} P_{cr} \\ &= \frac{1}{1.2} 5.5 \\ &= 4.58 \end{aligned}$$

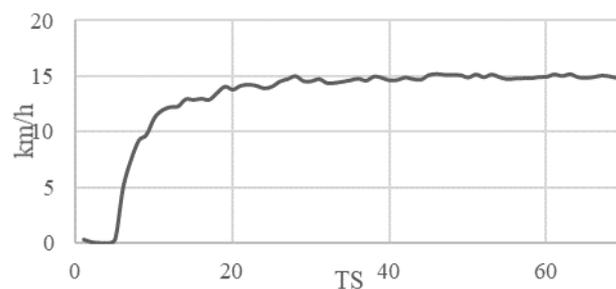
$$\begin{aligned} \text{Ki was calculated as } K_i &= \frac{K_p}{T_i} \\ &= \frac{3.37}{4.58} \\ &= 0.73 \end{aligned}$$

Tu values are taken from the difference between the waves that have the same height. The following are calculations according to the Zeigler Nichols 2 table. From the analysis,  $K_p$  is set to 3.37 and  $K_i$  to 0.73.

#### 4.2. No-load testing

First, this test is done by entering the values of  $K_p$  and  $K_i$  one by one. First of all, the system will be given  $K_p$  control only. This PI control has a function to adjust the motor speed RPM. This test is done by taking data in the form of testing the motor rotational speed response using PI control. The following is a motor test that has been inputted with a PI value without using a load:

- In testing this first system uses PI control without using load. The reaction curve method for retrieving data is done by entering a value:  $K_p = 3.37$ ,  $K_i = 0.73$ , and set point 15. The response results can be seen in the Figure 4.



**Figure 4.** No-load Testing Response with  $K_p = 3.37$ ,  $K_i = 0.73$ , and set point 15.

After obtaining a system response graph, it can be seen when the motor is controlled using a PI without using a load, the reaction curve shows that the response system has the following specifications:

- Rise time (rise time): Up time ( $t_r$ ) is the time required for the response to rise from the percentage of 10% -90% of the final value is 19.5s
- Delay time ( $t_d$ ) is the time needed for the response to reach the first half of the final value  $7 \times 1.5 = 10.5s$
- Peak Time ( $t_p$ ) is the time it takes for the response to reach the peak of the first pass 21.3s
- Similar sequence has been done to three other attempts as seen in Figure 4.

#### 4.3. Load testing

This test was carried out with the aim to determine whether the motor that has been controlled will experience recovery or not when the motor is experiencing a load. This test was taken with a set point value of 11km/h and 20km/h with a load of 50kg and 60kg in the terrain of a ramp of  $15^\circ$ . The results obtained from this test can be seen in Table 1.

**Table 1.** Load testing result.

	First Response	Second Response	Third Response	First Response	Second Response	Third Response
Load	50 kg	50 kg	50 kg	60 kg	60 kg	60 kg
Set Point	11 km/h	11 km/h	11 km/h	20 km/h	20 km/h	20 km/h
Speed	10 km/h	11 km/h	11 km/h	12 km/h	10 km/h	7 km/h
Current	4.10 A	3.70 A	3.70 A	3.10 A	4.10 A	4.80 A
Power	65.60 W	61.05 W	61.05 W	54.25 W	65.60 W	71.04 W

From Table 1, it can be seen that there is change in the present values. The response generated by the motor at a 50kg load is almost close to the Set Point value of 10km/h when the terrain of the ramp is

15° with a power of 65.60W, the current shown on the LCD is 4.10A. In the next phase, there is an increase in the value of the Present Value and reaches the Set Point value which is equal to 11km/h. This condition occurs because the PI control recovers the motor speed response to return to the Set Point value when the motor has passed through the ramp road. The resulting power is 61.05W with current of 3.70A. After the motorbike goes back through the flat road field, there is an increase in the PV value which is equal to 13km/h and exceeds the Set Point value. The current generated is -3.20A with a power of -55.68W.

In addition to the 50kg load change to a load of 60kg with a terrain of a 15° incline, it can be seen that when the bike starts passing the incline the Present Value value starts to decrease from the set point of 12km/h with a current of 3.10A and power of 54.25W. The impairment condition occurs because the condition of the motor is burdened by the terrain of the ramp. The resulting current is 4.10A with a power of 65.60W. In the table above, there is a significant decrease in the Present Value by reaching 7 km/h on the 20 km/h set point. This condition is caused by a 60Kg load with terrain ramp, so the motor RPM decreases. As a result, the resulting current becomes greater, namely the value of -4.80A and power -71.04W.

## 5. Conclusion

From the research that has been done, it can be concluded that Hybrid Electric Bikes design have been successfully implemented. The proposed hybrid electric bike was designed using a 24V DC motor and 24V battery. The control of motor speed using the PI method runs well in which the motor can provide a suitable response that matches the set point. The results of controlling motor speed on Hybrid Electric Bike using the PI method obtained a value of  $K_p = 3.37$  and  $K_i$  value = 0.73. The derived constant calculated using the Ziegler Nichols 2 tuning formula. When the 50kg load on the terrain of the 15° incline with a speed of 11km/h is obtained a steady speed at 10km/h, thus lacking accuracy of speed of 9%. Whereas the load of 60kg in the terrain of the 15° incline with a set point value of 20km/h produces a stable speed at 7km/h, thus lacking speed accuracy of 35%.

For further research, some improvements can be done such as the use of Rotary Encoder sensors with a greater number of holes so that measurement errors will be smaller and speed measurements will be more precise. The method used can be added with derivative control to see the motor rotational speed response. The algorithm used can be replaced by the Fuzzy Logic algorithm to compare the motor rotation response.

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