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Analysis of range extender electric vehicle performance using vehicle simulator

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Abstract

Range Extender Electric Vehicle (REEV) is a complicated multi-domain engineering system. The road ability on a range extender electric vehicle (REEV) is depending on the balance of subsystems. The important drive components, especially battery, electric machine, wheel and range extender unit are modeled. Vehicle simulation model named AVL Cruise has been used to simulate the balance of subsystems to increase road ability. The complex interactions among the components are taken into account in a complete multi-domain model. The power train system models have been developed, the dynamic behavior of REEV's is simulated under selected driving cycles using rule-based energy management strategy. According to the simulation results, the significant benefits of REEVs for performance and fuel consumption are proved.

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Keywords: range extender; AVL cruise; modeling; driving cycle; performance; electric vehicle

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1. Introduction

Fossil fuel as a biggest energy source in the world is the primary fuels for vehicles, where 93.8% of fuel consumed on transportation sector was derived from petroleum [1]. Utilization of fossil fuels continuously makes the oil reserves in the world will be depleted. The researchers and the automobile manufacture have to find new technology to reduce the dependence on single energy source such as fossil fuels. The current technology is available to decrease fuels consumption and reduce GHG emissions on transportation sector such as electric vehicle

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or hybrid vehicle. On electric vehicles, the source of energy is supported by electricity grid so that significantly reduce the fuels consumption. The advantages of electric vehicles are quieter than conventional vehicles, they produce no local emissions, no idling speed that consume specified energy, and good acceleration performance. With all of these positive attributes compared to conventional vehicles, why are electric vehicles virtually non-existent in the current transportation mix? The strongest limitation to electric vehicles is their expensive and low energy density battery.

Range Extended Electric Vehicles (REEV) is a solution to the limited range and exorbitant cost of electric vehicle. They operate essentially as an electric vehicle until their batteries become depleted, at which point they utilize an Auxiliary Power Unit (APU) to provide electricity by recharge the battery or directly to propel the vehicle during driving and allow the vehicle to continue operating [2]. The small auxiliary power unit could consist of an internal or external combustion engine coupled to a generator in series configuration. The APU energy source is conventional liquid fuel, and the vehicle can continue operating indefinitely assuming intermittent refueling.

REEV draws upon the strengths of both the conventional liquid fueled vehicle, as well as those of the electric vehicle. During short daily commutes the vehicle operates using locally produced electricity, stored in the vehicle’s on-board battery pack. If the battery pack becomes depleted, the vehicle can draw upon energy stored in its liquid fuel tank for continued operation. The liquid fuel tank can be refilled at a standard gas station, allowing the vehicle to operate as a conventional vehicle. In the eyes of the user, the only difference between operating REEV and a conventional vehicle is the option to fuel REEV with either low cost electricity, or regular liquid fuel. Compared to conventional hybrid vehicles, REEVs could significantly reduce fuel consumption and emissions; compared with pure electric vehicles, E-REVs could increase the driving range, therefore it is seen as one of the most promising technological bridges between the vehicles of today and the sustainable concepts of tomorrow [3].

The APU generally only provides the average power demanded by the vehicle, so it can be downsized compared to the power unit of a conventional vehicle. For this reason, the APU could be compact, lightweight and good performance on noise, vibration and harshness (NVH). The APU is decoupled from the road load, meanwhile its can be operated and optimized to produce high efficiency and low exhaust emissions. The REEV will operate smoothly and quietly as an electric vehicle, while the APU should be good in NVH, inexpensive and low maintenance. In addition, many vehicle trips will not require use of the APU.

The goal of this research project was to develop a procedure to predict the performance of internal combustion engines for extending the range of electric vehicles. To realize this goal, an engine testing facility was developed to measure the fuel efficiency and exhaust emissions of an engine operating at various loads and speeds.

The collected data was used to build a model of engine in AVL CRUISE powertrain simulation software [4]. The engine model was applied to an electric vehicle model as a range extender, and its performance was simulated while piloting two driving cycles.

2. Introduction of vehicle simulator

Vehicle simulation is a powerful tool which can predict the performance of a vehicle without requiring its physical construction. It allows for the size and configuration of components in an electric vehicle to be quickly and inexpensively designed and optimized. There are some popular simulation software developed to study advanced vehicle platforms are PSAT [5], ADVISOR [6] [7] and MATLAB/Simulink [8]. Vehicle simulation can be evaluated using a forward facing methodology, backward facing methodology, or a combination of both techniques.

The forward facing vehicle simulation methodology utilizes a driver model to control the vehicle. The driver model actuates a virtual throttle and brake pedal to achieve the requested driving cycle, generally using feedback control to minimize error. The forward facing methodology allows dynamics models to be evaluated, as well as for maximum effort simulation studies. The disadvantage of the forward facing methodology is its larger computational cost. The backward facing methodology begins its calculation by assuming that the vehicle was able to achieve the request of the driving cycle. It determines how much tractive force is required at the vehicle’s wheels, and works its way through vehicle components until it arrives upon the amount of fuel or electricity consumed. The backwards facing methodology does not include a driver model, and has difficulty accounting for dynamic effects. In addition, the assumption that the vehicle will be able to achieve the requested driving cycle does not always hold true. The advantage of the backward facing model is its computational efficiency.

PSAT utilizes a primarily forward facing simulation methodology, lending itself to hardware and detailed control system development [5]. ADVISOR utilizes a primarily backward facing simulation methodology, with some aspects of forward facing methodology to insure that the vehicle can deviate from the driving cycle when necessary [6] [7]. ADVISOR is effective at quickly comparing vehicle configurations, but is not intended for detailed hardware design. The vehicle simulation software selected to study the range extender engine was AVL CRUISE [4]. AVL CRUISE could be configured to operate using forward facing, backward facing, or a combination of the two methodologies depending on simulation requirements. During model development and troubleshooting, a backward facing model was utilized for simulation efficiency. A forward facing simulation routine was then used for model validation and detailed studies. AVL Cruise has many advantages such as: simple in the manufacture of vehicle models, the model calculation time is short, the information from the results of the calculations are fairly accurate, easy to change the configuration of the vehicle, and the support of experts in the field of vehicles worldwide [9].

3. Components and system modeling of REEV power train

3.1. Vehicle Design

AVL CRUISE uses a Graphical User Interphase (GUI) to allow users to build their own vehicle models, or modify basic models provided by AVL Cruise. Fig. 1 shows a model of a Range extender electric vehicle. Each box in the figure represents a module which can be customized to the specifications of the user. Blue lines show a mechanical connection between components, or "energy connection." Red lines show an electrical energy connection. In addition to the energy connections shown in the figure, components are also connected through information connections via a data hub [4]. The power train of REEV system consist mainly traction battery, electric motor, the engine generator unit and its performance was simulated while piloting two driving cycles.

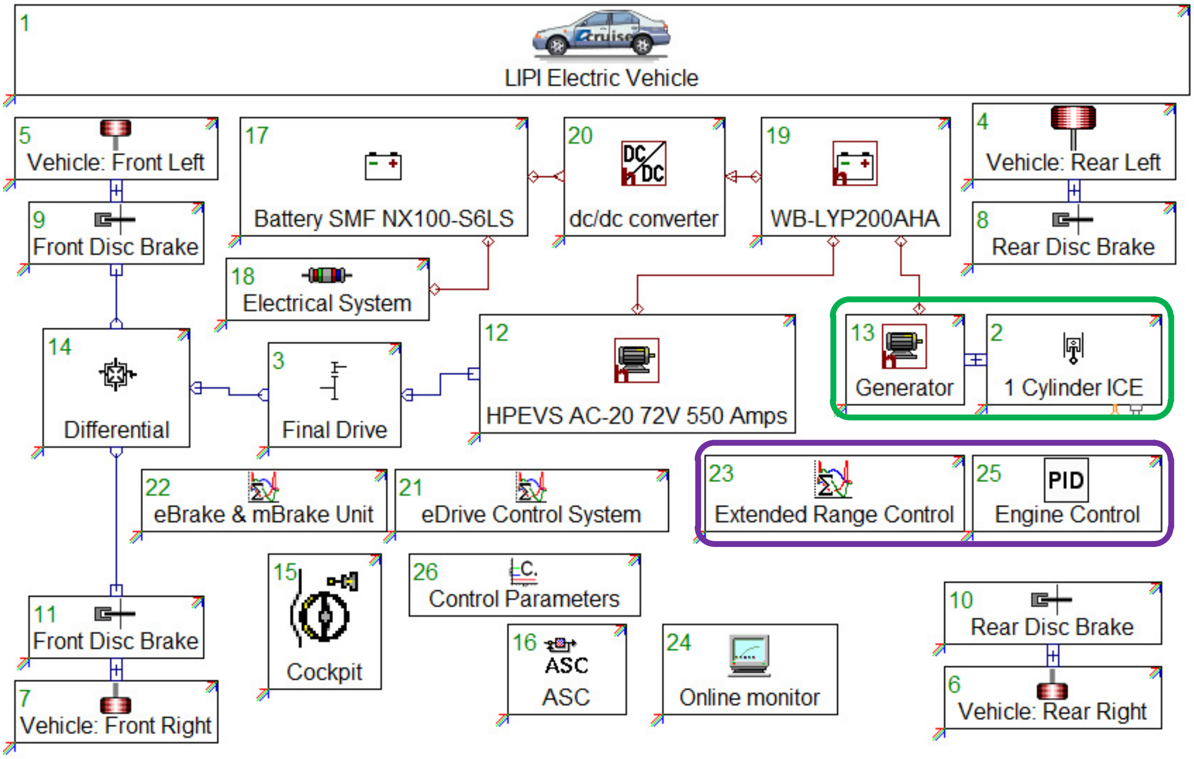

Fig. 1. AVL CRUISE component model of range extended electric vehicle.

3.2. Battery

The Electric vehicle’s energy storage was accomplished with 30 lithium-ion battery cells in series with capacity 200Ah. The battery cells studied are shown below in Table 1. The vastly different capacity of the two cells was intended to approximate the range of a battery electric vehicle as well as the reduced range of a plug-in hybrid electric vehicle. Manufacture data for the state of charge of battery was used to construct the model [10] and shown in Fig. 2.

Table 1. Specification of Battery [10].

Battery Parameter	Basic Data
Model	WB-LYP200AHA
Nominal Capacity	200 Ah
Operation voltage	2 V – 4 V
Nominal voltage	3.2 V
Maximum Operation temperature	85°C
Weight	7.3 kg
chemistry	LiFeYPO4
Size	362x256x56 mm

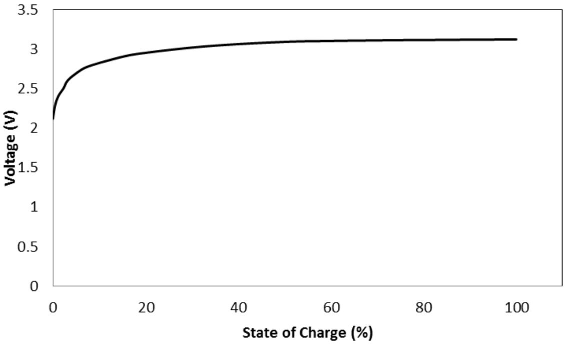

Fig. 2. WB –LYP200AHA State of Charge.

3.3. Electric motor

The electric motor model was based AC-20-72V, AC induction motor with a Curtis 550 amp regen motor controller. Manufacturer data for the efficiency of this motor/controller at full load was used to construct the model [11]. The system’s efficiency at partial load was estimated using the characteristic performance map of AC induction motors [11]. The detail specification of electric motor is shown below in table 2.

Table 2. Specification of electric motor [11].

Electric Motor Parameter	Basic Data
Model	HPEVS AC-20
Nominal voltage	72 VAC
Maximum speed	8,000 rpm
Controller	72 V/550 A
Maximum Power	63 HP

3.4. Engine

The goal of this research is to construct a model of a range extender electric vehicle based on the experimental performance of the engine. Engine model is constructed on AVL CRUISE and the engine specification is required. Basic engine parameters such as maps of engine performance and geometry were input into AVL CRUISE as shown in Table 3. Engine performance maps are collected by experiment at various engine speeds to get maximum torque, motoring torque, BSFC at full and partial throttle. Additional information could be input to allow thermal modeling of the engine as well as more detailed transient treatment. The engine model could be inserted as a component within a vehicle model, and the fuel consumption and exhaust gas emissions could be predicted for different vehicle configurations and different driving cycles.The full load torque output of the engine was input into CRUISE as shown below in Fig. 3. The dynamometer used to study the engine was able to absorb torque, but unable to operate as motoring system. The motoring torque was approximated as one fourth that of a 1.2 L 4-cylinder SI engine modeled by AVL in CRUISE. The motoring torque approximation is shown in Fig. 4. Utilizing the data points for each given engine speed, CRUISE was able to extrapolate, and build the BSFC map shown below in Fig. 5.

Table 3. Specification of Engine.

Engine Parameter	Basic Data
Engine type	Gasoline
Displacement	389 cc
Working temperature	80°C
Number of cylinder	1
Number of stroke	4
Maximum speed	5,500 rpm
Idle speed	1,500 rpm
Heating value	44,000 kJ/kg
Fuel density	0.737 kg/l
Torque maximum	22.3 Nm (2,900 rpm)

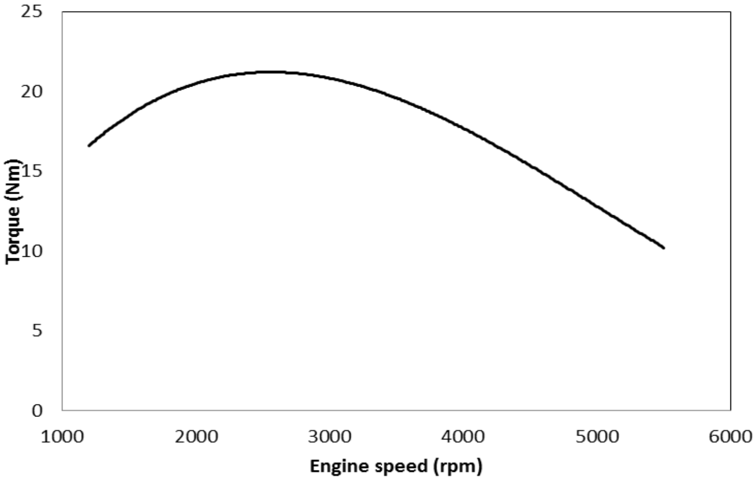

Fig. 3. Full load torque output of engine input intoAVL CRUISE.

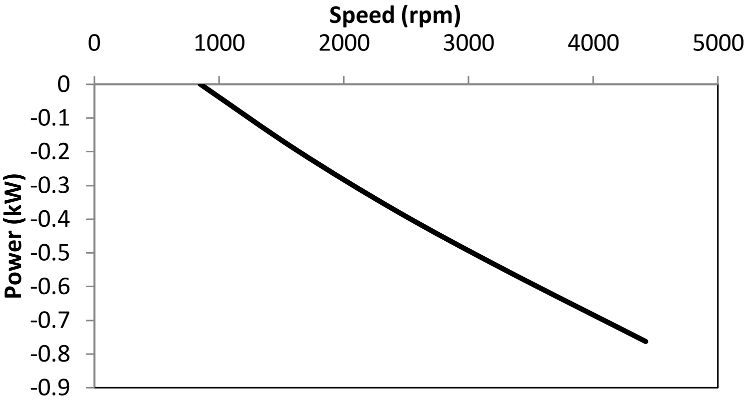

Fig. 4. Motoring curve of engine.

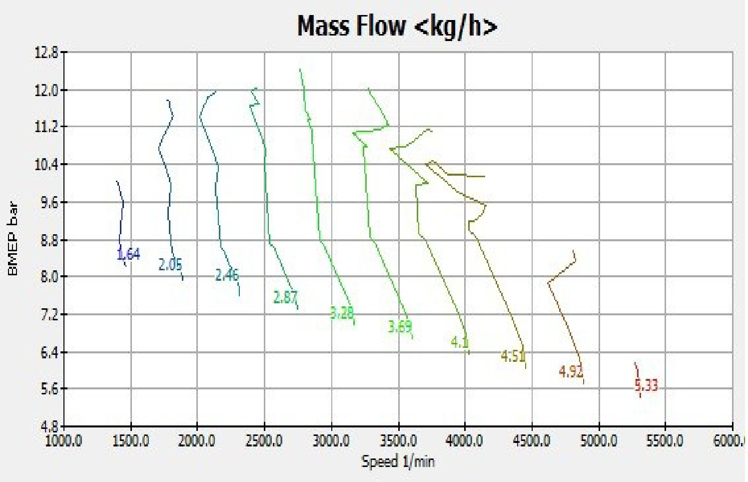

Fig. 5. Constant BSFC (g/kWhr) island map referenced by engine speed and engine load: generated by AVL CRUISE.

4. Simulation and results

The goal of the simulation study was to utilize the experimentally generated engine model as a range extender for an electric vehicle. An electric vehicle model utilized an AC induction electric motor with a peak power output of 35.6 kW, coupled to final drive. The electric vehicle's layout in AVL CRUISE is shown below in Fig. 6.

The engine model was coupled with a generator to comprise the range extending system. The maximum AC generator output is 5.5 kW and rated AC output 5 kW. This combination was selected to absorb the maximum power output by the engine and the battery charger needed.The range extending system was implemented in AVL CRUISE as already shown in Fig. 1, while the engine and generator are shown highlighted in green and the range extender control components is highlighted in purple.

The range extending system was implemented with engine speed 2,990 rpm, as shown in Table 4 and Fig. 7. In this condition, engine has highest efficiency and activated if the battery SOC dropped to 45%. The range extending system remained active until the battery was charged to 50% SOC, at which point the range extender was shut down. Such a method of operating the range extender is termed a thermostat, or engine on-off control strategy [12].

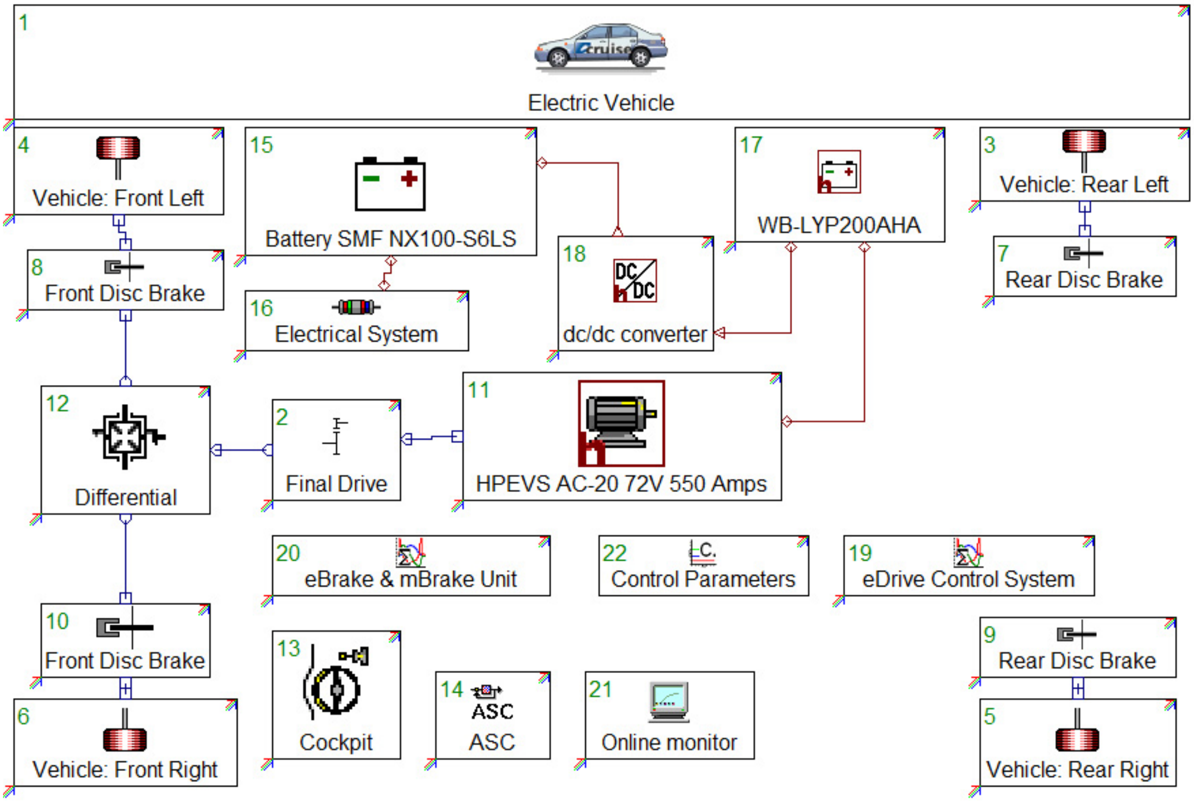

Fig. 6. AVL CRUISE component model of electric vehicle.

Table 4. Operating of range extending system.

Engine speed (rpm)	Engine power (kW)	Engine efficiency (%)	Generator efficiency (%)	Power output (kW)
2990	6.16	9.26	80	2.74

To test the performance of the range extending system, two vehicle configurations wereselected. Vehicle 1 was based loosely off of theelectric vehicle as shown in Fig. 6. Vehicle 2 added range extending systems to vehicle configurations 1 respectively as already shown in Fig. 1. Each vehicle was simulated piloting two driving cycles as shown in table 5. The Japan 08 transient cycle (JC08) and NEDC driving cycle are chose to simulate the REEV system. JC08 is performed both with cold and warm start and it represents driving in congested condition, with strong accelerations and decelerations. NEDC cycle wasdriving cycle designed to assess the fuel economy in passenger cars excluding commercial vehicles.NEDC cycle was New European Driving Cycle. NEDC cycle consists of four repeated ECE-15 urban driving cycles (UDC) and one Extra-Urban driving cycle (EUDC).Although originally designed for petrol-based road vehicles, the driving cycle is now also used to estimate the electric power consumption and driving range of hybrid and battery electric vehicles. Two mode of driving cycles were shown in Fig. 8a-8b.

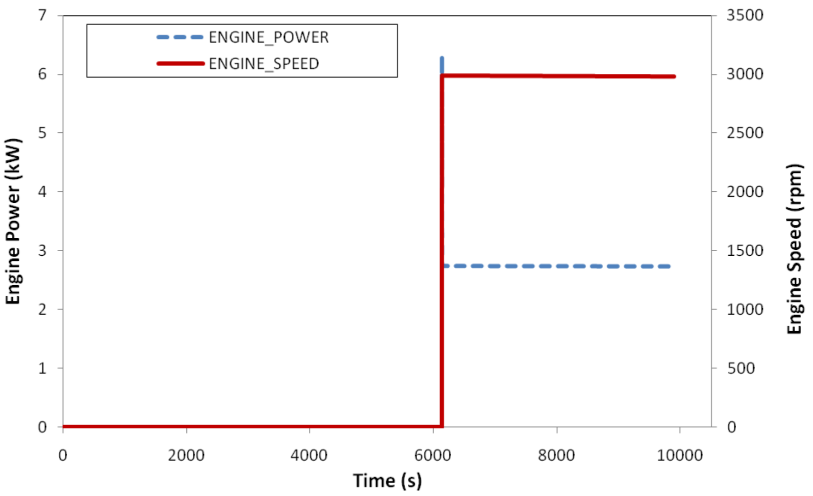

Fig. 7. Vehicle with WB-LYP200AH batteries and range extender operated at engine speed 2,990 rpm.

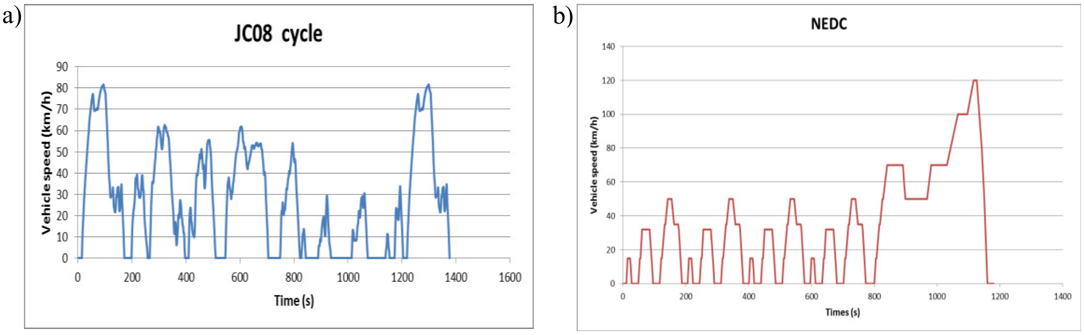

Fig. 8. Two mode of driving cycle: a) Japan 08 driving cycle, b) NEDC driving cycle.

Table 5. Performance vehicle configurations of various driving cycles.

Driving cycle	Vehicle Code	Electric Efficiency (kWh/100 km)	Range (km)	Fuel Efficiency (L/100 km)
Japan 08	1	17.02	53.12	na
	2	13.67	64.77	5.86
NEDC	1	16.08	61.85	na
	2	14.00	70.66	3.91

The electrical efficiency of each vehicle configuration for each driving cycle is tabulated in Table 5. Vehicle configuration 2 piloted the Japan 08 and NEDC driving cycles with the highest electrical efficiency.This was due the light weight of the vehicle compared to the other configurations.

Vehicle range was evaluated as the distance covered while the batteries discharged from 90% to 30% SOC. This test was applicable to vehicle configurations 1 and 2. Vehicle configuration 2 piloted the Japan 08 and NEDC driving cycles have higher range than vehicle configuration 1. Vehicle configuration 2 (range extender) with Japan 08 cycle increase the distance by 21.93% compared to vehicle configuration 1 (no range extender). Vehicle configuration 2 with NEDC increases the distance by 14.24%. Based on these result, using range extender on electric vehicle effectively improve the mileage of electric cars.

Fig. 9-10 show the operation of the engine piloted through the JC08 driving cycle for vehicle configuration 1 and 2 respectively. Fig. 9 show electric vehicle work from initial charge 90% to 30% with maximum prediction range up to 53.12 km. When compared the Fig. 9 to 10, it seems the battery effort to hold the current of SOC at 45% when the range is 40 km. In this condition, range extender should began working at the speed of 2990rpm (Fig. 10), while on fully electric vehicle when the extender engine is not installed, the slope of SOC is seems decrease significantly (Fig.9). Nonetheless battery SOC is not able to achieve the desired value by 50% but the value of SOC trended downward although not as drastic as in Fig .9.

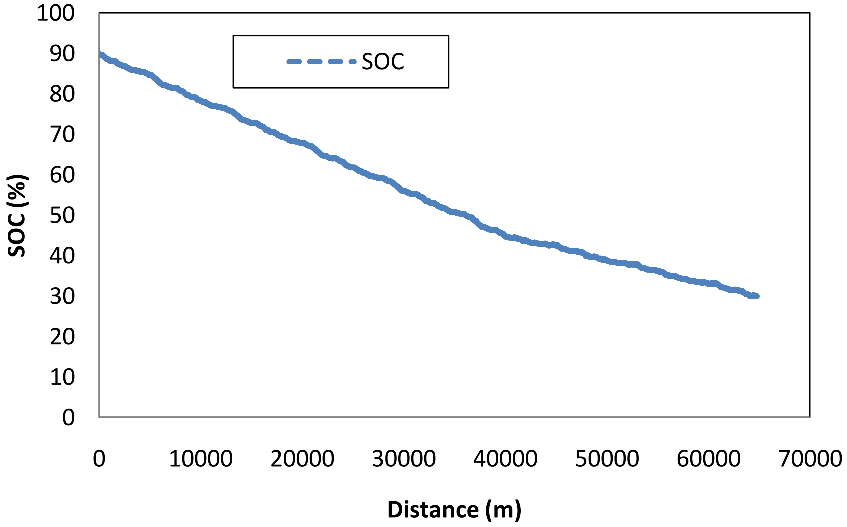

Fig. 9. Vehicle configuration 1 simulated over Japan 08 driving cycle.

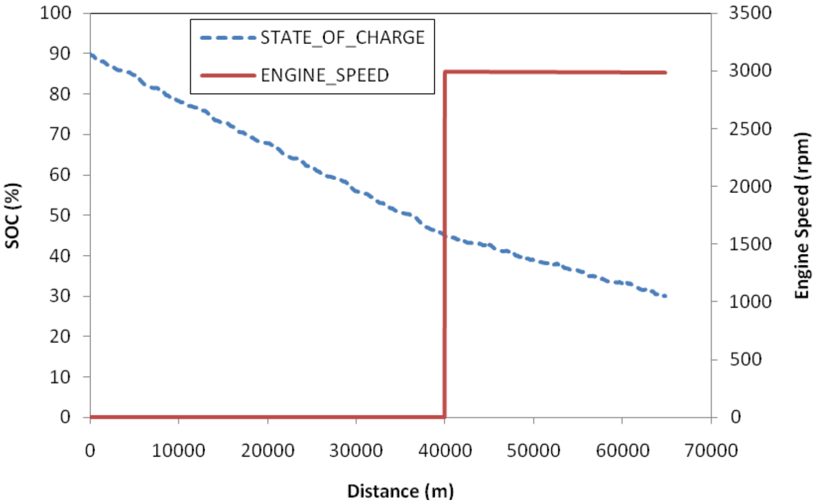

Fig. 10. Vehicle configuration 2 (range extender) simulated over Japan 08 driving cycle.

The fuel efficiency of vehicle configuration 2 over the two driving cycles is listed in Table 5.If the electric range of vehicle configuration 2 was exceeded, it would continue operation with a fuel economy of 4.89 L/100km. The slight fuel efficiency improvement was due to the lower mass of vehicle configuration 2.The simulated vehicles represent base line efficiencies for an electric vehicle equipped with a range extender.

5. Conclusions

Using experiment data, a model of the engine was populated in AVL CRUISE vehicle simulation software.The engine and a generator model was inserted into an electric vehicle model to extend the road ability of theREEV vehicle once its batteries were depleted.Various configurations of the model were successfully simulated piloting common driving cycles, electrical and fuel efficiency of the vehicles was recorded.On JC08 driving cycle, the fully electric vehicle has a range up to 53.12 km for single battery charge. The road ability is increase up to 21.93% and consume the fuel about 5.86 L/100km on REEV system compared with fully electric system. The comparison of two system on NEDC driving cycle is show on REEV system, the road ability is increase up to 14.24% (70.66 km) compared with fully electric system with the road range is 61.85 km. The engine performance are not competitive with modern vehicles. The component of vehicle configuration especially the range extender is not enough to fulfill the energy balance are needed on simulation worksheet. The optimization for this vehicle configuration is needed in the future.

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