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Experimental study of the effect of load and vehicle speed on energy consumption of electric vehicles

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ABSTRACT

The use of electrical energy for vehicles is increasingly relevant due to its high efficiency and environmentally friendly nature—primarily because it does not produce exhaust emissions. Indonesia holds tremendous potential for electric vehicle development, thanks to its abundant nickel reserves, which can be processed into batteries. However, to maximize the benefits of electric vehicles, it's important to consider their energy consumption. One key factor affecting this is speed. The efficiency of electrical energy use in an electric vehicle varies with speed, and identifying the optimal speed for energy-saving performance is essential to ensure both sustainability and practicality. This research is intended to study how much vehicle speed influences energy consumption and also to obtain the vehicle speed range with the lowest energy use efficiency in autonomous electric vehicles, Faculty of Engineering, University of Mataram. The lowest energy consumption occurs at a speed of 20 km/h with a load of 960 kg, which is 0.173 kWh/km. The most efficient speed for distance traveled per kWh is 30 km/h, regardless of vehicle weight. A speed of 40 km/h decreases efficiency, especially with a heavier load, while increasing the load at lower speeds (20 km/h and 30 km/h) does not significantly reduce efficiency, and even slightly increases the distance traveled.

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1. INTRODUCTION

In Indonesia, transportation is a daily necessity; almost all aspects of life cannot be separated from transportation. Every year the use of transportation increases, From the Central Statistics Agency in 2021, it was noted that vehicle ownership by the Indonesian population reached 143,797,227 vehicles of all types of fossil fuel vehicles. Cars are one of the most widely used transportation; cars use an internal combustion system that uses fossil fuels as their driving energy which contributes a lot to air pollution. Carbon monoxide (CO) and Hydrocarbons (HC) are dangerous pollutants which of course will greatly interfere with human health. In

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addition to these two gas contents, every day fossil fuel vehicles will release Carbon dioxide (CO_2) from combustion into the atmosphere which can increase the adverse effects of the greenhouse effect (Baghdadi, et. al, 2013). The various negative impacts caused by vehicles with internal combustion have made the automotive industry continue to innovate (Wu, et al, 2015), one of which is the electric motor as a driver for electric cars (Badin, et al, 2013) which is expected to be able to overcome the existing problems. Various groups, both academics and professionals, have begun to try to think about saving petroleum fuels and the environmental impact caused by vehicles with internal combustion engines. Electric cars are a solution to these problems because they use environmentally friendly energy and do not cause pollution (Jatmiko, et al., 2018)

Although electric cars are known as environmentally friendly vehicles and do not produce exhaust emissions, electric cars have limited energy stored in the battery (Fotouhi, et. Al 2020) and must be recharged when used (Hu, et al., 2017). Due to the limited charging speed and battery capacity (Hendra, et al., 2021) for most electric vehicles available today, the use of electric cars is limited and requires their operation to a certain limit. In this case, energy consumption is a determinant of how far an electric car can be operated (Skuza and Jurecki, 2022). Electric cars only rely on the energy stored in the battery pack, BEV type electric cars can reach a distance of 100 to 250 km on a single full charge. For higher classes, the distance can be further, reaching 300 to 500 km (Jiang, et. al., 2018). Based on empirical data, it has been shown that energy consumption in electric vehicles is usually higher than that stated by the manufacturer based on the driving cycle (Mediouni, et al., 2016). Based on research conducted by (Pielecha, et al., 2020) grouping factors that affect the energy consumption of electric cars into four categories, namely: driving style (speed, acceleration, aerodynamics and positive/negative kinetic energy) road topology (hills and bends), traffic density (congestion, toll roads and road types) and environmental factors (temperature).

Electrical power is the ability of an electrical device to do work due to changes in electrical work and changes in electrical charge per unit of time. The amount of electrical power is influenced by electrical voltage, current strength and electrical resistance, electrical power is expressed in Watt units (Jatmiko, et al., 2020). Motor efficiency can be defined as the ratio of the output power of the motor used to the input power on the Electric motor (Manalu, 2012). The energy consumption of a vehicle is the amount of energy used in kilo Watt hours (kWh) or can also be expressed in kilo Joules, however, the term kWh is more commonly used in measuring the energy consumption of a vehicle (Koengkan, et al, 2022). The energy capacity stored in an electric vehicle battery is usually expressed in kWh so that the battery life can be easily calculated, as in general gasoline-fueled vehicles, fuel consumption is measured in liters/km (l/km) or gallons/miles (GPM) (Rodgers, et. al, 2014, Mediouni, et al., 2022).

Based on several problems above, analyzing the energy consumption of electric cars is very important to do. Factors that affect the energy consumption of electric vehicles are so complex, there has been no detailed and specific research that discusses the effect of energy consumption of electric cars based on variations in speed and time. Therefore, the author is interested in conducting research on this matter, the author conducted a test on an electric car that is being developed by the Faculty of Engineering, University of Mataram. By conducting this research on the energy consumption of electric cars, it is hoped that it will be able to help design an energy-efficient and environmentally friendly city car model electric car that is being developed by the Faculty of Engineering, University of Mataram.

2. RESEARCH METHODS

In this study, an experiment was used to measure the parameters of electric current strength and the magnitude of the voltage difference in the electric vehicle circuit at various vehicle speed variations. The electric current data at each load variation is carried out using an ampere clamp measuring instrument as input data in the electric motor test which is measured on the positive battery output cable. Electric current is measured in the electric motor test with the vehicle load added in a varied manner. Electric current data will be used to determine the amount of input power required by the electric motor at each change in vehicle load and vehicle speed. The placement of the test equipment in this study was designed as shown in the following test scheme.

The electric vehicle testing track was carried out on the Mataram University campus route as seen in Figure 2. In the testing process, an electric car with a 10-kW motor is driving on a predetermined track with varying average speeds with varying vehicle loads. The battery power is checked before testing and the parameters of the power condition, voltage and battery capacity are recorded. Then the car is turned on and the accelerator pedal is pressed with variations in speed and time that have been determined, namely 20 km/h, 30 km/h, and 40 km/h with vehicle loads of 960 kg, 1028 kg and 1066 kg. Data collection at each speed and time variation (Voltage, Current) is taken three times and during the test the initial and final battery percentages and initial and final voltages are recorded.

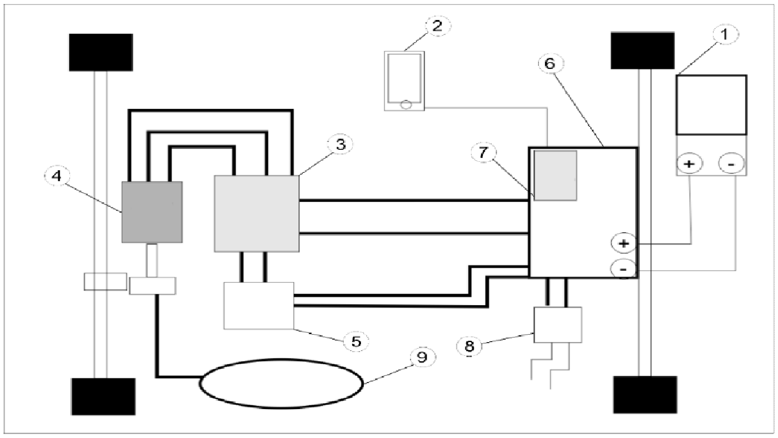

Figure 1. Test equipment schematic. 1 avometer, 2 BMS display monitor, 3 controller, 4 PMSM motor, 5 battery aux, 6 main battery, 7 BMS, 8 battery charger, 9 speedometer

Figure 2. Vehicle testing route

3. RESULTS AND DISCUSSION

Data analysis was performed to determine the electrical energy consumption corresponding to each speed variation, with the goal of identifying the underlying phenomena. The data were obtained from observations involving speed variations of 20 km/h, 30 km/h, and 40 km/h, along with vehicle load variations ranging from 960 kg to 1066 kg.

Figure 3 shows the relationship between voltage and various vehicle loads measured in kilograms. There are three data sets representing loads of 960 kg, 1028 kg, and 1066 kg. While the variations in vehicle speed are: 20 kph, 30 kph, and 40 kph. In general, the greater the vehicle load, the voltage tends to decrease at all vehicle speed variations. The highest voltage was recorded at a vehicle load of 960 kg with a pressure of 20 kph. However, when the vehicle load increases to 1066 kg, the electrical voltage becomes 78.80 V. At all vehicle load variations, the electrical voltage will decrease with increasing vehicle speed from 20 km/h to 40 km/h. This can be explained that when electric vehicles accelerate or move at high speeds, the load on the battery increases. This is due to the greater demand for power to overcome air resistance and friction at high speeds (Weiss, et al, 2020). As a result, the battery voltage can decrease because the battery energy is used faster. At high speeds, the

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internal resistance of the battery can also affect the voltage (Fotouhi, et al, 2020). When electric current passes through the battery, heating occurs due to internal resistance. This heating can cause a decrease in the effective voltage provided by the battery.

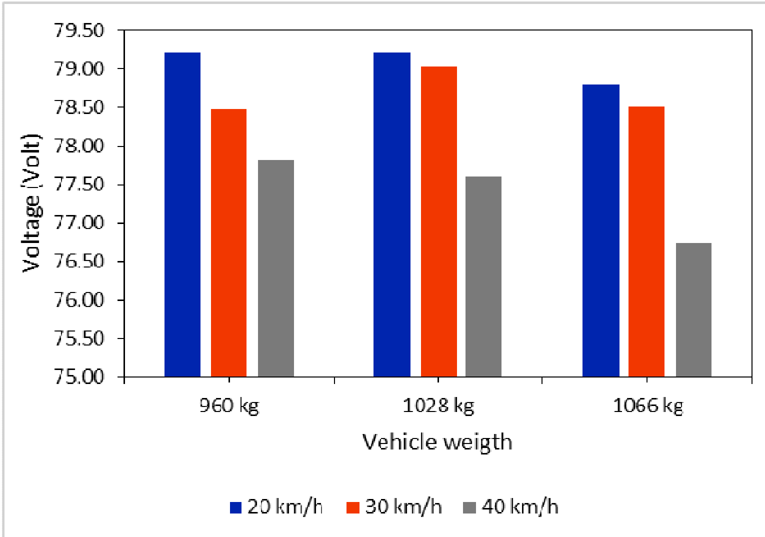

Figure 3. Relationship between vehicle load and electric current in an electric motor at various speeds.

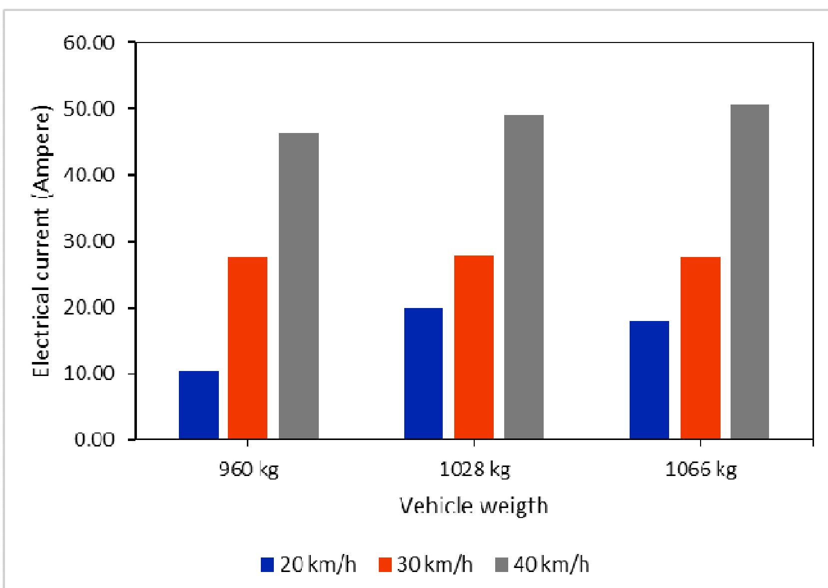

Figure 4. Relationship between electric current strength on vehicle load and vehicle speed.

Figure 4 above shows the relationship between vehicle load and electric current in amperes at various vehicle speeds, namely 20 kilometers per hour, 30 kilometers per hour, and 40 kilometers per hour. In general, the greater the weight of the vehicle, the electric current required tends to increase. This is due to the need for greater power to overcome resistance when the vehicle is moving. At each vehicle weight, the electric current also varies with speed. At a speed of 20 km/h, the current tends to be lower than at a speed of 30 km/h or 40 km/h. Increasing vehicle speed can affect the electric current used in electric vehicles, this is because when the vehicle moves at a higher speed, air resistance and friction with the road surface increase. This requires more power to overcome the resistance, which is reflected in the increase in electric current. In addition to this, higher

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vehicle speeds require more mechanical energy to overcome inertia and resistance so that electric motors must produce more power to maintain speed, which means higher electric current.

It is also seen that the heavier the vehicle weight, the greater the electric current required to travel at the same speed. Heavier vehicles require more mechanical power to overcome inertia and resistance when moving. This mechanical power must be provided by the electric motor through electric current. The heavier the vehicle, the greater the mechanical power required, and as a result, the electric current increases (Koengkan, et al, 2022). The heavier the vehicle, the greater the resistance that must be overcome, so the electric current increases. The heavier the vehicle, the more energy is needed to move it. The battery must produce a higher electric current to meet the power needs of a heavier vehicle. So, the heavier the electric vehicle, the greater the electric current required to overcome resistance and maintain speed. Good system design must take this factor into account for optimal electric vehicle performance.

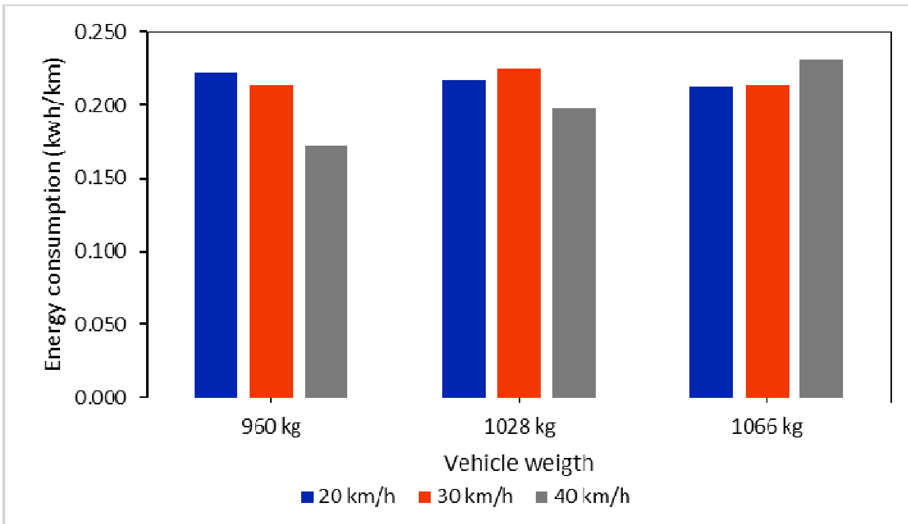

Figure 5. Amount of electrical energy consumed at various vehicle speeds and vehicle loads.

Figure 5 above shows the energy consumption (in kilowatt-hours per kilometer) of vehicles of various weights and speeds. As the vehicle speed increases from 20 km/h to 40 km/h, the energy consumption also increases for all vehicle weight categories. The heavier the load, the more energy is required to move the vehicle. This means that the range per battery charge will be reduced if the vehicle is carrying a larger load. the higher the electrical energy consumption required. In addition, the higher the vehicle speed, the greater the energy consumption. This information is relevant in discussions about energy efficiency and the impact of vehicle weight on energy use.

The energy consumption of electric vehicles was analyzed across different vehicle weights and speeds. At a vehicle load of 1028 kg and a speed of 20 km/h, the electrical energy consumption was recorded at 8.989 kWh/km. When the speed increased to 30 km/h, energy consumption rose slightly to 9.044 kWh/km. Interestingly, at a speed of 40 km/h, the consumption decreased to 6.801 kWh/km, indicating a potential efficiency improvement at higher speeds under this load condition This shows that the higher the speed, the more electrical energy is needed to keep the vehicle moving. As the weight of the vehicle increases, the amount of energy consumed tends to increase. This is because moving heavier objects requires more energy. When the vehicle carries a larger load, the electric motor must produce higher power to overcome resistance and maintain speed. This means that electrical energy consumption will increase. The electric motor in the vehicle must produce greater torque to overcome the heavier load. The heavier the load, the higher the torque required. This means that the motor must consume more electrical energy to maintain speed. At each speed, heavier vehicles consume more energy than lighter vehicles. This is because of the additional load that the electric motor has to overcome. So, the heavier the load carried by the vehicle, the more electrical energy is required. Good design must take this factor into account for optimal electric vehicle performance.

The electrical energy consumption of electric vehicles is calculated using the formula that relates power (kW) to time (hours). As illustrated in Figure 5, both speed and time are directly proportional to energy consumption: higher speeds and longer durations result in increased energy use. For example, with a vehicle weight of 950 kg, the energy consumption is 0.223 kWh/km at a speed of 20 km/h. At 30 km/h, it slightly

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decreases to 0.213 kWh/km, and at 40 km/h, it drops further to 0.173 kWh/km. This suggests that at lighter loads, vehicles may operate more efficiently at higher speeds. However, in general, heavier vehicles tend to consume more electrical energy, and increased speed contributes to higher consumption. These findings are particularly relevant in the context of energy efficiency and assessing the impact of vehicle mass on electricity usage.

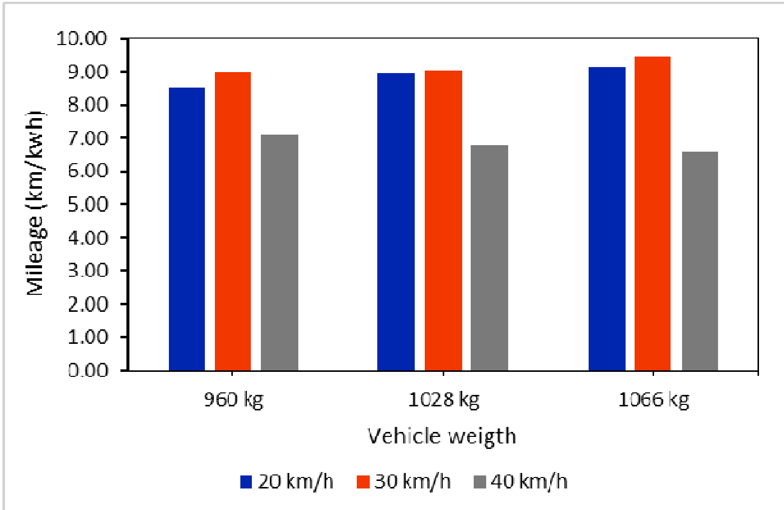

Figure 6. Relationship between vehicle travel distance and each kWh of energy consumed at various vehicle speeds and vehicle weights.

Vehicle load and speed have a significant effect on the energy efficiency of this electric vehicle. It can be seen that at lower speeds (20 km/h and 30 km/h), the vehicle has a greater distance traveled per kWh compared to higher speeds (40 km/h) at all variations of vehicle load. Where at a speed of 20 km/h and a load of 960 kg the distance that can be traveled is 8.535 km/kWh, while at a load of 1028 kg the distance traveled is 8.989 km/kWh and at a load of 1066 kg the distance increased to 9.148 km/kWh. With increasing vehicle load, there is a slight increase in distance traveled at lower speeds (20 km/h and 30 km/h), but a decrease at a speed of 40 km/h.

Figure 6 shows the relationship between distance traveled per kWh) with variations in vehicle speed and weight. Overall, the speed of 30 km/h (orange bar) shows the best distance traveled compared to speeds of 20 km/h (blue) and 40 km/h (grey) at all vehicle weights. This shows that at medium speeds, electric vehicles are more efficient in utilizing energy to cover more distance per kWh. This efficiency may be related to the balance between energy use to overcome vehicle speed resistance (Petersen, et al, 2021) and stable speed.

The driving range decreases significantly at 40 km/h at all loads (960 kg, 1028 kg, and 1066 kg). This can be seen from the lower gray bars compared to the other bars. This can be interpreted as higher speeds causing wind resistance and mechanical friction to become more dominant, thus reducing the vehicle's efficiency in converting electrical energy into driving range. At low speeds (20 km/h and 30 km/h): As the vehicle weight increases (from 960 kg to 1066 kg), the driving range actually increases slightly. This may be because at low speeds, the mass of the vehicle provides more stable inertia, allowing the vehicle to travel more efficiently. In contrast, at 40 km/h, the additional weight of the vehicle actually reduces the driving range slightly. This shows that at high speeds, the extra load causes greater energy consumption, thus reducing the efficiency of energy use in EVs. Although lower speeds are generally assumed to be more energy efficient, this graph shows that 20 km/h does not always produce the highest driving range. At all vehicle loads, a speed of 30 km/h is more efficient than 20 km/h. This can be interpreted as an indication that 20 km/h is too slow to achieve optimal efficiency, since the electric motor may operate more efficiently at a higher speed (30 km/h).

4. CONCLUSION

Based on the analysis and discussion, it can be concluded that electrical energy consumption in electric vehicles increases with both vehicle load and speed. The lowest energy consumption per kilometer—0.173 kWh/km—was recorded at a vehicle speed of 20 km/h and a load of 960 kg. Interestingly, a moderate speed of 30 km/h appears to be the most efficient in terms of mileage per kilowatt-hour, regardless of the vehicle's weight. However, higher speeds, particularly 40 km/h, lead to reduced energy efficiency, especially when combined with heavier loads. At lower speeds (20 km/h and 30 km/h), an increase in vehicle load does not significantly reduce efficiency and may even slightly improve mileage.

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