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FUEL CONSUMPTION AND CO_2 EMISSION INVESTIGATION OF RANGE EXTENDER WITH DIESEL AND GASOLINE ENGINE

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Abstract

Range extender engine is one of the main components of the range-extended electric vehicle (REEV) and together with a generator to extend the mileage of the electric vehicle. The main component of REEV is an electric motor, battery, and generator set that consist of generator and engine. In this study, we compared two models of REEV performance with two different types of the engine by simulation. Single cylinder 499 cc gasoline engine and single cylinder 667 cc diesel engine are chosen as the object of this research especially relating to the utilization of the fuel consumption and CO_2 emissions when fitted to an electric vehicle. The simulation was conducted by using AVL Cruise software and performed by entering the data, both experiment and simulation data, on all the main components of REEV. This simulation was performed in Japan 08 driving cycle. Based on the simulation, fuel consumption is reduced up to 35.59% for REEV with single cylinder diesel engine 667 cc compared to REEV with single cylinder gasoline engine 499 cc. The reduction of CO_2 emissions from REEV with single cylinder 499 cc gasoline engine compared to REEV with single cylinder 667 cc diesel engine up to 30.47%.

Keywords: range extender engine; performance; diesel; gasoline; AVL Cruise.

I. INTRODUCTION

Energy efficiency and emission are the most important aspects in the development of vehicle technology. In many types of research related to the energy and vehicle, many researchers give more attention to these aspects. Some countries have done a large number of studies with these focuses such as China [1, 2], US [3, 4], Portugal [5], UK [6], India [7] and etc. They do this type of research because of its great effects. The vehicle emission affects the air quality, health, and climate in the world [8]. On the other hand, based on the WHO research, the emission of the vehicle is responsible for the death of people accounted up to seven million per year [9]. With respect to energy efficiency, transportation has become the largest sector which needs fuel approximately 90% of the total energy consumption needed [10]. On the other hand, oil resources have been rapidly running out and expected to be completely depleted within 50 years [11].

Based on this situation, researchers in the world are required to conduct research that is able to reduce fuel consumption and decrease vehicle emissions. One of the latest technologies that have been developed is the electric car. But an electric car has some disadvantages such as limited mileage and expensive batteries. To solve this problem, a range extender technology has been developed. The range extender is a technology that uses a small engine installed in a series configuration with a generator in the electric car. The car is called the range-extended electric vehicle (REEV). Although this technology still has emission, but the number is

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relatively low because it works only when needed to charge the batteries. The main drive of REEV is the battery. The range extender is mounted in a car to increase the mileage of electric cars.

Similar researches have been conducted by researchers from several vehicles companies and research institutes such as AVL that develop a range extender with 2-cylinder engine with a power of 15 kW. This engine has a compact size but its emission is still high, and furthermore, the maintenance cost is also high [12]. The other researcher also developed a range extender from the fuel cell. The advantages of this range extender engine are able to produce lower noise, vibration, and emissions. The disadvantage of this range extender engine is high production cost [13].

This paper is focused on the investigation of range extender engine with 1 cylinder gasoline engine 499 cc and 1 cylinder diesel engine 667 cc, especially relating to the utilization of the fuel consumption and CO_2 emissions by using a simulation system of the vehicle. The goal of this research is to understand the comparison of the performance and CO_2 emission of the range extender engine by two types of engine on minimal engine capacity. This study is the continuation of the previous research that has been published previously [14]. In the previous research, some of the gasoline engines were compared to get the best performance and emission of the range extender engine. Based on this research, the performance and CO_2 emission of the engine will be well understood and the result can be used as a reference to build the real engine and optimization of the energy balance that can be applied in an electric vehicle especially in the electric vehicle developed in LIPI.

II. SIMULATION OF RANGE-EXTENDED ELECTRIC VEHICLE

In this study, range-extended electric vehicle (REEV) was chosen as the model. The components were all the same, it was only the engine that makes the difference in the two models. In this simulation, two engine models are used, *i.e*. the single cylinder 499 cc gasoline engine was compared against the single cylinder 667 cc diesel engine. The vehicle system simulation was performed by AVL Cruise and Japan 08 driving cycle was chosen as road condition characteristic. The details of electric vehicle size and specification of motor generator component are shown in Table 1 and Table 2.

The engine parameters used to investigate as the object on REEV modelling by AVL Cruise are shown on Table 3. The basic configuration of range extended electric vehicle (REEV) is shown in Figure 1. Range extended electric vehicle have

Table 1.
Basic Parameter of electric vehicle

Parameter	**Range Extended Electric Vehicle**
Fuel	Diesel, Gasoline
Frontal area	1.97 (m^2)
Dynamic rolling radius	301 (mm)
Final drive transmission ratio	4.266
Battery model	WB-LYP200AHA

Table 2.
Motor generator specification

Type	**GKN AF-130**
Max speed	8,000 rpm
Nominal torque	170 Nm
Peak torque @20 s	400 Nm
Nominal output power	80 kW
Peak output power @20 s	150 kW
Peak efficiency	95.10%
Dimension (L x D)	110 x 300 mm
Weight	30.5 kg

Table 3.
Engine specification

Type	**Gasoline 499 cc**	**Diesel 667 cc ***
Model	-	Hatz 1D81
Cylinder/valve	1/4 DOHC	1/2 OHC
Bore x stroke (mm)	86 x 86	100 x 80
Max torque (Nm/rpm)	27.3/3,500	32.6/2500
Max power (kW/rpm)	10.54/4,000	10.21/3000
Maximum speed (rpm)	6,000	3,600
Stroke	4	4
Inertia moment	0.35	0.51
Fuel system	EFI	DI
Fuel	Gasoline	Diesel
Heating value (kJ/kg)	43,500	43,100

*Based on experiment

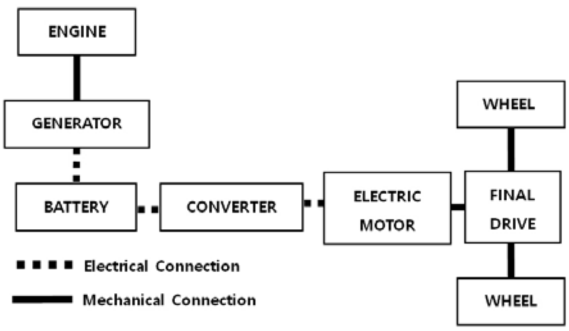

Figure 1. REEV drive train configuration

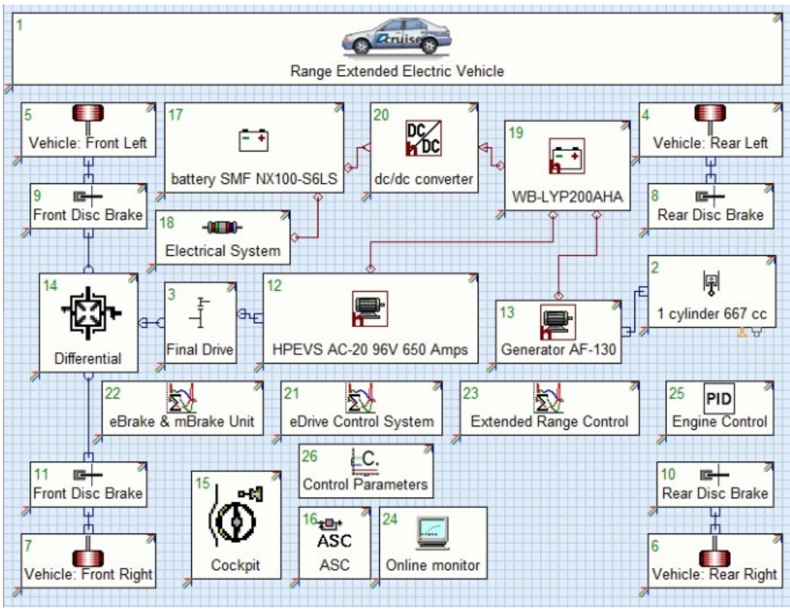

Figure 2. REEV model in AVL Cruise

some main components *i.e.* range extender that consists engine and generator in a series configuration, battery, and electric motor. In this study, we used two models of engine to investigate the performance of REEV *i.e.* a single cylinder 499 cc gasoline engine with maximum power 10.54 kW and a single cylinder 667 cc direct injection diesel engine with maximum power 10.21 kW. The model of the generator is AF 130 synchronous-axial flux with a maximum speed of 8,000 rpm and nominal output power is 80 kW [15]. The series configuration was chosen to minimize engine power capacity when the battery capacity drops to 30% of its capacity, the combustion engine starts the on mode to supply the battery by rotating the AF 130 generator. On this phase, the HPEVS AC 20 electric motor is powered by the battery that is charged by the AF 130 generator. The generator itself, in turn, was pulled by the combustion engine that is managed by the battery management system (BMS). The model of the battery was $LiFeYPO_4$ type lithium-ion batteries with 200 Ah/3.2 V, arranged in a series configuration consist of 30 unit of batteries [16]. The model of the electric motor is HPEVS AC-20 96 V 650 A, AC induction motor with a Curtis controller [17]. The weight values of two models vehicle are given in Table 4.

Table 4.
Weight for each component

Parameter	REEV with 1 cylinder gasoline engine 499 cc	REEV with 1 cylinder diesel engine 667 cc
Curb weight (kg)	873.0	873.0
Engine weight (kg)	53.0	105.0
Electric machine weight (kg)	27.2	27.2
Battery weight (kg)	237.0	237.0
Generator weight (kg)	30.5	30.5
Load (kg)	263.0	263.0
Gross weight	1,483.7	1,535.7

In this research, the model of REEV was built in the AVL Cruise vehicle simulation. The model of REEV is shown in Figure 2. All data from the main components of REEV and others data for the vehicle were input to the AVL Cruise. In this study, the Japan 08 driving cycle was used to represent the driving condition congested with city traffic, idling periods, frequently alternating acceleration and deceleration. Japan 08 driving cycle was chosen due to stop and go road condition. This Japan 08 driving cycle has been frequently used for emission measurement and fuel economy determination, both of gasoline or diesel vehicles. The mode of this driving cycle is shown in Figure 3.

In this research, two types of engine were modelled to determine the performance of the best model of range-extended electric vehicle. Maps of the engine performance came from the data that were collected through the experiment at various speeds in an internal combustion engine laboratory at LIPI and the simulation by

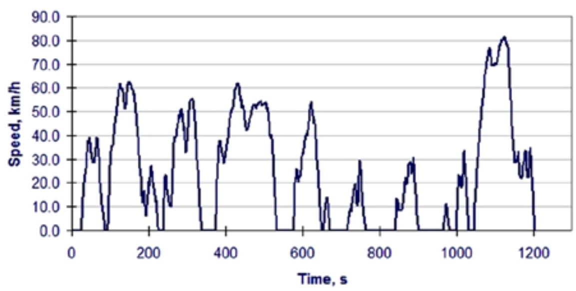

Figure 3. Japan 08 driving cycle

using AVL Boost to get the maximum torque, brake specific fuel consumption (BSFC) maps and motoring torque at full or partial throttle in each engine. Table 3 shows the specifications of each internal combustion engine. The full load torque output of each internal combustion engine was input into AVL Cruise, as shown in Figure 4.

III. RESULT AND DISCUSSION

In this simulation, it was assumed that the energy stored in the battery when the vehicle started to run was 90% of SOC as an initial charge and the vehicle would not run until the battery capacity was down to 30%. Range extender engine was used as one of the main components of REEV with the engine speed of 3000 rpm both in diesel engine and gasoline engine. The term of the range extender is used in order to describe that the engine is used to extend the operational range of the electric vehicle until the EV find the nearest EV charging point.

The engine used as the range extender will be off as long as there is enough energy in the batteries and will be activated when the total batteries capacity which is called as the state of charge (SOC) drops to 35%. The range extender system will still be active until the batteries are charged up to 48% SOC. The simulation results based on Japan 08 driving cycle of the REEV vehicle conducted with road range, fuel consumption and emissions of the two systems are shown in Table 5. Since the REEV is configured on a series system that means the engine is only propulsing the generator to generate the electricity for charging the batteries, then the batteries supply the energy to the electric motor, therefore it can be concluded that the engine should have enough energy to rotate the generator on it maximum rotation. The engine will only work when the SOC value dropped to 35%. On Figure 5, it can be seen that the single cylinder 499 gasoline engine is running harder to rotate the generator for charging the batteries. As the effect, the gasoline engine is always on and automatically increases the fuel consumption. The fuel consumption of REEV with a single cylinder gasoline engine 499 cc is 3.54 L/100 km, while the REEV with single cylinder diesel engine 667 cc is 2.28 L/100 km. This is because the REEV with a single cylinder diesel engine 667 cc have enough power to propulse the generator which charges the batteries that is controlled by battery management system (BMS).

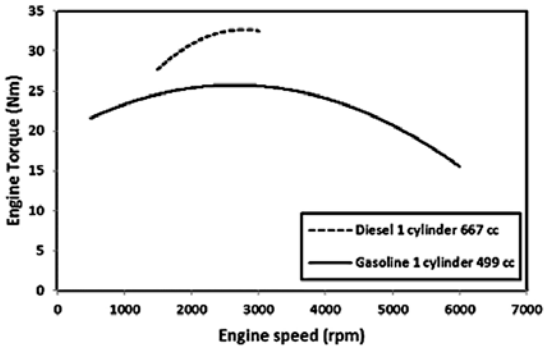

Figure 4. Full load torque output of engine

The diesel engine is working only when needed while the gasoline engine is running continuously to charge the batteries. After the engine is activated, the generator works and transmits the energy to the batteries. An REEV with a single cylinder diesel engine 667 cc is fast to increase the battery capacity up to 48%, so automatically the vehicle is powered by the batteries. The mode is repeated. This is different if compared with the REEV with a single cylinder gasoline engine 499 cc. In this condition, the REEV with a single cylinder gasoline engine 499 cc was unable to increase the SOC, due to lack of power to rotate the generator. Although the maximum power output of 499 cc gasoline engine is higher than 677 cc diesel engine but by modelling it shows that the continuous output power of the REEV with a single cylinder diesel engine 667 cc is higher than REEV with single cylinder gasoline engine 499 cc.

The continuous power output of the engine single cylinder diesel 667 cc that can be transmitted to rotate the generator up to 10.04 kW while the continuous power output of the range extender engine with a single cylinder gasoline engine 499 cc is 8.22 kW. This happens due to the lower torque generated by the gasoline (27.3 Nm/3,500 rpm) engine, while the torque of the diesel engine is 32.5 Nm/3,000 rpm (max 32.6 Nm/2,500 rpm). As the effect, the range extender engine with a single cylinder diesel 667 cc is easier to increase the SOC value of the batteries. This condition has a relation with the CO_2 emission of range extender engine. The difference of the fuel consumption of each vehicle model also affects the CO_2 emissions produced. It can be seen in Table 3 that CO_2

Table 5.
Performance of two vehicle model in Japan 08 driving cycle

Parameter	REEV with 1 cylinder gasoline engine 499 cc	REEV with 1 cylinder diesel engine 667 cc
Model	-	Hatz 1D81
Fuel consumption of engine (L/100 km)	3.54	2.28
CO_2 (g/km)	86.11	59.88

emission of the RE with a single cylinder diesel 667 cc is lower than the RE with a single cylinder gasoline 499 cc. In addition, the increasing of CO_2 emissions of the RE with a single cylinder gasoline 499 cc is also caused by the prolonged use of a range extender engine when the batteries capacity is down to its limit.

To increase the value of SOC from 35% to 48% of batteries capacity requires operation up to 30 minutes for a single cylinder diesel engine, while the RE with a single cylinder gasoline 499 cc operates continuously until the fuel is depleted. As the effect, CO_2 emission of the RE with a single cylinder gasoline 499 cc is 30.47% higher than the RE with a single cylinder diesel 667 cc. The operating condition of each range extender engine is shown in Figure 5. Figure 6 and Figure 7 show the characteristics of the range

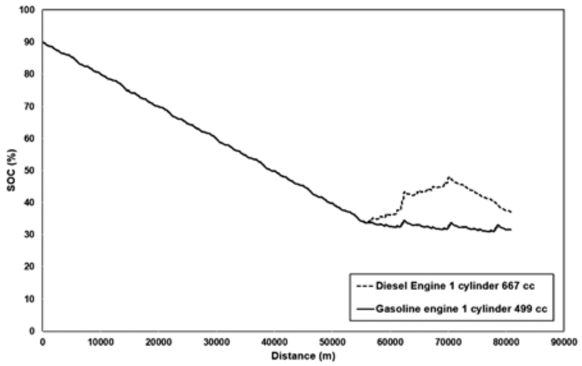

Figure 5. SOC of two vehicle model simulated over Japan 08 driving cycle

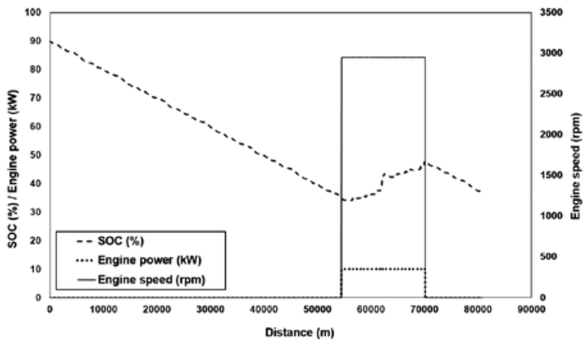

Figure 6. SOC, engine speed, and engine power in REEV 1 cylinder 667 cc simulated over Japan 08 driving cycle

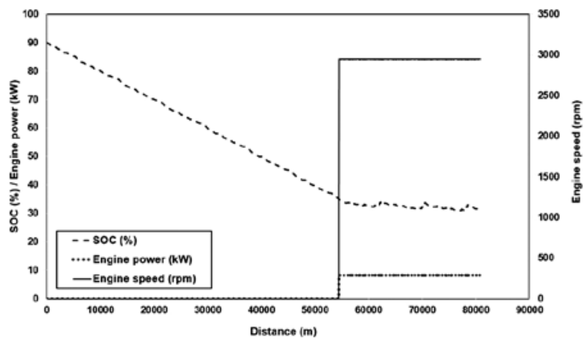

Figure 7. SOC, engine speed, and engine power in REEV 1 cylinder 499 cc simulated over the Japan 08 driving cycle

extender engine operation mode related to battery SOC curve versus operational range (distance). In addition, these two figures also show the engine output power versus operational range (distance). For the RE with the diesel engine that is shown in Figure 6, the generator set was operated temporarily to charge the battery, when the battery capacity was enough to power the electric motor then the generator set will be shut off. In addition for Figure 6, it can be observed that the minimum power that should be supplied to the vehicle to follow the road characteristic based on the Japan 08 driving cycle is about 10.04 kW. While Figure 7 shows the minimum power that should be supplied to the vehicle to follow the operational characteristic based on the Japan 08 driving cycle is about 8.22 kW. It is shown by the flatted dash line when the SOC falls to 35%. When this event occurred, it means the operational range of the electric vehicle becomes unlimited depend on diesel or gasoline fuels. This condition induces the generator set working as a range extender on the electric vehicle as known as REEV. Since the generator works in optimum conditions, the advantages of the range extender engine on the electric vehicle can be achieved.

Based on this simulation, the REEV model with the RE single cylinder diesel engine 667 cc gave the best performance on fuel consumption and CO_2 emission for range extender application.

IV. CONCLUSION

The simulation model of range-extended electric vehicle (REEV) was built using AVL Cruise software piloting a Japan 08 driving cycle. The diesel engine is better than gasoline engine if applied as a component of the range extender if the optimum rotation of generator is relatively low. The major factor that influences the engine ability to increase the battery capacity is torque rather than power at same optimum rotation for the generator. Based on the weight of the engine simulation and inertia moment of the engine, we found that there is not much effect the operational range of the REEV. Based on the simulation, the range-extender electric vehicle with a single cylinder diesel 667 cc appeared as the best choice when running on Japan 08 driving cycles. The performance characteristics of range extended electric vehicles can be predicted for further system development. A comprehensive study for building a better understanding of range extender systems for an electric vehicle is necessary to understand the compatibility of each component and characteristic of the range-extender electric vehicle.

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