A Comparison Study of Engine Performance in Range Extended Electric Vehicle and Conventional Vehicle

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***Abstract*—This study aimed to compare the fuel consumption and performance of engine in range extended electric vehicle (REEV) and conventional vehicle which contain different drive systems. For this purpose, a vehicle system simulation has been used to simulate these vehicle models. This simulation used data from 4 cylinders 1186 cc engine in a conventional vehicle and electric machine, battery, generator and engine 2 cylinders 999 cc in range extended electric vehicle. While aspects of vehicle dimensions such as wheels, brakes, differential, and transmission likened to both drive systems. The results of this simulation have been shown and compared with each other.**

***Index Terms*—Fuel Consumption; Range Extender Engine; Conventional; AVL Cruise.**

I. INTRODUCTION

Pollution in Indonesia has been a serious problem in recent years, especially in big cities. Several major sources of air pollution in Indonesia are emissions from factories, exhaust emissions from motor vehicles, household, and forest fires. However, research shows that about 70% of air pollution which occurs in big cities in Indonesia such as Jakarta is caused by motor vehicles [1] [2].

Based on research conducted by the WHO (World Health Organization), air pollution kills seven million people each year globally [3]. In addition, the researchers estimate that nearly 2/3 of total petroleum demand is from the transport sector [4]. While the daily production of oil is around 63.5 million barrels, the world's oil reserves are conservatively estimated to last about fifty years [5].

Based on these data, the main challenge of the automotive industry and research institutions in the development process of vehicles is developing vehicle technology through optimization of vehicle systems and vehicle components.

Direction of vehicle systems and vehicle components optimization will be based on several alternative technologies including improved efficiency of conventional propulsion systems and the use of alternative drive systems.

Conventional propulsion systems rely on energy sources of fuels, such as gasoline, diesel, or gas to drive the vehicles. In internal combustion engines, power from the combustion of fuel is utilized and transformed into the movement to drive the vehicle. Although this vehicle generally show a good performance at a low price, conventional vehicle produce high emissions, creates pollution and spend a lot of natural resources [6].

Vehicle with an electric drive system is one type of alternative drive systems. Vehicle with an electric drive system is the most practical vehicle candidate in order to reduce fuel consumption, exhaust emissions and vehicle operating costs. However, vehicles with electric drive systems still have drawbacks such as limited mileage and the high cost of batteries. To overcome this problem a range extender technology is then developed. Range extender is a type of small generator sets consisting of an engine and generator. Range extender works only when needed by electric vehicles. This system is a switching system that leads to an efficient automotive technology and cleaner. Althougth this system is still polluting, it is relatively low.

Similar research also has been carried out by some car companies like Lotus that develops range extender with engine capacity of 1.2 L 3-cylinder with a choice of two types of power (15 kW @ 1500 rpm and 35 kW @ 3500 rpm) [7]. Although the range extender has some advantages such as cheap, but it still produces emissions, although not too large. Capstone also developes a range extender uses micro turbine with 30 kW power with low weight and small volume (91 kg, 56 x 15 x 28 cm) [8]. Range extender has been tested on the super car concept Jaguar C-X75 with double Micro turbine (2 x 70 kW) of Bladon Jet [9]. The downside of this type of range extender is a low efficiency of about 25% at ambient temperatures and high acquisition costs [8]. Despite its high cost, AVL uses the Wankel engine with a power of 15 kW, 2-cylinder with minimum fuel consumption of 260 g/kWh [10]. Although the shape is compact, it still has some drawbacks such as high emissions and the maintenance costs is significantly high. Wankel engine also has an efficiency that is still low because the geometry is not flexible and undergoes heat loses. Research with a fuel cell range extender has been done by Sharer Phil and Aymeric Rousseau in 2013 [11]. The downside of the fuel cell range extender is the high cost in producing although other factors like noise and vibration, efficiency, and emissions are relatively small.

This study focuses on the comparison of fuel consumption and performance of range extended electric vehicles and conventional vehicles systems using a vehicle system simulation. If compared to the existing range extender engine, this model uses small engine with 2 cylinder 999 cc and maximum power of 49 kW. The motivation of this study is to know the comparison of fuel consumption and performance of range extended electric vehicles and conventional vehicles systems so that the simulation result can be used as a reference to create an energy efficient and environmentally friendly vehicles, especially in Indonesia and generally for electric vehicles in the world.

II. SIMULATION

In this research, the drive system in conventional vehicle is replaced by range extender drive system. In order to make the comparison equally, only the drive system elements are changed on the same vehicle and the power of the driving system elements are equalized at each different model. AVL Cruise, one of vehicle system simulation, was used to simulate these vehicle models. In this simulation, the same vehicle was used as a base to change the drive system. The details of the vehicle size and conditions are shown below.

Curb Weight	: 873 (kg)
Frontal Area	: 1.97 (m2)
Dynamic Rolling Radius	: 301 (mm)
Final Drive Transmission Ratio	: 4.266
Fuel Type	: Gasoline
Heating Value	: 43500 kJ/kg
Fuel Density	: 0.737 kg/l
Engine working temperature	: 80ºC
Specific carbon content	: 0.86

The configuration of range extended electric vehicle (REEV) and conventional vehicle are shown in the following Figure 1 and Figure 2.

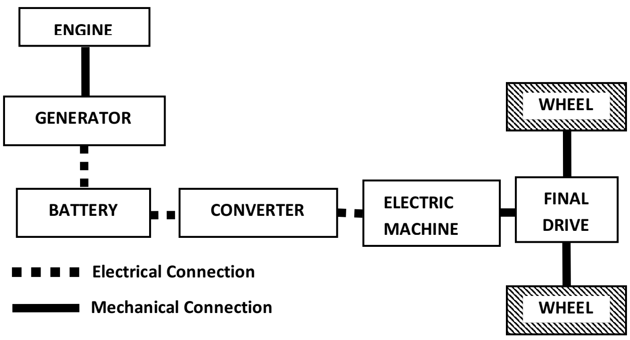

Figure 1: Range Extended Electric Vehicle configuration

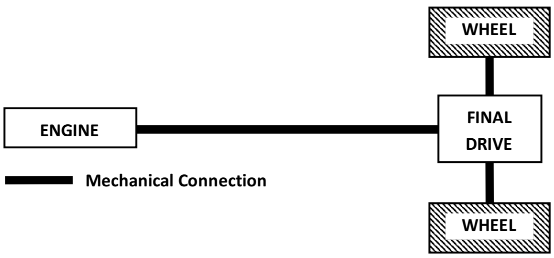

Figure 2: Conventional vehicle configuration

In this study, the driving systems can cover some components of vehicle. Range extended electric vehicle uses some main components such as engine and a generator as range extender, battery, and electric machine. The engine model is 2 cylinders 999 cc with maximum power 49 kW. The generator model is AF 130 synchronous-axial flux with nominal output power 64 kW and maximum speed of 8000 rpm [12]. The battery model is 30 unit LiFeYPO4 type lithium-ion battery , with 200 Ah / 3.2 V on series configuration [13]. The electric machine model is HPEVS AC-20 96V 650 A, AC induction motor with a Curtis controller [14]. Conventional vehicle uses engine 4 cylinder 1186 cc with maximum power 47.3 kW as engine model.

The parameter of components used in REEV and conventional vehicle are shown in Table 1. The values of power and weight of two models vehicle are given in Table 1. The total power of each vehicle is equal to each other. The difference weight between the vehicles is due to the difference between the driving system components.

Table 1
Parameter of Range Extended Electric Vehicle (REEV) and Conventional vehicle

Parameter	Range Extended Electric Vehicle	Conventional Vehicle
Engine Power (kW)	42.6	47.3
Generator Power (kW)	64.7	-
Electric Machine Power (kW)	48.7	-
Battery Number of Cell	30	-
Curb Weight (kg)	873	873
Engine Weight (kg)	57	77
Electric Machine Weight (kg)	27.2	-
Battery weight (kg)	237	-
Generator Weight (kg)	30.5	-
Load (kg)	263	263
Gross Weight	1487.7	1213

REEV model and conventional vehicle are shown in Figure 3 and 4. In this study, all of the components used in the two vehicle models were inputed in the vehicle simulation systems. AVL Cruise is used as vehicle simulation systems to build the vehicle models. AVL CRUISE has some advantages compared to other vehicle simulations such as the simplicity to build and change the model, and the speed and accuracy in model calculation [15].

In this simulation, the best performance of two vehicle models can be achieved by simulating the vehicle models and piloting driving cycles. A driving cycle describes a set point of time versus vehicle speed. Vehicle simulation offers comparison such as for the performance of vehicles, fuel consumption and exhaust gas emissions in many models. Extra Urban Driving Cycle (EUDC) was choosen for this simulation. EUDC is one of driving cycle to measure fuel consumption and electric energy consumption and exhaust gas emission of vehicles. This driving cycle has been designed to describe more aggressive and high speed. The maximum speed of the EUDC is 120 km/h. The mode of this driving cycle is shown in Figure 5.

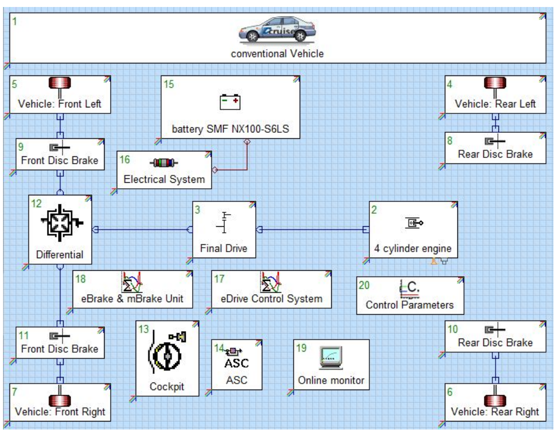

Figure 4: Conventional vehicle model in AVL CRUISE.

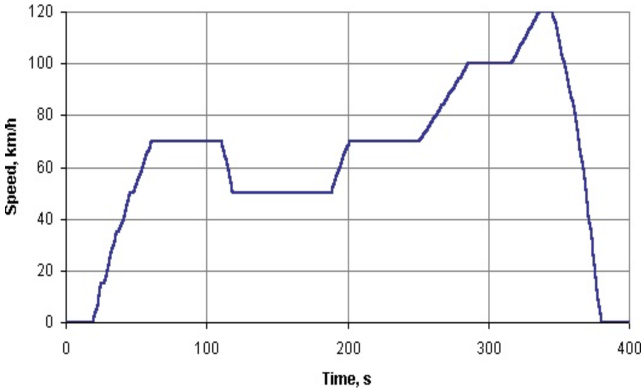

Figure 5: EUDC Driving Cycle

III. Results and Discussion

In this study, range extender, that covers engine and generator, was used in REEV with engine speed of 3200 rpm. Range extender will be off as long as there is enough energy in the batteries and will be activated whenever the state of charge (SOC) drops to 45%. The range extender system is still active until the batteries are charged up to 50% SOC. The simulation result of fuel consumption and emissions of two vehicle models can be seen in Table 2.

Parameter	Range Extended Electric Vehicle	Conventional Vehicle
Fuel consumption of engine (L/100 km)	1.47	6.41
Emission of NOx (g/h)	35.25	171.49
Emission of CO (g/h)	575.86	611.37
Emission of HC (g/h)	6.13	46.19
Emission of CO_2(g/km)	34.23	149.01
Distance range (km)	69.51	69.56

Based on the simulation result in Table 2, it can be seen that fuel consumption of engine in conventional vehicle in the same distance (around 69 km) is four times larger than that in REEV. This is because engine inthe REEV works only when needed since the main drive source of REEV is batteries. This study can be seen in Figure 6. When the vehicle has been activated, the battery was set in the initial position of 90% to 30%. Engine will only work when the SOC value dropped to 45%. At the same time, after engine was activated, the generator works and transmits the energy from engine to the batteries. Therefore the batteries can increase the value of SOC until it reaches 50%.

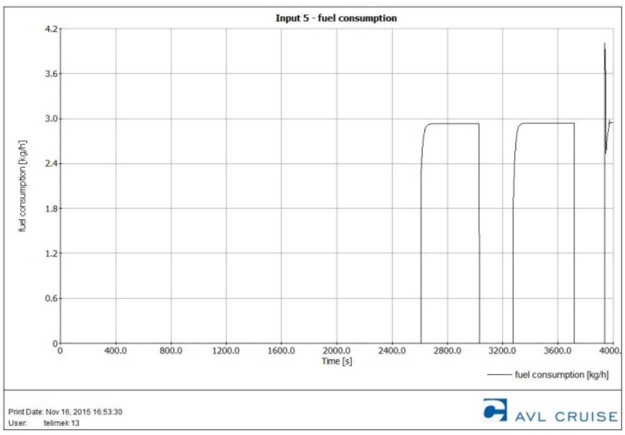

Figure 6: Fuel consumption of range extended electric vehicle model

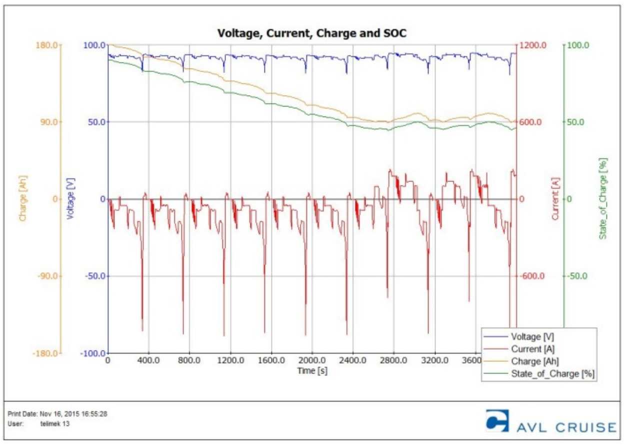

Figure 7: SOC of range extended electric vehicle model

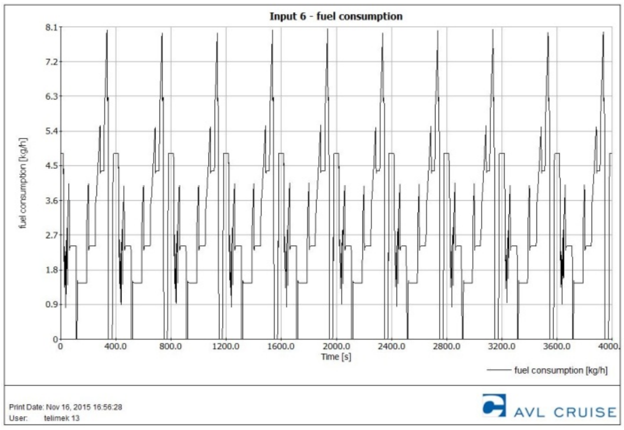

Figure 8: Fuel consumption of conventional vehicle model

When the value of SOC has reached 50%, the battery is back to work and the engine stopped. This process is repeated until the battery drop. The SOC process of range extended electric vehicle model can be seen in Figure 7. When the engine is turned on, current of the batteries increases. It seems different when compared to a conventional vehicle models. In the conventional vehicle models, engine works since the first time the vehicle runs. This process has a consequence that the amount of fuel to run the vehicle becomes greater. It can be seen in Figure 8. The difference of the fuel consumption of each vehicle model also affects the emissions produced. It can be seen in Figure 9 and 10 that each emission decreases when the vehicle model uses a range extender. On the contrary, the production of emission is so high when the vehicle model is conventional vehicle. This is valid to all types of emissions. NOx Emission of conventional vehicle is 4 times larger than REEV. CO emission of conventional vehicle is 7 times larger than REEV. CO2 emission of conventional vehicle is 4 times larger than REEV. The last pollutant, CO emission of conventional vehicle is bigger than REEV.

The simulation results of range extender engine and conventional engine power are shown in Figure 11 and 12. In Figure 11, the maximum power output of the REEV is 22 kW with constant engine speed 3300 rpm. The REEV works when the value of SOC has reached 45% (the simulation time at 169 s). Based on the simulation result, this REEV model could be applied in LIPI electric vehicle. If compared to the existing REEV in the world, this model has bigger output power although using smaller size engine.

In Figure 12, the maximum power output of conventional engine is 32 kW. In this model, the simulation works at varying engine speed and works in the first time the vehicle runs. Consequently, the fuel consumption of this vehicle model requires more than the range extended electric vehicle (4 times).

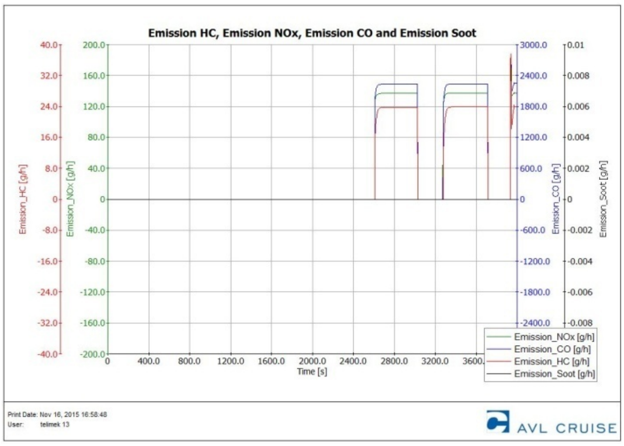

Figure 9: Emission of NOx, CO and HC of range extended electric vehicle model

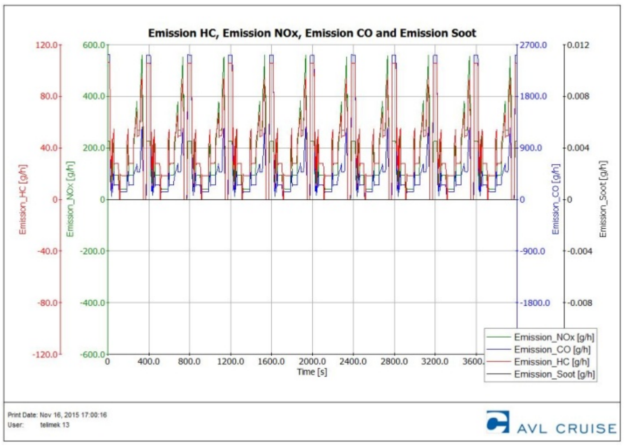

Figure 10: Emission of NOx, CO and HC of conventional vehicle model

IV. CONCLUSION

Based on simulation results, it can be concluded as follows:

1. The simulation results shows that the fuel consumption for REEV system is lower than a conventional vehicle systems with a reduction in fuel consumption of 73.48%.
2. The simulation results also indicate that exhaust emissions for REEV system is lower than a conventional vehicle system.
3. From the comparison, the vehicle with range extender is more fuel efficient and more environmentally friendly than with conventional drive systems.
4. The maximum power of range extender engine is enough to be applied in LIPI electric vehicle.

In the future, the optimization of the range extended electric vehicle model is needed including the calculation of maintenance cost and robustness of the model.

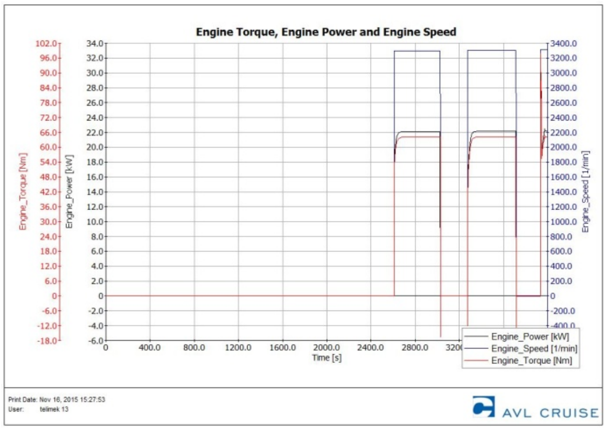

Figure 11: Engine power, engine torque and engine speed of range extender engine

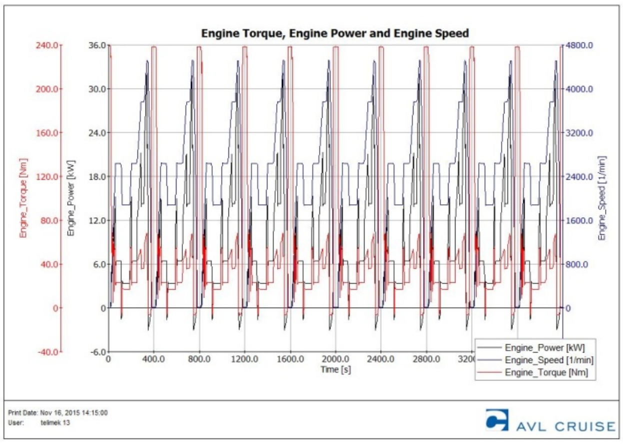

Figure 12: Engine power, engine torque and engine speed of conventional engine

ACKNOWLEDGEMENT

This work is supported by Research of Competitive 2015, Indonesian Institute of Sciences. The author would like to thank all members of Internal Combustion Engine Laboratory, Indonesian Institute of Sciences for their assistance in obtaining experiment data, especially Mr. Ahmad Dimyani.

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