Theoretical Performance of EV Range Extender Compared with Plugin Hybrid

Koji Imai [1], Takashi Ashida [2], Yan Zhang [3], and Shigeyuki Minami [4]

[1] *Department of Electrical Engineering, Osaka City University, k_imai@grace.ocn.ne.jp*
[2] *Department of Electrical Engineering, Osaka City University, ashida@tgmy.jp*
[3] *Department of Electrical Engineering, Osaka City University, iwtgtjp0707@yahoo.co.jp*
[4] *Department of Electrical Engineering, Osaka City University, minami@elec.eng.osaka-ac.jp*

Abstract
This paper shows that EV range-extender (RXT) with a trailer will provide better mileage than the plug-in hybrid (PHEV) when an appropriate system is used. A weekly driving pattern is assumed to be: 30 km (6 days a week), 100 km (1 day a week). The RXT system made for this evaluation is composed of a pure BEV and a trailer with an electric generator. Japan 10-15 mode is used for the calculation. The result shows that 35.4 kWh/weeks is obtained for RXT, while 36.5 kWh/week for PHEV. This would be the first evaluation of RXT based on the fuel economy.

Keywords
RXT, PHEV, fuel economy, electric vehicles

1. INTRODUCTION
Recently the development of the higher performance batteries has become remarkable and there is an possiblity to run almost all automobiles without use of oil in the future. The situation of battery EV is, however, still needs some kind of range extending devices to satifsy consumer's desire toward the safety. Nissan BEV planed to sale by 2010 will be offering a range extender (RXT) with ICE. The purpose of our research is to evaluate the system performance of RXT and PHEV numerically by comparing the mileage performances with each other. HEV is becoming popular in the world and Toyota has sold more than one million HEV's totally in 2007. HEV is aimed to reduce fuel consumption. Recently, PHEV has also become popular in research to minimize the use of gasoline. For short range driving, PHEV is regarded as a pure EV. PHEV, however, always carries heavy ICE systems. RXT has an advantage in finding a more efficient system in the use of car performance. RXT is classified into following two categolies by the location of generator: (1) Small engine is carreid by the electic vehicle to extend the range [Gelman and Perrot, 1993; Powell and Pilutti, 1994; Gage and Bogdanoff, 1997; Kempton et al., 2001]. This RXT carries ICE only in the case of long distance use. (2) This system of RXT is consisted of pure BEV and an sufficient performance engine-generator carried by a trailer. The ICE engine can provide an sufficient power to run the EV without charging the BEV battery [Gelman and Perrot, 1993; BEV-RXT, 1993; Ashida, 2007]. In this paper, RXT of the category (2), so-called range extending trailer, is taken into account. One RXT system is produced to evaluate the performance of mileage of RXT in comparison with PHEV system [Ashida, 2007].

2. PRODUCTION OF RXT SYSTEM
A pure BEV modified from Civic is used for the towing EV. Figure 1 shows an AC motor and AT1200 gearbox used for the BEV. Figure 2 shows the configuration of the BEV. The specification of the BEV Civic is shown in Table 1. Table 2 shows the performance of the EV used for the evaluation.

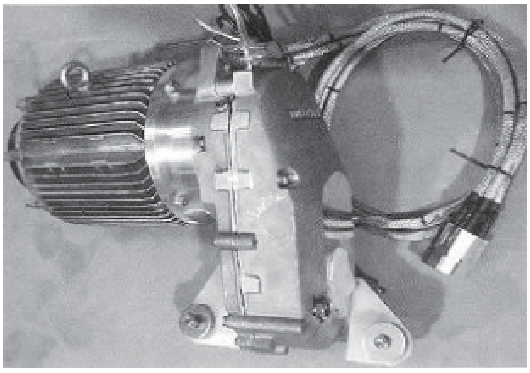

Fig. 1 A photograph of the Solectria motor

3. GENERATOR TRAILER
Figure 3 shows the configuration of the generator trailer and the photograph. Table 3 shows the performance of the enginer-generator mounted on a trailer for the evaluation.

4. NUMERICAL EVALUATION OF RXT SYSTEM
A comparison between RXT and PHEV are made using the following 3 values:
(1) Required power to the running velocity of vehicles.

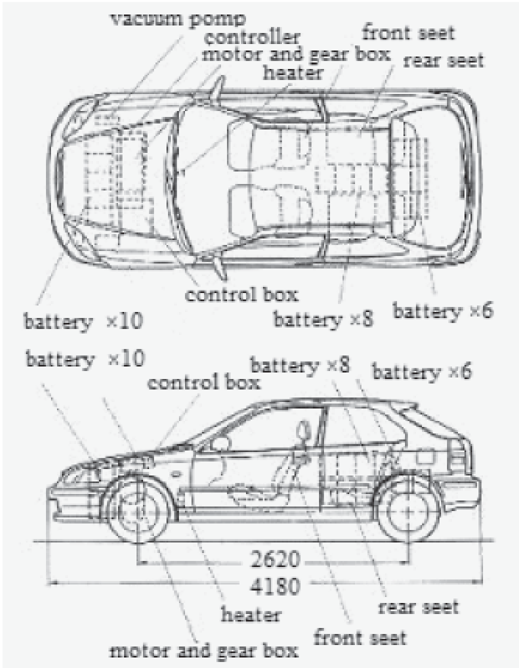

Fig. 2 The BEV Civic configuration

Table 1 Specification of the BEV Civic Compared with the Origical

Item	Honda Civic ('95)	BEV Civic
Fuel		
Type of Engine		
Engine Capacity or Output power	1.493 [liter]	67 [kW]
Length [m]	4.180	
Width [m]	1.695	
Height [m]	1.375	
Wheel-base [m]	2.620	
Passengers	5	4
Total weight [kg]	1275	1538
Tire size	175/70R13 82S	
Rotating radius [m]	5	

(2) Total energy required to run one driving cycle of Japan 10-15 mode velocity profile, average energy per 1 km based on Japan 10-15 mode.

(3) Required total energy to run a given weekly usage pattern of RXT and PHEV

For the comparison, vehicle parameters are obtained by the following method.

The vehicle parameters of RXT are deduced by experimental test. The value of Cd·S (product of Cd and the front area in m^2) is 1.49 (without generator trailer), while Cd·S is 1.73 with generator trailer. The rolling factors

Table 2 Specification of the BEV Electric motor

Item	Specification
Model	Solectria 3 phase induction motor
Output power	18kW, Max. 67 kW (DC 288 V)
Max torque	140 Nm
Revolution	0-12000 rpm (Reverse 0-3000 rpm)
Motor efficiency	Over 90%
Controller	Solectria UMOC 78 kW
Controller efficiency	Over 98.5 %
Gear box	Solectria 10:1
Battery	12 V 58 Ah Lead-acid battery 24 series (288 V)

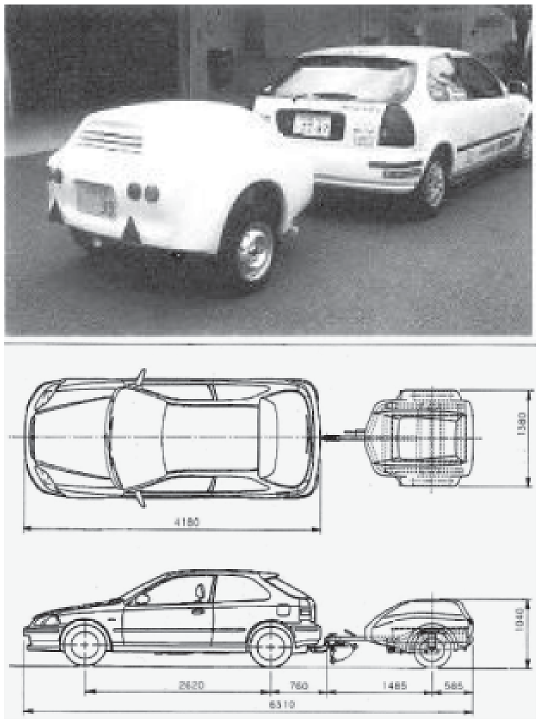

Fig. 3 Configurations a photograph of the engine-generator mounted on the trailer and the BEV

Table 3 Specification of the generator trailer

Item	Specification
Length [m]	2.130
Width [m]	1.380
High [m]	1.040
Mass [kg]	375
Output voltage [V]	DC350
Max power [kW]	15
Net power [kW]	11

measured experimentally of RXT are 0.0074 and 0.0095 without and with generator trailer respectively.
The vehicle parameters of PHEV are obtained by calculation. The total weight of PHEV is 1888 kg because the generator weight of 350 kg is added to the RXT without the generator trailer. These parameters are listed in Table 4.
The method to obtain the required energy to run is explained. It is assumed that the charging loss by the generator is neglected. The transmission loss from the motor to the wheel is also neglected for the evaluation of the required energy. The energy for the comparison is calculated based on the required energy to run against the rolling resistance, drag force and the acceleration resistance.

Table 4 Specification of vehicles for the evaluation

		Mass [kg]	μ	Cd·S
RXT	Generator trailer	1913	0.0095	1.73
	No generator trailer (EV mode)	1538	0.0074	1.49
PHEV		1888	0.0074	1.49

4.1 Relations between the velocity of the vehicles and the required power
Figure 4 shows the required power, P, to the vehicle velocity for the pure EV mode of RXT, RXT with the generator, and the PHEV. RXT with the generator trailer needs higher power because of the large value of the rolling resistance and the drag resistance.

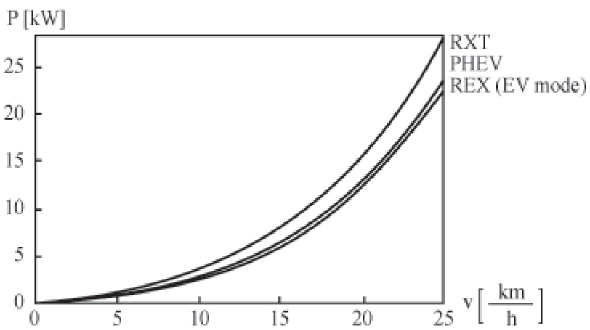

Fig. 4 Required power vs. velocity for the different kinds of vehicles

4.2 Required energy based on Japan 10-15 mode
Table 5 shows the calculated total energy required to run one driving cycle of Japan 10-15 mode and the running distance per 1 kWh. The result shows that pure EV mode of RXT has the best mileage, while RXT with the generator trailer has the worst mileage.

Table 5 Required energy based on 10-15mode running

		Energy required for one 10-15 mode [Wh]	Running distance for 1 kWh [km/kWh]
RXT	Generator trailer	770	5.30
	No generator trailer (EV mode)	595	6.86
PHEV		690	5.91

4.3 Required energy for the weekly usage pattern
To evaluate the best mileage of 3 vehicle usages, the parameter of γ is used. The value of ã is determined as the ratio of the total usage distance of EV-mode RXT to the total distance of RXT with the generator trailer. The bigger value of γ means the running distance of EV mode is longer than the RXT mode. Figure 5 shows the calculated running mileage [km/kWh] to the value γ.
This result shows that RXT has better mileage [km/kWh] than PHEV if ã is greater than 0.83. It is assumed that EV mode can be used when the running distance is less than 110 km.
For example, a weekly usage pattern is taken into account. The pattern assumed here is that the running distance per day is 30 km for 6 days a week as a pure EV mode without the engine-generator trailer. Once a week, the running distance becomes 200 km as RXT with the generator trailer mode. All running patterns are assumed to be based on Japan 10-15 mode.
The resulted mileage is listed in Table 5. The weekly required energy for RXT is 64.0 kWh, while it is 64/3 kWh for PHEV. The value of γ is 0.9. If the daily running distance is large and there are few chances to take a long distance trip, the value of γ is large and the mileage of RXT becomes better than PHEV. The good mileage of RXT becomes saturated to 6.86 km/kWh if the value of γ is higher than 20. It is concluded that the PHEV is not always better than the pure EV as well as RXT. For the small value of γ, this result shows that the mileage is not good for the pure EV. RXT has a strong advantage, however, over the pure EV because of the long

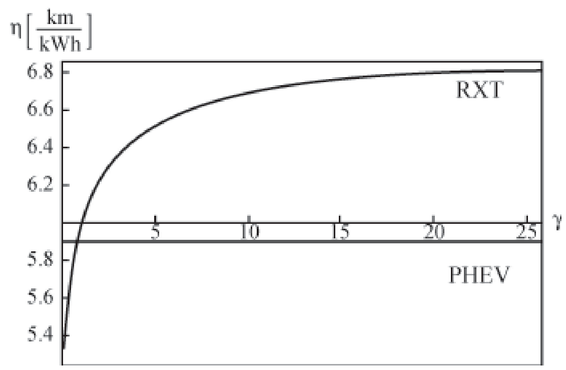

Fig. 5 Ratio of long running to short running vs. required energy

distance running ability. It is necessary to consider a better solution to possible EV systems for different driving patterns.

5. CONCLUSION

This experimental result shows that the RXT would have a better mileage rather than PHEV for a model velocity pattern. More generalized research will provide the performance of RXT qualitatively.

References

Ashida, T., Development of a Trailer-type Series Hybrid System to Extend Driving Range of EV., *WEVA Journal*, 1, 197-204, 2007.

BEV-RXT, http://www.hawkins.info/1993_tevan_RXT-B.html, 1993.

Gage, T. B., and M. A. Bogdanoff, Low-Emission Range Extender for Electric Vehicles, *SAE International*, Document No. 972634, 1997.

Gelman , D. J., and T. J. Perrot, Advanced Heat Engines for Range Extender Hybrid Vehicles, *SAE International*, Document No. 930041, 1993.

Kempton, W, J. Tomic, S. Letendre, A. Brooks, and T. Lipman, *Vehicle to Grid Power: Battery, Hybrid and Fuel Cell Vehicles as Rsources for Distributed Power in California*, Institute of Transportation Studies, 2001.

Powell, B. K, and T. E. Pilutti, A Range Extender Hybrid Electric Vehicle Dynamic Model, *Proceedings of 33rd IEEE Conference on Decision and Control*, 2736-2741, 1994.

Rav Long Ranger Hybridizing Trailer, http://www.evnut.com/rav_longranger.htm, 2008.

(Received October 10, 2008; accepted November 27, 2008)