Driveline Analysis of Electric Vehicle Conversion Performance

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Abstract: Along with the development of electric vehicle in Indonesia, one of the effort from Universitas Indonesia is developing on electric car that converted from usual car. But, after it was converted from conventional car which named Makara Electric Vehicle 02 still need crosschecking on several aspects, especially on braking. The author will focus on the effect of center of gravity and total mass to the braking characteristics which is braking forces and stopping distance by doing weigh testing and after that data processing to the characteristics that needed. The author also explained data result and compared it to the same M1 vehicle type before it was converted. The result of the test showing that center of gravity MEV 02 start from 0,57-0,62 meter along increase in passengers, for braking force start from 4900-6200N along increase in passengers, and for stopping distance start from 2-18m for velocity on 20 km/h, 40 km/h, and 60km/hours. Transportation is one of the biggest sectors that contributes to pollution in cities area. This happens because of the exhaust gas produced by the vehicles contains dangerous gases that causes air pollution. Electric vehicle is the alternative mode of transportation that does not produce any exhaust gas at all, yet it will take a long time for the masses to adapt to this new source of energy for the vehicle, and that was when the idea came up to convert a conventional vehicle. Makara Electric Vehicle 02 is an electric vehicle conversion project, using Daihatsu Ayla as the base platform, the internal combustion engine is replaced with AC Induction Motor 7.5 kW, while all the rest of the driveline components remains the same to use the standard components. This research will test the vehicle performance using dynamometer, calculating the resistance force working on the vehicle, and the maximum road incline handled by the vehicle by calculating tractive effort produced by the vehicle. The result is that the vehicle produced maximum power of 12.08 HP, with maximum torque of 86.25 Nm at 750 RPM. With used of the dyno test it is measured that the maximum vehicle speed is 46 km/hour. The transmission mapped the powertrain RPM to work and the range of 1237-3759 RPM on first gear, 776-3527 RPM on second gear, 720-2624 RPM on third gear, 692-1989 on fourth gear, and 566-1626 RPM on fifth gear. The maximum road incline is 22 degree of slope. When the battery condition is not in a full state of charge, the performance of the motor dropped 29% form the maximum capabilities of the motor.

1 INTRODUCTION

The development of electric vehicle is continue expanding in the world. The demand of electric vehicle and the infrastructure that supporting electric vehicle continue to expand (Zainuri et al., 2017). This issue is getting attention from Universitas Indonesia to always develop the electric vehicle. Universitas Indonesia is conducting research on electric vehicle especially conducting researching on conversion vehicle from conventional vehicle. This thing become research target especially on urban communities who are matched with economic, social, and legal studies. Electric vehicle can produce four times less particulate and twenty times less nitrogen oxides (Rozman et al., 2019). This advantage suitable with Indonesia's purpose to reducing the country's emission gas (Spanoudakis et al., 2019). Another objective on this research is to prove that people can convert conventional car into electric car according to their budget, however, after doing the conversion, there are many things that needed to be tested for the

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conversion car can meet the standard for the vehicle in general. There are still many things that need to be tested for the conversion car that developed by Universitas Indonesia, such as the influence of the vehicle's center of gravity and also the braking characteristics of the conversion car. This research was developed to analyze the data of center of gravity, and braking characteristics for further development. Air pollution in Jakarta is rapidly increasing from year to year, based on the data collected by the Air Quality Stations in Jakarta, it shows that from 2016 to 2019, the air quality considered as 'not healthy' has drastically increased. One of many factors that contributes massively to this issue is the gas exhaust produced by vehicles. This problem is also faced by developed countries as well, hence the focus on which to increase the use of electric vehicle instead of internal combustion engine (ICE) vehicle has been massively progressing (Zainuri et al., 2017).

It would take some time for the masses to adopt this new mode of transportation of using electric vehicle, for the change would create some new obstacles in the way. In the case of Indonesia, currently electric vehicles are not sold commercially from the manufacturers to be bought by the customers, on which this issue challenged Universitas Indonesia to start a research on converting conventional ICE vehicle to electric vehicle. The purpose of the research itself is to prove whether converting a vehicle would be more cost-efficient. The baseline of the vehicle that is converted is Daihatsu Ayla with 998cc engine with 5-speed manual transmission, converted to use AC Motor 7kW powered with lead-acid battery, but still using the standard drivetrain configuration. The project is named Makara Electric Vehicle 02 (MEV 02).

The main focus on this paper is to analyse whether MEV 02 can perform well enough to be used in a real-world scenario by considering the performance output of the vehicle by pairing the standard drivetrain configuration with the new powertrain of the vehicle.

2 LITERATURE REVIEW

2.1 Electric Conventional Vehicles

An electric conversion vehicle is a vehicle designed from a conventional vehicle with a fossil fuel engine (internal combustion motor) replaced with an electric motor as a propulsion with a power source from a DC battery which is adjusted to the capacity of the motor driven. By replacing the internal combustion motor with an electric motor, many components are no longer needed, such as the entire fuel system, air filter, exhaust system and engine control unit. However, there are also some components that can still be utilized because they still perform the same function, such as the transmission, clutch, and also all drivetrain components of the vehicle (Adhitya et al., 2018).

In converting a car into an electric vehicle, we must know the type of car we are converting and consider the weight of the car in order to ensure that the electric motor that replaces the combustion motor in the car is able to keep the car running as it should, therefore, the power and torque that are can be generated by an electric motor to be one of the parameters to consider in converting. The type of electric motor used in this electric conversion vehicle is an AC motor 7.5 kW. In addition, because the electric motor is powered by a battery, we also have to consider the type of battery to be used, whether the battery is able to provide the power needed for the electric motor used. There are two types of batteries commonly used in electric vehicles, namely Deep Cycle Lead Acid and Lithium. The better type to use is the lithium battery type, however, due to its very high price, the conversion of the Makara Electric Vehicle 02 is the Deep Cycle Lead Acid Battery. This research will focus on the subject of analysis on the power and torque generated by electric motors used in conversion vehicles (Trovão et al., 2013).

The option to convert vehicles has been made by several communities as well as government agencies. Electric Vehicle of America (EVA) revealed that the impact of converting electric vehicles includes lower maintenance costs. Some of the advantages of convertible electric vehicles are as follows: Recycling of used vehicles, Reduction levels of air pollution, Eliminating the need to replace lubricants, Eliminating the obligation to use the system water cooling, allowing users to perform the majority of vehicle maintenance independently (Pamungkas et al., 2017). The author uses power and torque as the main variables as part of the analysis and also the results of his research. the rate of work that occurs because the force applied is power. If the force does work ($\mathbf{w}$), in a unit of time ($\Delta\mathbf{t}$), the average power due to the force exerted on that time frame, can be made as an equation:

$$\boldsymbol{P} = \frac{\boldsymbol{w}}{\boldsymbol{\Delta t}} \tag{1}$$

Torque is a product of the force and distance perpendicular to the axis of rotation. Like the above equation, torque can be calculated by the force we get at a certain distance, where on a rotating object, the distance we use is the radius of the force to the rotating axis of the object.

2.2 Gear Ratio

Gear ratios once a series of gears area unit want to transmit power from the drive to the wheels, the gear connected to the drive is named the motive force gear or input gear, and therefore the gear connected to the wheel is named the driven gear or output gear. In general, the gear that's situated between the motive force gear and therefore the driven g ear is named the bum gear (Susanto et al., 2017). Gear quantitative relation (GR) is that the quantitative relation of teeth within the output gear (connected to the wheel) to the teeth within the input gear (connected to the drive or motor). The gear quantitative relation is that the description of the quantitative relation of the output force to the input force (Walker et al., 2017). Thus, we are able to multiply the drive shaft force (input) by the gear quantitative relation to seek out the force at the shaft (output).

Table 1. Vehicle gear transmission ratio

Gear Ratio I	**3,417**
Gear Ratio II	1,960
Gear Ratio III	1,250
Gear Ratio IV	0,865
Gear Ratio V	0,707
Gear Ratio Reversr	3,143
Final Gear Ratio	4,643
Tires Dimention	155/80 R13

For the needs of the main electric motor (bus driving) is calculated by analyzing the vehicle traction force. The traction force needed to move a vehicle is influenced by several drag forces that work when the vehicle is moving which is illustrated by the following equation:

$$F = m\,a + R_a + R_{rl} + Rg \qquad (2)$$

Where: $\boldsymbol{F}$ is the traction force, $\boldsymbol{m}$ is the mass of the vehicle, $\mathbf{R_a}$ is the aerodynamic drag force, $\boldsymbol{R_{rl}}$ is the friction force, $\boldsymbol{a}$ is the acceleration of the vehicle, R_g is the gravitational force arising from elevation (Morozov et al., 2016).

In the vehicle performance analysis, only uphill operations are considered. This grading style is usually called gradation resistance from Figure 2.5,

To simplify calculations, the street angle, α, is usually replaced with the grade value when the street corner is small. As shown in Figure 2.5, a class is defined as:

When road corners are small, roadblocks can be simplified.

$$i = \frac{H}{L} = \tan\alpha + \sin\alpha \qquad (3)$$

2.3 Electric Motor

Based on the business concept, electric power is the amount of effort in moving the charge in units of time or the amount of electrical energy per second. The formulation is written as follows [16].

$$W = V.I.t \qquad (4)$$

Where: $\boldsymbol{V}$ is Voltage (Volt), $\boldsymbol{I}$ is Current (Amperes), $\boldsymbol{t}$ is Time (Second) $\boldsymbol{W}$ is Energy (Joule), t is Time (Second)

Then:

$$P_o = V.I.P_f \qquad (5)$$

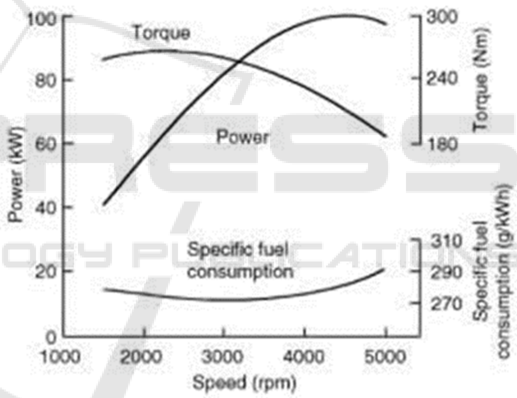

Figure 1. Types of gas engine characters (Wu et al., 2015). Internal combustion engines have a relatively flat (compared to ideal) torsion speed profile, as shown in Figure 1.

As a result, multi gear transmission is usually used to modify it, as shown in Figure 3.a. An electric motor, however, usually has a much closer to ideal speed-torque characteristic, as shown in Figure 3.b. In general, electric motors start at zero speed. As it increases to basic velocity, the voltage increases to its rated value while the flux remains constant (Zainuri et al., 2021).

Table 2. Three-phase AC motor specifications

Tipe	***XYQ-7.5-3AHV***
Rated Power	***7,5 kW***
Rated Voltage	***51 V (A.C)***
Rated Current	***118 A***
Speed Range	***0 - 5875 r/min***
Frekuensi	***0 - 200 Hz***
Rated Speed	***3440 r/min***

3 RESEARCH METHOD

From the previous description that in order to achieve the research objectives by conducting drivetrain testing on electric conversion vehicles to obtain 2 optimal gearshift combinations, several stages of implementation were carried out, namely: Preparation of Material Specifications, Preparation of Tool Specifications, Analysis Methods, Processing Time, Testing Standards

In this research, the data were taken by doing a weighing test. The object of this research is M1 type vehicle which named Makara Electric Vehicle 02 that converted from conventional car. Weight of test has purpose to obtain center of gravity which will be processed further to obtain braking force and also the stopping distance. The braking characteristics which are braking force and stopping distance obtained by doing some formula calculation. Data was collected for conversion car and conversion base vehicle. This method referring to government policies that usually applied (Lei et al., 2019) and for the stopping distance using policies that published by Ministry of Transportation (Zainuri et al., 2021).

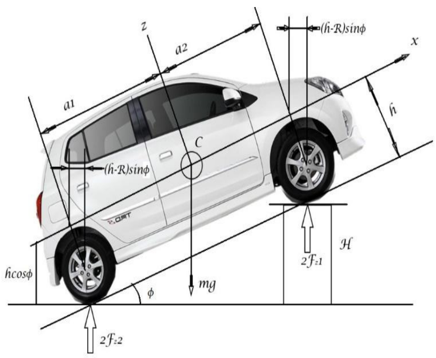

Figure 2. Freebody Diagram of Vehicle

The calculation for center of gravity collected by figuring out the free body diagram first then insert the result to the equation (Ahssan et al., 2018) that writer got from another references.

When collecting data using PQA, it can be done in the condition of the vehicle being measured in place or in running conditions so that it is more practical in operation. Make sure the circuit is installed correctly so that the validity of the data can be accounted for.

This research aims to give a concluded result of measuring whether or not the drivetrain can deliver the performance needed for a real-world usage scenario. To measure the performance output of the vehicle, this research focuses more on experiment to collect the data of the vehicle power output by using a chassis dynamometer then, to simulate the real-world scenario by calculating the resistance force acting on the vehicle.

Figure 3. Installation of tools when testing scales

4 RESULT AND DISCUSSION

From the previous description that in order to achieve the research objectives by conducting drivetrain testing on electric conversion vehicles to obtain 2 optimal gearshift combinations, several stages of implementation were carried out, namely: Preparation of Material Specifications, Preparation of Tool Specifications, Analysis Methods, Processing Time, Testing Standards

1. Power Train Characteristic

Based on the data collected from the dynamometer, we calculate those data measured from the hub resulted in the torque and power produced by the powertrain. From the data collected at 4^{th} gear, the torque reached peak number by 94 Nm and the peak power is 13 HP. By using statistic approximation of third order polynomial, we could map the graph of the performance characteristic of the motor.

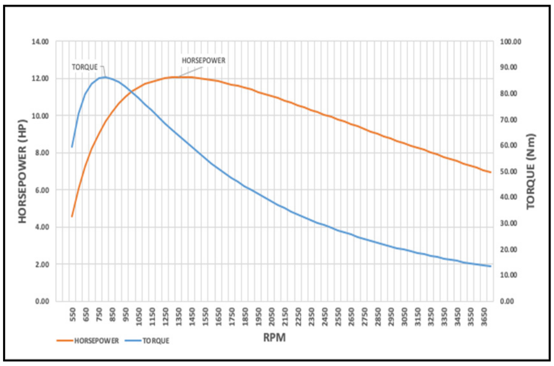

Figure 4. Powertrain characteristic

The tractive effort value is used to measure the capability of the vehicle to withstand the resistance force acting on the vehicle. On this experiment we simulate force by combining all the three resistance forces with the variance of speed the vehicle travels and the road inclination.

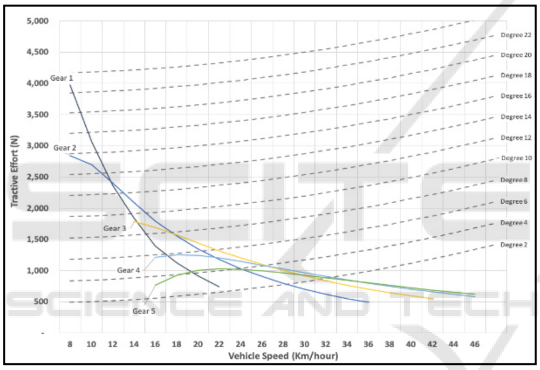

Figure 5. Tractive Effort vs Resistance Force

As shown in Fig. 5 we could determine the gear need to be used to counter the varying resistance force by road inclination. We could also determine the maximum vehicle speed of each gear used by the vehicle on which it is 46 km/h. Indonesian Toll Road regulated that the minimum speed vehicle needs to travel is 60 km/h (Adhitya et al., 2018) on which MEV 02 haven't pass. By referencing to the Indonesian National Standard of city roads inclination geometry, it is mandated that the inclination can't pass 8% (Trovão et al., 2013), based on the result MEV 02 already passed the standard.

2. Centre of Gravity (COG)

In the implementation of this research carried out by measuring the weight of the vehicle on each wheel as a fulcrum by comparing the various conditions of the different variables, both the vehicle variable and the additional passenger variable. 802.5 kg to 1011 kg in electric conversion vehicles (after the addition of batteries and motorbikes) means that there is an additional weight of 208.5 kg with details as the addition of the total weight of each wheel. Furthermore, in electric conversion vehicles simulated with the addition of passengers from the first passenger (78 kg), second (74kg), third (69 kg) and fourth passenger (54.5) which are respectively distributed to each part of the wheel.

Table 4. Calculation results of COG length and width

Center of Gravity (Horizontal)	Konvensional	KONVERSI (empty)	KONVERSI (1Pass.)	KONVERSI (2Pass.)	KONVERSI (3Pass.)	KONVERSI (4Pass.)
Front to Rear (cm)	95.6	133.8	132.6	131.2	135.5	137.6
Front to Rear %	38.94%	54.50%	53.99%	53.44%	55.19%	56.04%
Left to Right (cm)	70.5	71.3	73.8	71.4	73.6	72
Left to Right %	50.34%	50.94%	52.71%	50.99%	52.56%	51.42%

The following is one of the measurements with PQA when operating the vehicle in a condition without tires on the wheels

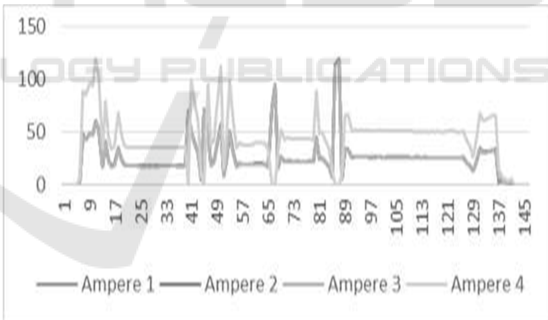

Figure 6. 3-Phase Motor RST Ampere Graph

The following are the results of measuring the voltage and amperage of a 3-phase AC motor where when the measurement uses the Power Quality Analyzer (PQA), the measurement is done by running the vehicle without a load by lifting the front wheel and varying the rotation of gear shifting 1 to 4 with maximum speed as following:

- The maximum speed of 1st gear is 20 km / hr
- The maximum speed of 2nd gear is 40 km / h
- The maximu m speed of 3rd gear is 60 km / h
- The maximu m speed of 4th gear is 80 km / h

From these results, the measurement results of the current and voltage on the 3-phase motor (attached) are obtained and when the displacement conditions occur a very high amperage spike, this if it occurs continuously will result in the ability of the battery to run out quickly.

Spesification for Inverter:

Rated Power	Rated Voltage	Rated Speed	Rated Torque	Peak Power
7.5KW	72V	3000rpm	22.3NM	16KW

Theoretically, the vehicle will have the following torque and power characteristics:

$$Po = \left(m\,a + \frac{1}{2}\rho\,C_d\,A_f\,v^2 + f_{rl}\,m\,g + m\,g\sin\alpha\right).v$$

In light of the means above, in this examination, the motor was supplanted with a 3-stage AC electric engine, in addition to 6 batteries as a force source, which the Charging cycle was done on 6 batteries with a limit of 150 Ah and 12 Volt DC (the most extreme voltage was 72 Volt DC.) which is introduced in arrangement is completed at a lingering voltage state of 65 Volts (80%) did for 3 hours to have the option to get the limit together to 100% of 72 Volt DC examples and phases of charging. From Figure 4.1, we can know how the charging interaction that happens in the battery, where when the charging cycle increments around 7 volts from 65 to 72 volts stable, it requires around 3 hours with a direct pattern.

When seen from the limit of the battery 150 AH times 6 pieces and the limit of its utilization with an engine heap of 118 A, it very well may be determined that its utilization is equipped for turning the engine as long as 7 hours of activity with stable conditions, but since there are a few factors that make this capacity not satisfied, including: vehicle load, the course of the vehicle so it should be changed both straight all over and slowing down because of hindrances this condition powers the genuine capacity to be acquired around 4 hours of activity. DC-DC Converter introduced on the change vehicle as demonstrated in Figure 37 is an instrument that capacities to charge the battery emotionally supportive network by decreasing the voltage from 72 volts to 12 volts. This supporting battery capacities to supply capacity to the vehicle's actualize the two wipers, horns and even the main thing is the inventory to the slowing mechanism.

In the execution of this exploration completed by estimating the heaviness of the vehicle on each wheel as a support by looking at the different states of the various factors, both the vehicle variable and the extra traveler variable. 802.5 kg to 1011 kg in electric transformation vehicles (after the option of batteries and motorbikes) implies that there is an extra weight of 208.5 kg with subtleties as the expansion of the complete load of each wheel. Moreover, in electric transformation vehicles recreated with the expansion of travelers from the primary traveler (78 kg), second (74kg), third (69 kg) and fourth traveler (54.5) which are individually dispersed to each piece of the wheel. The extra weight brought about a huge change according to changes in the focal point of gravity which brought about the deliberate and determined focus of gravity in great condition in light of the fact that the worth had changed from 38.94% (front to back) to 54.50% and was in the vehicle since it was getting lower, the center, the better. Similarly, the change from 50.34% to 50.95% (from left to right) so the lower the focal point of the vehicle, the impact will be felt when the vehicle is bowed at a turn or move.

5 CONCLUSIONS

From the results of the research and analysis presented, the following conclusions can be drawn:

1. Conventional vehicle conversion (power 65 HP / 6000 RPM and torque of 86 Nm / 3600 RPM) is one solution considering the large population of conventional vehicles and the possibility of expensive electric vehicles being the background for the research on the conversion of these vehicles into electric vehicles.
2. Charging the battery is done with a fast process with a duration of about 3 hours for a charge of 5-7 volts (65-72 volts) with a battery capacity of 150 AH times 6 pieces and the capacity of its use with a motor load of 118 A real capability obtained about 4 hours operation.
3. The results of the calculation of the power and torque generated by the motor, the maximum power of the motor is 61.13 kW at 5000 rpm motor rotation and the resulting torque is 116.75.
4. Selection of the transmission ratio that is very suitable for use in two-speed transmissions is the transmission ratio 1.96 for 2nd gear and 1.25 transmission ratio for 3rd gear based on calculations and from the results of analysis and calculations. Between 2nd and 3rd gears, the value of torque and power to speed optimization has the highest value so that the vehicle is only capable of traveling at 65.30 km / h at two speeds

and the vehicle is also capable of traveling at 49.98 km / h in second gear.

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