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Theoretical Performance of a New Kind of Range Extended Electric Vehicle

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Abstract

Typical automotive trips are within the driving range of efficient electric vehicles (EVs), but sometimes exceeding EV range is needed for occasional trips. This paper proposed a new kind of range extended electric vehicle. A mobile generator set is used as a range extender, when assembled in an EV, effectively converts the EV to series-hybrid mode for long trips. The new kind of range extended EV, which integrates the charger, rectifier and DC/DC into a charger, is more suitable for use in low-speed micro EVs than Plug-in Electric Vehicle (PHEV) and a Range Extender Trailer (RXT) system. The fuel economy and main performance criteria of the new range extended EV are shown in this paper. In some drive cycles, the new range extended EV has a better fuel economy than PHEV and RXT system.

Keywords: range extended electric vehicle, charger, fuel economy

1. Introduction

Hybrid Electric Vehicle (HEV), which is aimed to reduce fuel consumption, is becoming popular. Recently, Plug-in Electric Vehicle (PHEV), which is regarded as a pure EV for short range driving, had also become popular to minimize the use of gasoline. PHEV, however, always carries heavy internal-combustion engine (ICE) systems. A Range Extender Trailer (RXT) for Electric Vehicle is motivated by the limitations in existing batteries for providing extended range for electric vehicle [1]. This RXT carries ICE only in the case of long distance use. This system of RXT is consisted of pure EV and sufficient performance engine-generator carried by a trailer. A trailer-mounted generator-set can extend the range and increase the utility of a battery-powered electric vehicle if it provides adequate power for sustained highway cruising and does not create

unacceptable inconvenience for the user. Such EVs will require the use of the RXT only for long trips during low battery State-Of-Charge (SOC). The limited use-ratio for the RXT provides significant dilution of the overall emissions and fuel consumption of the RXT/EV combination.

The primary requirement for an RXT power unit is the ability to sustain battery charge continuously. The RXT power output must match the EV road load at the desired cruising speed. For medium size EVs, RXT output of 20kW is necessary to provide comfortable freeway cruising [2]. For a micro EV, which only needs 5kW output for RXT, the system of RXT can be simplified. This paper proposes a new system configuration for range extended electric vehicle. In this new system, the RXT is replaced by a mobile generator set, which can be assembled in the trunk of EV for long trips. Size and weight critically affect the usability of the mobile

generator set. It must also be easy to connect and easy to store if it is to provide acceptable convenience for the user. To achieve these objectives, a weight target of 60kg is available from commercial generator-sets. Without the trailer, the new range extended EV will have smaller rolling resistance and air resistance than the RXT system.

2. System Scheme and Configuration

2.1 System Scheme

Three separate families of PHEV configurations exist: Series, Parallel, Power Split. In this study, the series engine configuration was selected to compare with the RXT system and the new range extended EV. The scheme of the series engine configuration, which is shown in Fig. 1(a), is often considered to be closer to a pure electric vehicle when compared to a parallel configuration. In this case, engine speed is completely decoupled from the wheel axles, the vehicle is propelled solely by the electric motor. The RXT system is similar to the series engine configuration. The difference is that the engine-generator is carried by a trailer in the RXT system when needed. The new range extended EV, as shown in Fig. 1(b), integrated the charger, rectifier and DC/DC into a charger, which is significantly simply the hybrid system. Compared PHEV and RXT system, the new range extended EV configuration is more suitable for use in low-speed micro EVs.

Figure 1: The powertrain configurations of PHEV and new Range extended EV

There are two operation modes: the pure EV and the range extended EV. For daily short-distance travel, the EV operates in pure battery EV mode without the range extender. At weekend, you can assemble the range extender on the EV for a long-distance travel. A system operating strategy is such that the RE is to be activated during estimated low battery State-of-Charge (SOC) and operates until a desired SOC has been achieved. The generator set is controlled with constant speed and its output is constant voltage and frequency, such as 220V, 50Hz. The output of the generator set is connected to the interface of the charger. Unlike a conventional generator set, this generator set provides rated output by controlling the output current of the charger. This ensures that the generator set works at the highest efficient point and has a low emission. The battery can also be charged by the charger with a household outlet or fast charged at charging station.

2.2 System Configuration

There are two electric drive system solutions: four wheel hub motor drive system and single motor drive system. The layout of the four wheel drive system is shown in Fig.2. Fig. 3 shows the main components layout of the single motor drive system with range extender. Table 1 shows the performance of the two micro EV's electric drive systems. In this study, the single motor drive system is used to compare the three powertrain configurations: series PHEV, the RXT system, the new range extended EV.

Figure 2: The layout of the four wheel hub motor drive system

The scheme of the engine-generator and charger system is shown in Fig.4. The battery can be recharged by both generator and 220-Volt household outlet using the charger. Table 2 shows the performance engine-generator and charger units. The rated engine output power is 3.3 kW at 3600 r/min, while the maximum engine power is 5.67 kW at 7000r/min [3].

Figure 3: The layout of the single motor drive system with range extender

Figure 4: The diagram of the engine-generator and charger unit

Table 1: Specification of the two micro EV's electric drive system

Item	Single motor	Four wheel hub motor
Motor type	Permanent Magnet Synchronous Motor	Brushless DC Motor
Motor output power	4.8kW, Max. 10kW	1kW, Max. 2kW×4
Motor max torque	80N·m	100N·m
Motor efficiency	85%	83%
Controller	12kW	3kW×4

Controller efficiency Over 95% 97%

Gear box 5:1 N/A

Battery 48V 150Ah Lead-acid Battery 48V 150Ah Lead-acid Battery

Table 2: Specification of the micro EV's engine-generator units

Item	Specification
Charger power	6kW
Charger efficiency	94%
Generator type	Permanent Magnet Synchronous Motor

Generator power	6kW
Engine type	125cc, electric fuel injection
Engine power	3.3kW(3600r/min)
Engine max power	5.67kW(7000r/min)

3. Numerical Evaluation of the New System

A comparison among the new system, PHEV and RXT is made using total energy required to run a uniform driving cycle in a week. A weekly driving pattern is assumed to be: 30 km (6 days a week), 100 km (1 day a week).

The specification of the Micro EV is shown in Table 3. Table 4 shows the performance of the engine-generator mounted on a trailer for the evaluation.

Table 3: Specification of the micro EV

Item	Specification
Length	2500 mm
Width	1200 mm
Height	1470 mm
Wheel-base	1050 mm
Passengers weight	3×65 kg
Chassis, body and accessories	410 kg
Battery	4×35 kg
Total weight	745 kg
Tire size	145/70R12
Rotating radius	3.5 m

Table 4: Specification of the generator trailer

Item	Specification
Length	686 mm
Width	425 mm
High	505 mm
Mass	80 kg (60kg without trailer)
Output voltage	230 V
Output power	5 kW

For the comparison, vehicle parameters are obtained by the following method. The vehicle parameters of RXT are obtained by experimental test [4]. The value of Cd·A (drag coefficient and the front area in m²) is 0.68 without generator

trailer while Cd·A is 0.75 with generator trailer. The rolling resistance coefficient is 0.014 and 0.019 without and with generator trailer respectively.

The vehicle parameters of the new RE system and PHEV are obtained by calculation. The total weight of PHEV and the new system with RE is 805 kg because the engine-generator weight of 60 kg is added without the generator trailer. Table 5 lists these parameters.

Table 5: Specification of vehicle parameters for the evaluation

Configuration	Mass (kg)	f	Cd·A	Fuel consumption (g/kWh)
EV mode	745	0.014	0.68	N/A
New range extended EV	805	0.014	0.68	0.287
RXT	825	0.019	0.75	0.287
PHEV	805	0.014	0.68	0.265

It is assumed that the charging loss by the generator is neglected. The transmission loss from the motor to the wheel is also neglected. The required energy to run against the rolling resistance and drag force is calculated for the comparison. The required drag force F_t and power P_e are calculated by

$$F_t = F_f + F_w = fmg + \frac{C_D A u_a^2}{21.15} \quad (1)$$

$$P_e = \frac{F_t u_a}{3.6} \quad (2)$$

where, F_f is the rolling resistance force, F_w is the air resistance force; f is the rolling resistance coefficient, m is the vehicle mass, C_D is the air resistance coefficient, A is the frontal area, u_a is the vehicle speed [5].

Figure 5 shows the required power P_e to the vehicle velocity u_a for the pure EV, new RE system, PHEV and RXT. The new RE system needs the same power as PHEV, but the RXT system with the generator trailer needs higher power because of the larger value of the rolling resistance and drag resistance.

Figure 5: Required power to velocity for the different kinds of vehicles

To evaluate the best mileage, a weekly usage pattern is taken into account. The pattern assumed here is that the running distance per day is 30km for 6 days a week as a pure EV mode and 100km for 1 day with the generator set. It is also assumed that the EV is driving at a speed of 60 km/h. The resulted mileage is listed in Table 6. The weekly required energy for new system with RE is 17.19 kWh, lower than either RXT system or PHEV.

Table 6: Energy required for a week

Configuration	Energy required for a week (kWh)
New range extended EV	17.19
RXT	18.72
PHEV	17.60

4. Simulation Results

PHEV, the RXT system and the new range extended EV are respectively simulated. All the three vehicle operations can be divided into two modes: charge depleting (CD) and Charge sustaining (CS) [6]. To compare the different powertrain configurations as fairly as possible, we tried to maintain the consistency of the controls as much as possible. Because the engine of the three vehicles is completely decoupled from the vehicle operation, numerous control strategies can be chosen. To simplify the analysis, the engine “on” logic is based on battery SOC. We assumed the

initial battery SOC is 90%. The engine turns on when the battery SOC drops below 25% and stays on until the battery SOC gets recharged to 70%.

Several approaches are considered to calculate the fuel economy of the three powertrain configurations, we will use the fuel consumed on low-speed urban and suburban drive cycles to compare the different configurations, as shown in Fig. 6. The simulation block diagram based on Matlab/Simulink is shown in Fig. 7.

Figure 6: The urban and suburban drive cycle

We also use a weekly pattern to evaluate the best mileage of the three powertrain configurations. The pattern assumed that the running distance per day is 30km for 6 days based on urban drive cycle and 100km for 1 day based on suburban drive cycle in a week. Table 7 shows the fuel economy simulation results in a week for each powertrain configuration.

In a week, the new range extended EV and the RXT system respectively consume 23.34 kWh electric energy, less than the PHEV, which consumes 24.43 kWh electric energy. However, because of the higher engine efficiency, the PHEV consumed 1.858 L gasoline, less than the new range extended EV and the RXT system. For a larger rolling resistance and air resistance, the RXT system consumes the most gasoline among the three powertrain configuration.

Figure 7: The Range extended EV simulation model based on Matlab/Simulink

Table 7: Battery electric energy required and fuel consumption in a week

Configuration	Battery Energy (kWh)	Fuel Consumption(L)
New range extended EV	23.34	2.012
RXT	23.34	2.823
PHEV	24.43	1.858

5. Conclusion

This study shows that the new kind of range extended electric vehicle will have a better mileage than RXT and PHEV in some drive cycles. The higher percentage of pure electric driving, the better fuel economy will be achieved. This new low-speed micro EV with or without range extender will have good fuel economy and convenience, which will relief the transportation and energy pressure to some degree.

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