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# Monitoring System Design of ECU (Electrical Control Unit) in Increasing Performance Efficiency of the Direct-Current Motor in Electrical Vehicle Using Fuzzy Logic

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***Abstract***- Electronic Control Unit (ECU) is an essential element in the process control and measurement of energy consumption in an electrical vehicle. For improving the work efficiency of DC motors in electric cars, it is required to add the fuzzy control monitoring system for remote controlling. In this study, there are two testing modes, namely the ECO Mode is a mode with the addition of fuzzy control, so that the PWM output is adjusted automatically while the sports mode is a non-fuzzy mode with PWM output was done manually. The results of the measurement sensor have an error value compared with measurements of the instrument. An average error of measurements of current, voltage and the RPM is 1.03%, 0.18%, and 0.08% respectively. The test data indicated if the measured current is 13,2A with RPM 163, the setting the current cut-off was 7A, and it automatically causes the motor stopped for 3 seconds and after restarting the PWM output is at 90. When ECO mode run, the time required the electric cars to pass five rounds at each cycle distance of 300 meters is approximately 5 minutes with an energy of 15.47 Wh while in sports mode, it takes about 6 minutes with an energy of 20.498 Wh.

***Keywords***- *Efficiency, ECO Mode, Sports Mode, DC Motors, System ECU*

## I. Introduction

The electric car is the car of the future because this car has high efficiency. This is because it applies clean energy without emitting $CO_2$ so that it has no contribution to impact in the climate change. Besides, it also is assumed that it is optional to be able to answer problems on energy resources limitation even now it tends to be exhausted. This is due to the limitations of the fossil energy sources, even today tend to be depleted. Electric cars have several advantages over cars with conventional fuels. This car is 100 percent free emissions. The engine is very smooth, not causing noise pollution and conserves more energy, and has a lifetime of up to 90 years if driven 50 miles per day.

In addition, the development of electric vehicle technology during this period began to grow rapidly. The cost of rechargeable electric cars are also very affordable, the average electric car recharge cost 2 cents per mile compared to a conventional-fueled vehicle, which cost 12 cents per mile. This car has lower maintenance costs, compared with ordinary cars, because it has about 5 parts in its engines, compared with ordinary cars that have hundreds of components in internal combustion engines. Important components in electric cars are composed of an electric motor, the battery, the gearbox wheels. Recently, inseparable part of each vehicle is computers. It may supervise and take over virtually the functions of all vehicle, but worked and viewed a lot of additional data as well, which help a lot to make comfortable and safe. The acquired outcome depends on accuracy, or the situation is displayed on the monitor and the decision depends on the human [8-9].

One of the improvement efforts of car performance is employing ECU to get high efficiency. ECU often called by Electronic Control Unit, is a critical part which has the authority to perform optimation of electricity on the vehicle i.e process controlling and current measurement. It still has problems on Electronic Control Unit (ECU). Usually, the monitoring and measurement of current or voltage has been done manually and must be directly related to the object. This resulted in the process of controlling electric cars to be longer and considered less profitable. It is necessary to make a system which can monitor and control current and voltage measurements automatically using the wireless network. This is called by monitoring system as well. With this control system, the control and data of current and voltage measurement results can be done in real time using the computer, and it is expected to improve the working efficiency of the electric car.

Some researchers have investigated performance improvement by regulating System Cooling [11], battery behavior, battery settings, battery transmission systems and ECU systems using Computer and Network [10]. But there has been no performance improvement results by way of monitoring system without wiring.

This research used fuzzy logic as a means of monitoring and controlling the readings of voltage, current and power consumption. The data was transmitted by wireless as measurement data. In addition to current monitoring and voltage measurements, the system can perform PWM control and energy management of ECU (Electronic Control Unit) devices remotely via computer as well.

## II. THE MATERIAL AND METHOD

As to alleviate the design of the system, it was required some components of the Electronic Control Unit and supporting materials as illustrated in figure 1. Such devices and materials including batteries, INA219 sensors, voltage divider sensors, magnetic sensors, DC motor controls, DC motors, Arduino Uno, 915 MHz Radio Telemetry modules, SD and Personal Computer (PC). Of the several tools and materials have their respective functions in the system circuit. The materials used in this research are: Modules for Arduino, electric current sensor Module and Module of the voltage sensor. In this system, the microcontroller used in the form of Atmega 328P (Arduino UNO R3) with 22 lines i/o, 32 KB flash memory, 6 channel PWM, 8 channel 10-bit ADC, 2 channel Timer/Counter 1 8-bit channel Timer/Counter, 16-bit and interface USART, SPI, I2C. The tools needed to do this are: Avometer, Tachometer, Solder and High-speed Computer.

Motor drivers on the tool were used to control the engine on the Electric Car. This motor driver circuit consisted of several main components namely battery, relay, diode, resistor, capacitor, IC7812, BC574 transistor, optocouplers 817, and MOSFET.

The circuit obtained a voltage source from the battery. To be able to rotate the motor, the relays and all components in the circuit must be activated. To activate it, the required voltage was 12V which was obtained after passing IC7812. The relay acted as a circuit breaker or an electrical current from the source to the circuit. Meanwhile, to turn on and off this relay using transistor switching, the transistor used was NPN BC547 transistor and for setting PWM used optocoupler and MOSFET K4145. The image of the motor driver circuit can be seen as shown in Figure 2.

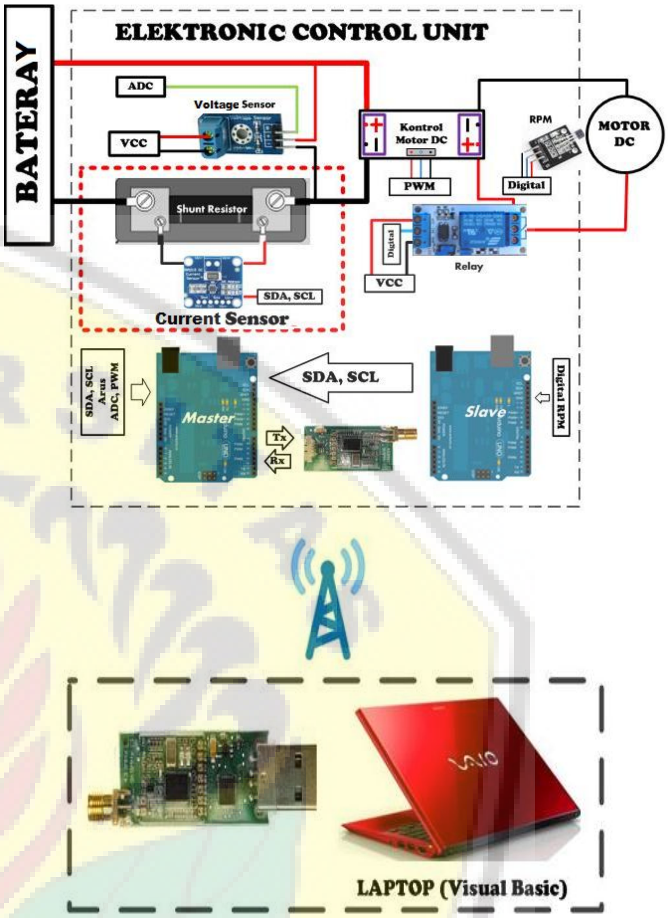

Figure 1. Block diagram of ECU control system of motor DC

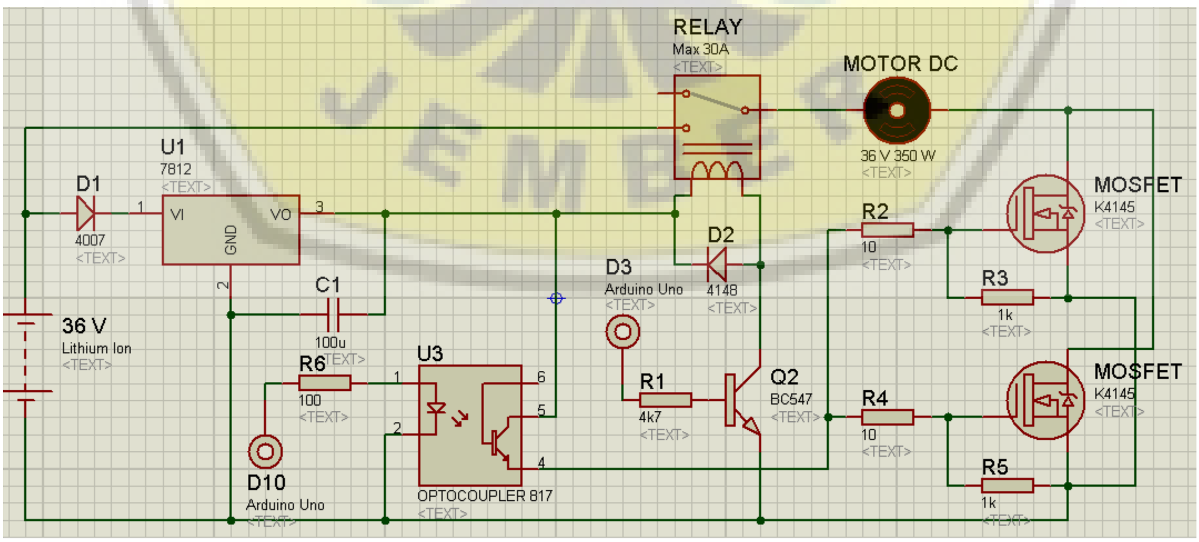

Figure 2. DC Motor Driver Circuit



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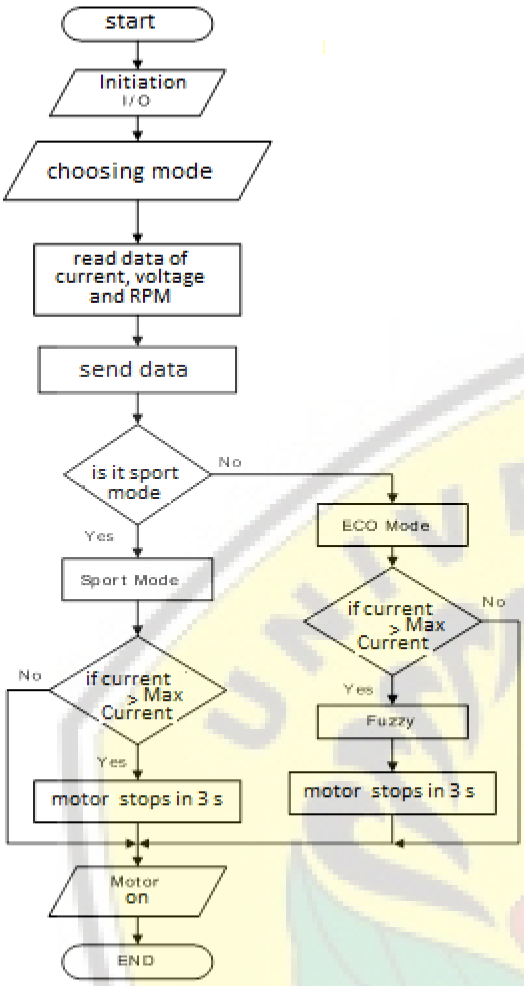


Figure 3. Flow Diagram of ECU System

The Fuzzy set was used to extend the range of characteristic functions so that it can include real numbers at intervals between 0 and 1. So that the values obtained are not just two kinds of true (1) and false (0), but still there are values that lie between Right and wrong. In this research, Fuzzy is used to manage ECU performance. There were two Memberships of Fuzzy used i.e. currents and RPM.

TABLE I. PARAMETER SET OF CURRENT

| Parameter | Value |
|---|---|
| Low Current (AR) | 0 – 6 |
| Moderate (AS) | 4 – 11 |
| High (AT) | 9 – 15 |

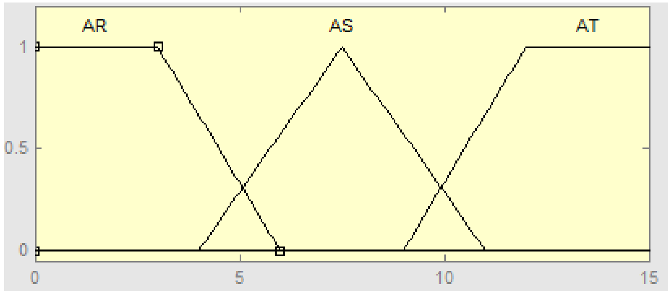


Figure 4. Representation of the current variable of fuzzy set

Here is the formula used to set current parameter above:

$$\mu \text{ Low Current (AR)} \begin{cases} 1 & : \rightarrow x \leq 1{,}5 \\ \frac{(3{,}5-x)}{(3{,}5-1{,}5)} & : \rightarrow 1{,}5 \leq x \leq 3{,}5 \\ 0 & : \rightarrow x \leq 3{,}5 \end{cases}$$

$$\mu \text{ Moderate Current (AS)} \begin{cases} 0 & : \rightarrow 3 \leq x \geq 7 \\ \frac{(x-3)}{(5-3)} & : \rightarrow 3 \leq x \leq 5 \\ \frac{(7-x)}{(7-5)} & : \rightarrow 5 \leq x \leq 7 \end{cases}$$

$$\mu \text{ High Current (AT)} \begin{cases} 0 & : \rightarrow x \leq 6{,}5 \\ \frac{(x-6{,}5)}{(8-6{,}5)} & : \rightarrow 6{,}5 \leq x \leq 8 \\ 1 & : \rightarrow x \geq 8 \end{cases}$$

TABLE II. PARAMETER SET OF RPM

| Parameter | Value |
|---|---|
| Low RPM (RR) | 0 – 180 |
| Moderate RPM (RS) | 130 - 350 |
| High RPM (RT) | 300 - 500 |

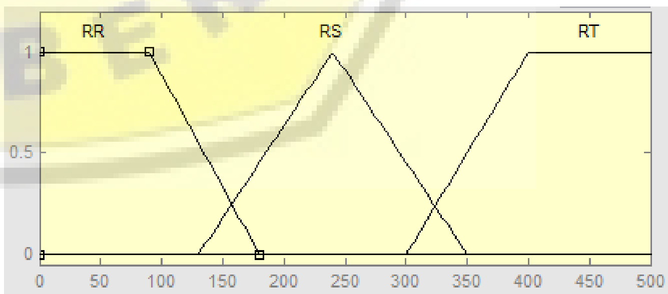


Figure 5. Representation of RPM variable of fuzzy set

The formula of the current parameter settings are as follows:

$$\mu \text{ Low RPM (RR)} \begin{cases} 1 & : \rightarrow x \leq 100 \\ \frac{(200-x)}{(200-100)} & : \rightarrow 100 \leq x \leq 3{,}5 \\ 0 & : \rightarrow x \leq 200 \end{cases}$$

$$\mu \text{ Moderate RPM (RS)} \begin{cases} 0 & : \rightarrow 175 \leq x \geq 350 \\ \frac{(x-175)}{(260-175)} & : \rightarrow 175 \leq x \leq 260 \\ \frac{(350-x)}{(350-260)} & : \rightarrow 260 \leq x \leq 350 \\ 0 & : \rightarrow x \leq 325 \end{cases}$$

$$\mu \text{ High RPM (RT)} \begin{cases} \frac{(x-325)}{(425-325)} & : \rightarrow 325 \leq x \leq 425 \\ 0 & : \rightarrow x \geq 425 \end{cases}$$

TABLE III. FUZZY'S OUTPUT

| Parameter | Nilai |
|---|---|
| Stop | 0-5 |
| Start | 5-10 |

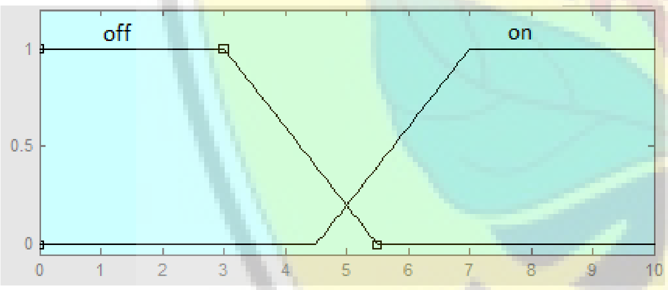


Figure 6. Representation of the current variable of the fuzzy set

The formula of output's parameter set are as follows:

$$\mu \text{ Off} \begin{cases} 1 & : \rightarrow x \leq 3 \\ \frac{(5{,}5-x)}{(5{,}5-3)} & : \rightarrow 3 \leq x \leq 5{,}5 \\ 0 & : \rightarrow x \leq 5{,}5 \end{cases}$$

$$\mu \text{ On} \begin{cases} 0 & : \rightarrow x \leq 4{,}5 \\ \frac{(x-4{,}5)}{(7-4{,}5)} & : \rightarrow 325 \leq x \leq 7 \\ 1 & : \rightarrow x \geq 7 \end{cases}$$

## III. RESULT AND DISCUSSION

### A. *Energy Measurement*

Energy measurement in this research consists of a current sensor and voltage measurement. The current sensor testing was performed, so that the current sensor results measured values corresponding to the measurement results of the measuring instrument. The measuring apparatus used as a comparison was the amperemeter. The current sensor used in this research was INA219 with additional shunt resistors in the module mounted in series after the battery before the DC motor control by the block diagram of the system in Figure 5. It was Obtained 10 sample data of results of current sensor testing compared with amperemeter as in table 4 below.

TABLE IV. CURRENT SENSOR TESTING

| Amperemeter (A) | Current Sensor (A) | *Error* % |
|---|---|---|
| 0,33 | 0,32 | 3,03 |
| 0,54 | 0,53 | 1,85 |
| 0,64 | 0,64 | 0 |
| 0,74 | 0,74 | 0 |
| 0,9 | 0,91 | 1,11 |
| 1 | 1,02 | 2 |
| 1,15 | 1,16 | 0,87 |
| 1,25 | 1,26 | 0,8 |
| 1,33 | 1,33 | 0 |
| 1,53 | 1,52 | 0,65 |
| Average of Error % | | 1,03 |

It can be observed that the results of current sensor testing compared with amperemeter measurement has an average error value of 0.99% as seen in Table 4. Current sensors used have a high degree of accuracy.

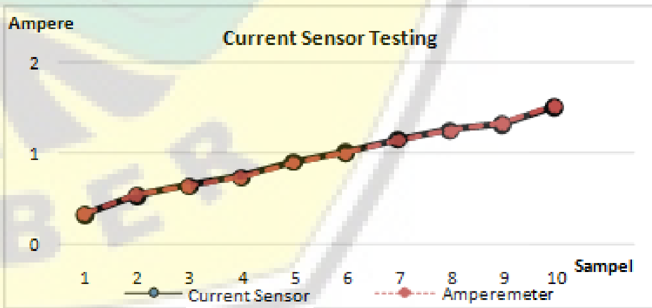


Figure 7. Current Sensor Testing

The graph of the difference in current sensor and measurements from ampere meter can be seen in Figure 7. Testing the voltage sensor was executed to get the measurement results of sensor voltage values according to the results of voltmeter measurement. The voltage sensor used is a voltage divider circuit arranged in parallel with the battery as in the block diagram of the system image 3.2. The result of the test of the voltage sensor compared to the voltmeter measurement can be seen in the following table 4.2.

TABLE V. VOLTAGE SENSOR TESTING

| Voltmeter (V) | Voltage Sensor (V) | *Error* % |
|---|---|---|
| 33,87 | 33,8 | 0,21 |
| 34,27 | 34,22 | 0,15 |
| 35,36 | 35,34 | 0,06 |
| 36,08 | 36,04 | 0,11 |
| 37,88 | 37,83 | 0,13 |
| 38,59 | 38,56 | 0,08 |
| 39,48 | 39,41 | 0,18 |
| 40,18 | 40,15 | 0,07 |
| 41,17 | 41,14 | 0,07 |
| 42,55 | 42,23 | 0,75 |
| Average | | 0,18 |

The comparison of the voltage sensor to voltmeter measurement was shown in table 5. It was obtained by taking 10 samples of data then the average value of measurement error was calculated to equal to 0.18%.

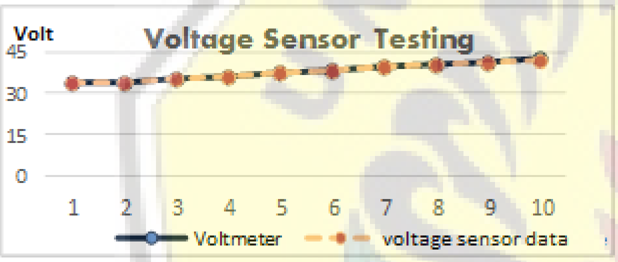


Figure 8. Voltage Sensor and Measurement Comparison

The Current sensors showed a high degree of accuracy. The graph of the difference in voltage and voltmeter measurement can be seen in Figure 8.

*B. Motor Control*

In fact, there are two things that can affect the value of the torque and speed of a DC motor is separate amplifier type, i.e. the voltage and flux field. This can we observe from the basic equation of DC motor, as follows:

$$V = Ea + Ia\ Ra \quad (1)$$

$$Ea = c\ n\ \Phi \quad (2)$$

$$Vt = c\ n\ \Phi + Ia\ Ra \quad (3)$$

$$n = \frac{V_t - I_a.R_a}{c.\Phi} \quad (4)$$

RPM test was performed to get the measurement results of RPM sensor values according to tachometer measurement results. The test was conducted by taking 10 samples of data with parameters of the measurement of the number of magnetic rotations across the magnetic sensor and then compared with the measurement of rotation based on the tachometer. Magnetic sensor test results compared with tachometer can be seen in table 6 below.

TABLE VI. RPM SENSOR TESTING

| Tachometer | Sensor RPM | *Error* % |
|---|---|---|
| 198,90 | 198,75 | 0,08 |
| 201,55 | 201,35 | 0,10 |
| 259,00 | 259,28 | 0,11 |
| 299,98 | 300,23 | 0,08 |
| 355,22 | 355,24 | 0,01 |
| 357,00 | 356,52 | 0,13 |
| 411,20 | 410,85 | 0,09 |
| 447,36 | 447,75 | 0,09 |
| 469,00 | 468,77 | 0,05 |
| 470,00 | 470,32 | 0,07 |
| *Error average %* | | 0,08 |

It can be recognized the comparison of magnetic sensor measurement with tachometer measurement that Current sensor compared with ampere meter measurement has an average error value of 0.08%.

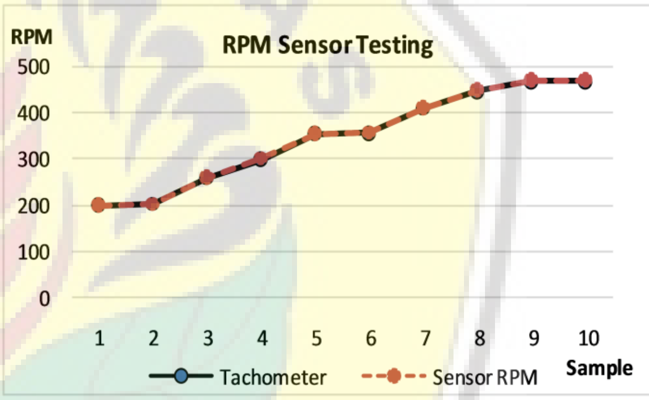


Figure 9. RPM Sensor Testing

RPM sensor adapted a high degree of accuracy. The graph of the difference of measurement of RPM and tachometer can be noticed in figure 9.

*C. Managing Performance of ECU*

The ECU (Electronic Contol Unit), System Monitoring Test with Sports Mode, was performed to determine the performance of ECU System without fuzzy. This sports mode was a mode with initial manual PWM values. The average PWM value used in this sports mode was 229, this was because at the time of taking track data in wet conditions to avoid the risk of slipping. However, if the current exceeds the maximum value that has been determined, then the motor will automatically stop for 3 seconds and then will activate again with the same PWM value with the PWM value before the cut-off. The existence of cut-off can occur due to overload such as bend, incline or bumpy road so it can cause high peak power value. The graphical results and analysis of the test using the sports mode were charted below.

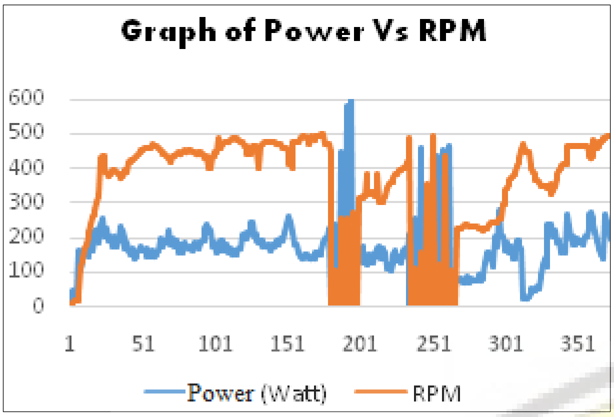


Figure 10. Power and RPM Electrical Vehicle

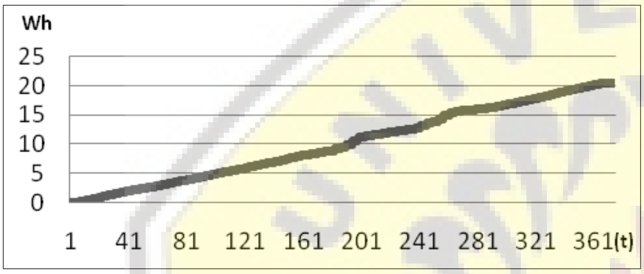


Figure 11. Electrical Vehicle Energy

The RPM value was strongly influenced by the load on the motor when the load value on the motor was high then the RPM value will decrease. But when the load value on the high motor will cause high current value so that the power value will be high as well. It can also be stated that the power value with RPM was inversely proportional. The condition was influenced by the transmission used in electric cars, with a ratio of 1: 6 teeth, so that it owned a large torque. The superiority of torque was great when in high RPM continuously resulting in a decreased current. Therefore, when the value was at high power then the value of RPM will be low and vice versa. But in the note in the use of the same PWM value.

The ECU (Electronic Control Unit) Monitoring System Testing with ECO mode was performed to determine the performance of ECU System with fuzzy control. This ECO mode was a mode with PWM output automatically after a cut-off in an electric car and basically, this ECO mode, as well as sports mode for the initial PWM assignment, was performed manually. The average PWM value used in this ECO mode were 229 and 255, this is because at the time of track data retrieval in dry condition. Yet, that distinguished from the sports mode happened when the current exceeded the maximum value or in a cut-off state, then automatically the motor will stop for 3 seconds and then will come back to start with an automatic PWM value in accordance with the given fuzzy. The existence of cut-off can occur due to overloads such as bend, incline or bumpy road so that it can cause high peak power value.

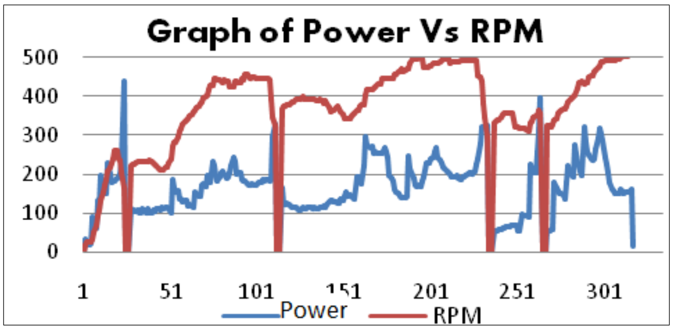


Figure 12. Relationship of Power and RPM of Electrical Vehicle

At the time of data retrieval occurred four times power surge (in units of watts) with four times defuzzification process and was obtained power value that was equal to 438,29; 327.19; 325,85; and 395.47 then returned in a stable state. At 23:29:38 for the current value of 13.15, the value of RPM and PWM were 163 and 178 respectively, then the motor in cut-off condition for 3 seconds where the current maximum value was set 6 ampere due to the fuzzy control.

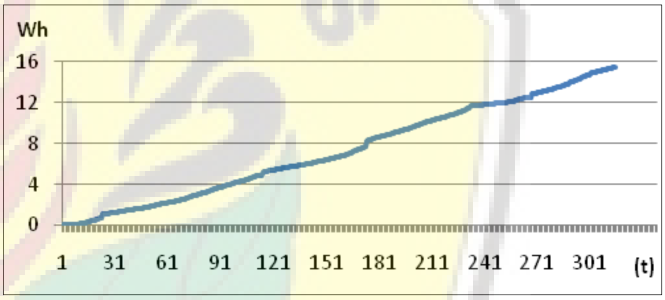


Figure 13. Electrical Vehicle Energy

The PWM value changed automatically into 90. This can be proved by defuzzification results in Matlab that has been in accordance with testing conditions on fuzzy control during ECO mode. Similarly, the fuzzy control was active at 23:31:04; 23: 33: 04; 23:33:35, defuzzification result on Matlab was according to ECU system testing of this ECO mode.

## IV. Conclusion

Based on the results of the study, a concise conclusion can be drawn that: the average error of the measurement of current, voltage and RPM reached 1.03%, 0.18 %, and 0.08% respectively. On ECU System fuzzy control applied to ECO mode. If the measured current was of 13.2A with RPM 163 and the current cut-off setting was of 7A, the system made the motor automatically shut down for 3 seconds and after the resumption, the measured PWM output was of 90 having a controlling system. The results on the ECU system showed the amount of energy consumption in the sports mode of 20.498

Wh, while in the ECO mode was obtained a smaller at 15.47 Wh.

## NOMENCLATURE

| | |
|---|---|
| n | velocity of rotation (rpm) |
| V | voltage (Volt) |
| c | constanta |
| R | resistant (Ohm) |
| I | current (Ampere) |

Greek letters

| | |
|---|---|
| Φ | Magnetic flux (Wb) |

Subscripts

| | |
|---|---|
| an | anchor |
| t | flops |


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