Performance Analysis of Power Train Electric Vehicle Transmission
Two Speed with Reverse Engineering Method

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ABSTRACT: This study analysed the powertrain electric vehicle (EV) system performance with two-speed transmission. This research analysed various terrain conditions as a variable that will be used as a reference in measuring the level of reliability of the vehicle’s performance, refers to its specification, center of gravity and tires radius. The results were obtained by selecting suitable transmission ratio which are 1.96 for the first gear and 1.25 for second gear. The required traction to do gearshift by the motor is not big enough thus the gearshift becomes smoother. Base on the friction analysis with traction, it can be concluded that in a 10° road slope, the vehicle is unable to yield traction of 6000 rpm at second gear due to the slope drag is higher than the vehicle traction. As a result, the vehicle is able to travel of 65.30 km/h at second gear while of 49.98 km/h at the first gear. Whereas at a slope of 20°, the result showed that the vehicle is able to yield traction of 5000 rpm at first gear due to the slope drag is higher than the vehicle thrust/ traction. Therefore, the vehicle is able to travel of 41.65 km/h at the second gear and of 49.98 km/h at the first gear. Three variations of the existing slope will be used to determine the performance of electric vehicles based on the performance of the transmission that will be used as the basis for designing a new transmissions box for further electric conversion vehicles.

KEYWORDS: Powertrain; traction force; electric vehicle, EV transmission; gear ratio.

INTRODUCTION

The availability of fuel which tends to decrease will lead to motivation for researchers to make more environmentally friendly vehicles, one of which is electric vehicles as vehicles with electric current as a source of propulsion. Awareness of environmental protection and energy savings continues to increase, where with the presence of electric vehicles the consumption of fossil fuels will be reduced because the vehicle is zero emissions. The biggest difference between an electric vehicle (EV) and a combustion engine vehicle is located in the powertrain system where traditional vehicles with a combustion engine are driven by fossil-fueled engines to provide energy for the vehicle to be able to drive while the energy source of electric vehicles is electric energy that is the driving system includes motor system, control system, and battery system. [1].

City streets, which are congested with vehicles, will not allow cars to run at high speed. However, some people demand their cars to have the same speed before and after conversion. It is to ensure satisfaction in converting E [2]. Target speed depends on the performance of the electric motor. The component performance of an electric motor is determined by the propulsion system used. The efficiency of the propulsion system depends on the type of electric motor used and the efficiency of the motor controller. The efficiency is also available on vehicle power transmission components, namely transmission, propeller shaft, and differential. But in EV conversion, the efficiency of power transmission components is considered ideal or constant. Work obstacles on the vehicle must be determined to find out the performance requirements. It is to achieve speed targets, including; vehicle specifications, the gravity and tire radius, calculation of vehicle friction force, final drive transmission ratio, and vehicle traction calculation [3].
The simulation results showed that the proposed controller reduces fuel consumption in the real driving cycle and additional capital of about 21% and 6% respectively. The combination of renewable energy resources can be applied to hybrid electric vehicles (HEV) for the next generation transportation that exploits various aspects and techniques of HEV from energy management system (EMS) [3].

Figure 1: Power Train System [5]: 1 – Motor and Battery, 2 – Clutch, 3 – Transmission, 4 – Differential, 5 – Brake, 6 – Steering, 7 – wheel

The storage system consists of fuel cell (FC) as the main power source and solar cell (SC) as an additional resource. A nonlinear controller based on a nonlinear model system utilizes Lyapunov stability design techniques [4]. In Battery Electric Vehicles (BEV), heat that arises from the mistake of the battery work process needs to be anticipated, because of incorrect traction and friction can cause overheating that can make dangerous [5]. The effect of strength performance on the layout of the powertrain system was verified by using computer aided engineering (CAE) and the electric weight balancer [6].

Several studies presented an increase in energy efficiency in EV by exploiting several considerations which are in the spotlight as the main transportation of the future [7]. They are, first, integrated motor-transmission (IMT) with motors and gearboxes directly installed and the adoption of controller area network (CAN) technology. Secondly, wireless power-transfer-systems (WPTS) based on wireless electric vehicles (WEVs). Third, classified as roadway powered electric vehicles (RPEVs) and stationary charging electric vehicles (SCEVs). Fourth, the design and implementation the online electric vehicle (OLEV) system [8] [9].

Figure 1. The transmission ratio of gear [10]: 1. Motor, 2. Input shaft, 3. 2nd gear, 4. Counter Shaft, 5 – 1st gear, 6 – Reverse, 7 – Idler, 8 – Output shaft

The testing of the role of renewable energy and powertrain optimization in order to minimizing daily carbon emissions were conducted for plug-in hybrid electric vehicles and electrically-powered vehicles [11]. For manual transmission, the zero-shift mechanism is an ideal arrangement to increase transmission efficiency [12]. The combination of the electric engine and the powertrain distinguishes powertrain architecture and increases the energy efficiency and reduces torsional vibration [13]. The proposed gear ratio transmission can be seen in Figure 2. The aim of this study is to find out the performance of traction force when the vehicle goes on a flat plane 0° and incline angle > 0°.[14]

THE AIM AND OBJECTIVES OF THE STUDY

This research aims to obtain the most suitable gear ratio for two-speed transmission. Then an analysis is performed
to get the value of the motor's performance in moving the unit with slope variations of 0°, 10°, and 20° at two different speeds.

The following objectives are done to achieve that goal:

1. Change the ICE vehicle into an electric car.
2. Calculate the ability to move electric vehicles on three types of road slope

LITERATURE REVIEW

Vehicle Specifications

The vehicle that will be reviewed is the city car-type vehicle with the required vehicle data can be seen in Table 1. The center of the car is the place of operation of the earth's gravitational force (gravity) on the overall mass of the vehicle. The location of this center of gravity depends on the geometry and the weight distribution of the car.

**Table 1: Vehicle data [15]**

<table>
<thead>
<tr>
<th>No</th>
<th>Item</th>
<th>Value</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>A.</td>
<td>Main dimension and Vehicle Weight</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Wheelbase</td>
<td>2.455</td>
<td>Mm</td>
</tr>
<tr>
<td>2</td>
<td>Overall length</td>
<td>3.600</td>
<td>Mm</td>
</tr>
<tr>
<td>3</td>
<td>Overall width</td>
<td>1.620</td>
<td>Mm</td>
</tr>
<tr>
<td>4</td>
<td>Overall height</td>
<td>1.520</td>
<td>Mm</td>
</tr>
<tr>
<td>5</td>
<td>Wheel track front</td>
<td>1.420</td>
<td>Mm</td>
</tr>
<tr>
<td>6</td>
<td>Wheel track rear</td>
<td>1.415</td>
<td>Mm</td>
</tr>
<tr>
<td>B.</td>
<td>Vehicle Performance</td>
<td></td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>V max.</td>
<td>65</td>
<td>Km/h</td>
</tr>
<tr>
<td>8</td>
<td>Passenger carrying capacity</td>
<td>320</td>
<td>Kg</td>
</tr>
<tr>
<td>9</td>
<td>Transport capacity</td>
<td>50</td>
<td>Kg</td>
</tr>
<tr>
<td>10</td>
<td>Curb Weight</td>
<td>780</td>
<td>Kg</td>
</tr>
<tr>
<td>11</td>
<td>GVWR</td>
<td>1.150</td>
<td>Kg</td>
</tr>
</tbody>
</table>

Different power and torque characters are obtained by combining the ratio of input gears and output gears. In general, the gear chain in the transmission box consists of several combinations of gears to make a vehicle move forward and a pair of gears to reverse, which are usually mediated by idle gear. Furthermore, this comparison of gear transmission ratios that follows the population transmission ratio of one city car in Indonesia aims to find out how much tractive force performance is produced when the vehicle is running on a flat plane of 0° and the tilted slope > 0°.

The Gravity and Tire Radius

In Figure 2, shown modeling the normal force of the wheel. Where is the distance of the front wheel shaft toward the center of mass of the Z (center) car, and is the distance from the mass center of the car Z to the rear wheel axle, and the wheelbase or total front wheel axle distance to rear wheel axle. When a car is idle on a flat road, the normal force on each axle of the front and rear tires are called \( F_{z1} \) and \( F_{z2} \), to calculate the force that occurs on the front and rear tires are[2].

\[
F_{z1} = \frac{1}{2}mg \frac{a_z}{\ell} \tag{1}
\]

\[
F_{z2} = \frac{1}{2}mg \frac{a_1}{\ell} \tag{2}
\]
where $F_z$ is the force (N), $m$ is mass (kg), $g$ is gravity (m/s$^2$), $a_1$ is distance of the center of gravity to the rear axle (m), and $a_2$ is distance of the center of gravity to the rear axle (m) and $\ell$ is the distance of the front axle to the rear axle (m).

**Figure 2**: Modeling Normal Wheel Force

Knowledge and selection of tires are essential because to determine the characteristics of traction performance, the ability to drive and control a vehicle. The tires used must pay attention to the amount of friction rolling because the wider the tire, the higher the rolling resistance. The chosen tire is radial tire type 175/65 R14. The tires have specifications as below: wheel diameter=14 inch; tire width=175 mm; the ratio of tire height to width=65 %. To calculate the tire radius based on known tire specifications in equation (3) [16].

$$R_w = \frac{1}{2} \cdot d + t$$  \hspace{1cm} (3)

Where $R_w$ is tire radius (m), $t$ is tire height (m), and $d$ is diameter wheel (m).

Rolling resistance is a necessity for the vehicle to move. The value of rolling resistance is mainly dependent on the type of tire material and road material. In general, tire raw material is rubber, while road material is usually asphalt, concrete, or a combination of both.

**Calculation of Vehicle Friction Force**

The vehicle will move when traction is higher than the friction received. The causes of rolling resistance include tire specifications and tire surface conditions. It also depends on the quality of the road being traversed. In this case, urban roads are in the form of asphalt in good condition so that the amount can be calculated by equation (4)[17].

$$P_r = f \cdot G$$  \hspace{1cm} (4)

where $P_r$ is rolling resistance (N), $f$ is friction rolling coefficient and $G$ is total weight (N).

The value of the friction rolling coefficient is determined based on Table 2.

**Table 2: Rolling Resistance Coefficient [16]**

<table>
<thead>
<tr>
<th>No</th>
<th>Type of the road</th>
<th>For at v 14 m/s</th>
<th>$F$ (mean value)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>In excellent state</td>
<td>0.017</td>
<td>0.014-0.018</td>
</tr>
<tr>
<td>2</td>
<td>In a satisfactory state</td>
<td>0.018</td>
<td>0.018-0.020</td>
</tr>
</tbody>
</table>
The vehicle gets air resistance in front of it and the forces due to the fractional action of the air around it. Additional energy is required to overcome the air resistance associated with the cross-section area of the vehicle.

**Figure 3**: The dimensions for the area of air resistance

When a vehicle moves, the air particles will pound the surface of the car causing friction on the vehicle's speed. Air friction is only calculated if the vehicle speed is ≥ 60 km/hour. This vehicle is only planned to have a speed of 65 km/hour. In Figure 3, a look at the front of the car being reviewed. The projection of the front area of the vehicle for the vehicle can be calculated by

\[
A_f = 0.78 \cdot B_a \cdot H_a
\]  

(5)

Where \( A_f \) is a front area (m\(^2\)), \( B_a \) is max. width (m) and \( H_a \) is max. height (m)

The amount of power needed to overcome air friction is calculated by equation

\[
P_{ud} = \frac{1}{2} \cdot \rho \cdot C_d \cdot A_f \cdot v^2
\]  

where \( P_{ud} \) is air resistance (N), \( \rho \) is air density (1.2 kg/m\(^3\)), \( v \): speed (m/s) and \( C_d \) is air resistance coefficient (N.s\(^2\)/m\(^2\))

When a vehicle moves uphill, a weight component of the car acts downward, along the plane of the way. It creates a force acting in a direction opposite that of the motion. A vehicle traveling uphill will, therefore, tend to lose speed unless an acceleration force is applied.

**Figure 4**: The forces that occur when climbing on the incline

A vehicle moves on a climbing road so that friction motion is a component of force in the direction parallel to the
road surface shown in Figure 4. The amount of friction of the climb is [16].

\[ P_g = G \cdot \sin \alpha \]  

(7)

Where \( P_g \) is climb barriers (N), \( G \) is total weight (N), and \( \alpha \) is tilt slope (°). Traction force must not exceed the magnitude of the frictional force between the wheel and the road surface so as not to slip, to calculate the amount of frictional force experienced by the vehicle can use equation (8) [7]

\[ P_t \leq \varphi \cdot W_p. \]  

(8)

where \( P_t \) is traction force (N), \( W_p \) is friction (N), and \( \varphi \) is coefficient force

**Final Drive Transmission Ratio and Vehicle Traction Calculation**

The vehicle that will be designed will use a differential gear to make it easier when turning. Final reduction gear serves to reduce rotation and change the direction of rotation. If the vehicle is planned to have a maximum speed of 65 km/h and it is known that the rear wheel diameter (\( D_w \)) is 0.58 m, then the rotation on the final drive shaft can be calculated using equation (9) [15].

\[ n = \frac{60 \cdot (v)}{\pi \cdot D_w} \]  

(9)

where \( n \) is rotation motor (rpm), \( v \) is speed (km/h) and \( D_w \) is diameters wheel (m)

Then the rotation on the final drive shaft is 595.38 rpm. The motor is known to have an initial reduction ratio of 3.33 and two speeds ratio=1.25, assuming transmission efficiency (\( \eta \)) 80 %. The characteristic of an electric motor is a graph that illustrates the relationship between power, torque, etc. to the motor rotation with the throttle opening in a permanent position. So that it can be described the relationship between traction force (\( P_t \)) and vehicle speed for several levels of speed. The amount of torque for a particular round can use equation (10) [9]

\[ T = 9549 \frac{N}{n_m} \]  

(10)

where \( T \) is torque (Nm), \( N \) is power (kW) and \( n_m \) is rotation (rpm)

The magnitude of the traction force (\( F_t \)) for each motor rotation and the scale of the velocity (\( v \)) in certain transmission conditions can be calculated using equation (11) and (12) [1]

\[ F_t = \frac{i_n \cdot i_{diff} \cdot \eta \cdot T_m}{r_w} \]  

(11)

\[ v = \frac{60 \cdot \pi \cdot D_w \cdot n_m}{n_{total} \cdot 1000} \]  

(12)

where \( F_t \) is traction force (N), \( i_n \) is reduction ratio, \( \eta \) is efficiency transmission \( i_{diff} \) is differential ratio, \( T_m \) is torque motor (Nm) and \( n_{total} = i_n \cdot i_{diff} \)

To get results that are close to reality, the equations that cause vehicles to move must be used in detail. These
equations are related to vehicle weight, acceleration, wind resistance, and incline slopes.

**RESEARCH METHOD**

The research began by designing and making a test bench for the 2-speed transmission. Then a simulation is performed to represent several conditions. This experiment is also equipped with simulations and calculations in accordance with existing theories. All results will be validated as a discussion and conclusion. A city car is used as the main comparison.

**RESULTS**

Based on the calculation of the vehicle's weight, the load of the normal force received by Eq. (1) and (2) each wheel is $F_{z1} = 304.75$ N and $F_{z2} = 270.25$ N. Furthermore, based on the calculation of tire radius by Eq. (3) the result Rw is 291.5 mm. The total resistance experienced by the vehicle is used to check the ability of the motor to climb the road when the weight of the vehicle is maximum. This vehicle is designed for urban (city car). The average slope of roads in urban areas is between 3 - 36% (1.7 ° -20 °). So that this vehicle is planned to have grade-ability of 20 °. Air resistance in such conditions can be ignored because the vehicle speed is not too high. So the amount of traction that must be met by a Pt vehicle is 2143.47 N. The magnitude of the frictional force is influenced by the coefficient of friction (φ). The value of the coefficient of friction for the asphalt road taken is 0.5-0.7. [16]. This calculation takes a coefficient of friction of 0.7. The vehicle designed is a rear-wheel-drive vehicle where Eq. (8) $Pt = 3711.61$ N. Based on the analysis results, Pt vehicle is still smaller than the value of the friction so that there is no slip on the vehicle.

Characterization of Motor Performance

Based on the calculation of the power and torque produced by the motor in Eq. (10), the maximum power of the electric motor is obtained at 61.13 kW at 5,000 rpm, and the torque produced is 116.75 Nm. In Figure 5.

![Characteristics of Torque and Power](image)

**Figure 5:** Characterization of Motor Performance

Traction force characteristics of speed

Based on the calculation of the traction force and torque produced by the motor in Eq.(11) and (12). Furthermore, the traction force characteristics of speed for each transmission level will be shown in Figure 6 in graphical form.
According to the analysis of the transmission traction force characteristics (Figure 6), it can be concluded that the transmission ratio suitable for three slope conditions is the transmission with a ratio of 1.96 for first gear and 1.25 for second gear. The chart above shows that the traction force required by the motor to do gearshift is not too large. It is smoother compared to the transmission ratio of 3.417 to the ratio of 1.25. The transfer is less efficient, and the traction force required will be massive.

Traction Force Characteristics with Friction on Vehicle Speed

The calculation of the traction force produced by the motor rotation at 0°, 10°, and 20° an inclined slope can be solved with Eq. (11) and (12). Friction experienced by vehicles that travel at a constant speed on a flat road (with a 0° incline slope) is air friction and bolt friction only. In a flat way, zero friction and friction inertia are also zero due to constant acceleration. Figure 7 shows the relationship between the traction force and resistance on the car speed at a slope of 0°.

The results of friction analysis with the traction force shown in Figure 7, it can be concluded that air friction and rolling resistance do not affect the traction force experienced when the vehicle is moving on a flat plane.

The graph that shows the relationship between traction force and friction on vehicle speed at 10° incline can be seen in Figure 8.
The graph that shows the relationship between traction force with friction on vehicle speed at 20° incline can be seen in Figure 9.

Based on the results of friction analysis with the traction force shown in Figure 9, it can be concluded that the vehicle is unable to produce a traction force of 5,000 rpm in gear 1 with a slope of 20°, due to slope drag > vehicle thrust/traction force.

DISCUSSION

This research analyzes various terrain conditions as variables used as a reference when measuring the unit performance level of reliability. The center of interest measured unit performances is the vehicle specification variable, the center of gravity of the vehicle, and the radius of the tire. The powertrain system in a car is one of the most critical things in it because it carries power from the motor to the final drive to produce traction performance. The resulting traction performance will change depending on the amount of load received by the vehicle. The choice of the right motor ratio and gear transmission is also a key driver of proper vehicle traction performance. Based on the results of the analysis, the Pt vehicle is still smaller than the value of the friction force so that there is no slip on the car.

Based on the calculation of the power and torque produced by the motor in equation
(11), the maximum power of the electric motor is obtained at 61.13 kW at 5,000 rpm and the torque produced. And according to the analysis of the transmission traction force characteristics (Figure 6), it can be concluded that the transmission ratio suitable for three slope conditions is the transmission with a ratio of 1.96 for first gear and 1.25 for second gear. The chart above shows that the traction force required by the motor to do gearshift is not too large. It is smoother compared to the transmission ratio of 3.417 to the ratio of 1.25. The transfer is less efficient, and the traction force required will be massive. The results of friction analysis with the traction force shown in Figure 7, it can be concluded that air friction and rolling resistance do not affect the traction force experienced when the vehicle is moving on a flat plane. Friction analysis with the traction force shown in Figure 8, it can be concluded that the car is unable to produce a traction force of 6,000 rpm at two speeds with a 10° slope, due to the slope drag greater than the vehicle traction force.

That vehicle is only capable of traveling at 52.24 km/h in the 2nd gear, and the car is also capable of moving at 49.98 km/h in the 1st gear. Friction analysis with the traction force shown in Fig. 10, it can be concluded that the vehicle is unable to produce traction force of 5,000 rpm in gear 1 with a slope of 20°, due to slope drag greater than the vehicle thrust/vehicle traction force. So that the car is only capable of traveling at 41.65 km/h in the 1st gear, and the car is also capable of moving at 49.98 km/h in the 1st gear. These results are used as a reference in determining vehicle operations with various terrain conditions traversed, in addition to the ability of an electric conversion vehicle to carry variations in passenger load. The most importantly its ability to pass a variety of incline conditions, in this case, varying at a slope of 0°, 10° and 20°. The results of this analysis can also be used as a basis for converting conventional manual vehicles into electric vehicles in terms of determining the capacity of the motor and battery, along with other supporting devices.

CONCLUSIONS

The conclusions of this research can be explained as follows:

1. The ability to convert electric vehicles by calculating the ability of motor performance with a power of 61.13 kW and torque of 116.75 Nm in moving the unit at a car carrying capacity of 1150 kg well.

2. The performance of the electric vehicle power train system with two-speed transmission using slope variations of 0°, 10°, and 20° the following conclusions are obtained:

   a. at a slope of 10°, the vehicle is not able to produce traction force of 6000 rpm on gearshift two due to the incline drag greater than the vehicle’s thrust/vehicle traction force. In this condition So that the car is able to go with a speed of 52.24 km/h in the second gear, and the vehicle is also ready to go with a speed of 49.98 km/h in the first gear.

   b. At a slope of 20° that the car is not able to produce a traction force of 5000 rpm in 1st gear due to the incline drag greater than the vehicle’s thrust/vehicle traction force. In this condition, the car is able to go with a speed of 41.65 km/h in the second gear, and the vehicle is also capable of driving at a speed of 49.98 km/h in the first gear.

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