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Energy Efficiency and Economy Analysis of a Range-extended Electric Bus in Different Chinese City Driving Cycles

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Abstract

Based on establishing the powertrain simulation model of the range-extended electric bus, the selected driving cycles are Chinese city and Zhuzhou city of Hunan province, the energy efficiency and economy of the range-extended electric bus is simulated and analyzed with the energy management strategies of CD-CS and Blended. The simulation results show that, the energy efficiency and economy of the range-extended electric bus is different in different driving cycles. Compared with the conventional fuel bus, the energy efficiency is the highest with CD-CS strategy, cost saving can reach 32.81%.

Keywords: *Range-extended Electric Bus, Driving Cycle, Modeling, Energy Efficiency, Economy Analysis*

1. Introduction

With the increasing population of vehicle, energy security and city environment pollution are widely concerned. Compared with the conventional fuel vehicle, electric vehicle gets rid of the dependence on fuel and has the advantages of high energy efficiency and low environment pollution [1]. But the power battery has problems of limited life, high cost, low energy density, and long charging period. In addition, with the high power consumption of air-condition, the trip mileage of pure electric bus is substantially decreased.

To solve the problems above, the range-extended electric vehicle with on-board generator system is put forward. The configuration is shown in Figure 1.

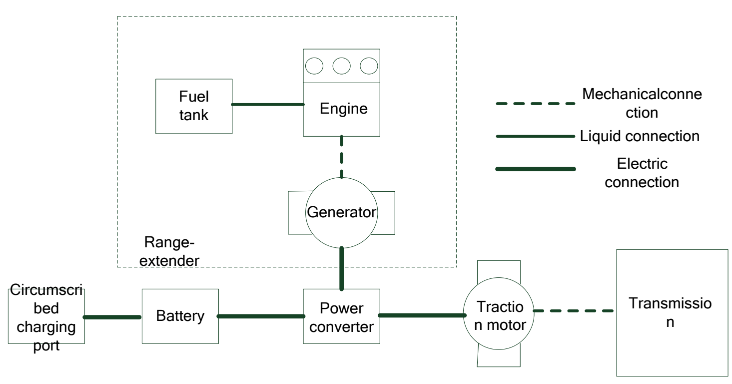

Figure 1. Powertrain Configuration of the Range-Extended Electric Vehicle

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The range-extended electric vehicle technology is between plug-in hybrid vehicle technology and pure electric vehicle technology. Compared with the pure electric vehicles, range-extended electric vehicle adds on-board generator system (range-extender) [2]. The range-extender consists of engine, generator, and rectifying device. The engine can persistently charge the power battery, so the trip mileage is substantially increased near the conventional fuel vehicle. The range-extended electric vehicle can optimize the working condition of the engine and power battery at the same time. On the one hand the engine working area is optimized, and the engine efficiency is increased. The high efficiency area of the internal-combustion engine can be selected by the average power demand of the driving cycle, so the internal-combustion engine can work in low fuel consumption and pollution and the optimum working point can realized. On the other hand, the power battery working condition is optimized, the power battery can keep working in good condition, avoiding over charge or discharge. The utility life is increased, the braking energy can be recovered, and the energy consumption and cost is decreased. The range-extender solves the problems of the high power consumption of air-condition, and other electric auxiliaries for lighting, heating, defrosting. So the range-extender is suitable for the city bus.

Now the studies home and abroad of the range-extended electric vehicle mainly focus on the configuration and energy management. Literature [3] put forward a Plug-in hybrid configuration using the conventional fuel engine and hydrogen internal-combustion engine to transfer power. Literature [4-5] respectively used Chevrolet Volt produced by GM and the range-extended electric vehicle produced by FEV as examples to introduce the system configuration and working mode. Literature [6] used series range-extended electric vehicle as study object to simulate the online management system. Literature [7-8] respectively analyzed the heat management system and NVH of the range-extended electric vehicle. Literature [9-10] analyzed the energy efficiency and emission of the range-extended electric vehicle with different engines. Literature [11] summarized the development tendency of the plug-in electric vehicle through the view point of the influence factor of the vehicle and the power grid. Literature [12] used AVL-Cruise to establish model and simulation of the plug-in hybrid electric vehicle, and optimized the engine start-stop control strategy in different driving cycles and trip mileages. Literature [13] analyzed the configuration and matched the main parameters of the range-extended electric vehicle, and used AVL-Cruise/Simulink to analyze and simulate the powertrain. Literature [14] compared the common energy management algorithms of the range-extended electric vehicle and verified through the simulation.

In summary, the studies of the range-extended electric vehicle mainly focus on passenger vehicle, and configuration analysis and system simulation. The more suitable utility of the range-extended electric vehicle, city bus economy analysis, is rarely reported. This paper uses Chinese city driving cycles of Chinese city and Zhuzhou city of Hunan province, establishes the system model in Matlab/Simulink, and compares the energy efficiency and economy in different city driving cycles and energy management strategies.

2. Analysis of the Driving Cycle and Vehicle Characteristic Parameters

The vehicle performance is determined by the driving condition, so in design the driving cycle and road demand should be considered. Figure 2 is the statistical result of the typical Chinese city driving cycle determined by the Chinese automotive technology and research center. Figure 3 is the statistical result of Zhuzhou city driving cycle. Table 1 is the comparison of the two driving cycles.

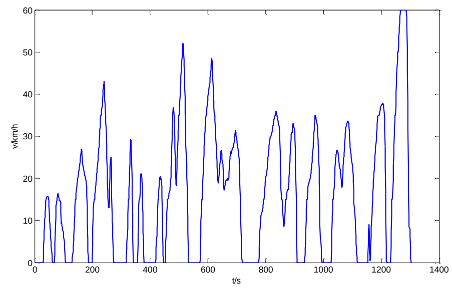

Figure 2. Time-speed Curve in Chinese City Driving Cycle

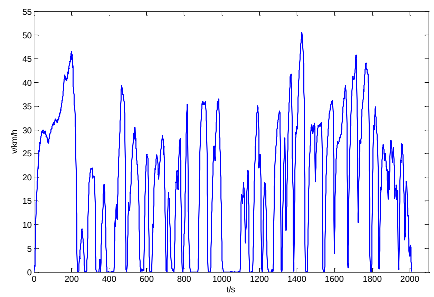

Figure 3. Time-speed Curve in Zhuzhou City Driving Cycle

Table 1. The Comparison of the Parameters in Two Driving Cycles

Performance statistics	Chinese city driving cycle	Zhuzhou city driving cycle
Cycle time/s	1304	2010
Trip mileage/km	5.83	10.56
Maximum speed/km/h	59.98	50.55
Average speed/km/h	16.1	18.91
Maximum acceleration/m/s^2	1.25	1.26
Maximum deceleration/ m/s^2	-2.47	-2.75
Average acceleration/ m/s^2	0.31	0.27
Average deceleration/ m/s^2	-0.43	-0.37
Idle time/s	375	254

As is shown in Table 1, the statistical data performance is mainly same. But the idle time ratio is substantially different. In Chinese city driving cycle, the idle time ratio is 28.76%, while is only 12.64% in Zhuzhou city driving cycle.

Referencing to the main technology indexes and the maximum slope data in garage roadway of the different levels road in China, the design objective of the range-extended electric bus is shown in Table 2. According to the vehicle in study, the vehicle parameters in calculation are shown in Table 3.

Table 2. Design Objective of the Range-Extended Electric Bus

Maximum speed(km/h)	80
Maximum slope (%)	15
0 ~ 50km/h acceleration time(s)	<25
Fuel economy deceleration(%)(including fuel saving in pure electric condition)	30 ~ 40

Table 3. The Vehicle Parameters in Calculation

Unladen mass(kg)	13000
Windward area A(m^2)	7.83
Rolling radius r(m)	0.478
Air resistance coefficient C_d	0.75
Rolling resistance coefficient f	0.0076+0.000056u_a, u_a is vehicle speed
Air density ρ(kg/m^3)	1.23
Main reducer ratio i_0	6.2
Transmission efficiency η_T	0.96(only one shift)

3. Vehicle Economy Simulation

To compare the economy of the conventional fuel bus and the range-extended electric bus, this paper makes simulation study based on establishing the vehicle model, as is shown in Figure 4, the model mainly consists of driver model, range extender model, traction motor model, power battery model, transmission model, vehicle and controller model. The diesel engine model, permanent magnet synchronous generator model and battery model are based on the test data of the bench test in laboratory.

Based on the model in this paper, the economy of the conventional fuel bus and the range-extended electric bus are compared with different energy management strategies in Chinese city and Zhuzhou city driving cycles. The energy management strategies are CD-CS strategy with switching control method of the range-extender and Blended strategy with power follow control method of the range-extender. In CD-CS strategy, range-extender uses switching control method to maintain SOC between 0.2 and 0.4. In Blended strategy, battery output settled power, the range-extender output power is determined by the difference value between the power demand in road condition and battery output settled power. According to the study of the daily trip mileage in Chinese city, the trip mileage is 200km in simulation. The description of the energy management strategies used in this paper is shown in literature [15].

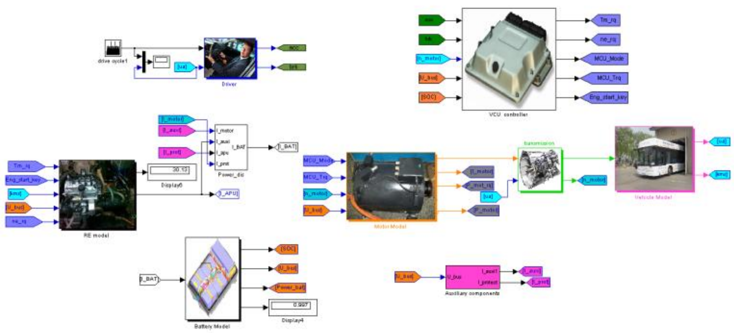

Figure 4. System Simulation Model of the Range-Extended Electric Vehicle

Figure 5 is the powertrain energy follow in Chinese city driving cycle with CD-CS strategy. As the range-extender uses switching mode, engine efficiency can reaches 33%. But at the end of the trip mileage, the range-extender is charging the battery; the final consumption of the battery energy is only 36.7kWh.

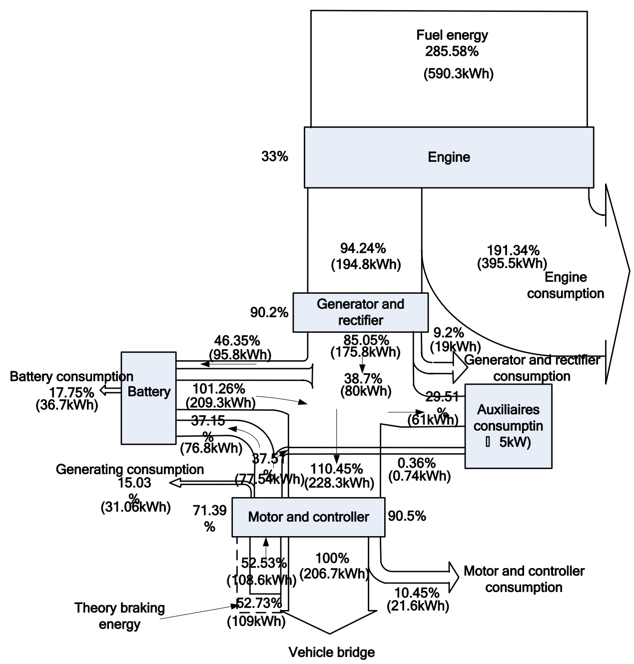

Figure 5. Powertrain Energy Follows in Chinese City Driving Cycle with CD-CS Strategy

Figure 6 is the powertrain energy follow in Chinese city driving cycle with Blended strategy. As is shown in Figure 6, with Blended strategy, the output power control method of the range-extender is load follow, the engine efficiency only reaches 30%, but battery consumption reaches 54.28kWh. With Blended strategy can fully uses the electric energy in battery shortage, and the range-extender needn't to charge the battery, so the charging consumption is decreased.

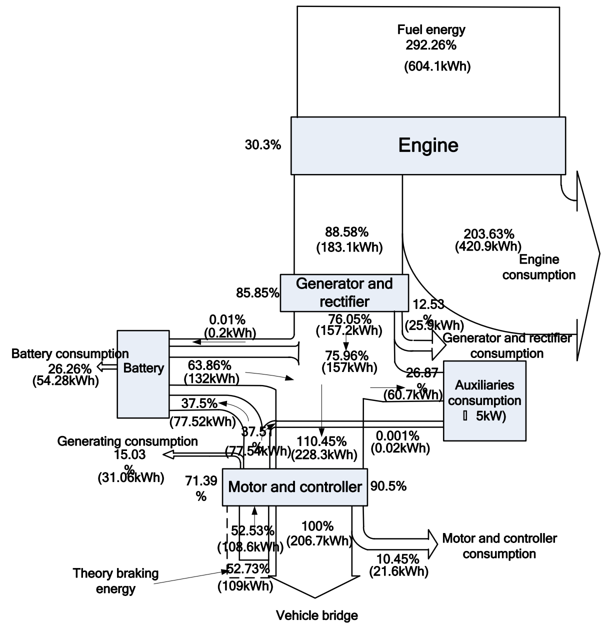

Figure 6. Powertrain Energy Follows in Chinese City Driving Cycle with Blended Strategy

Figure 7 is the powertrain energy follow in Zhuzhou city driving cycle with CD-CS strategy.

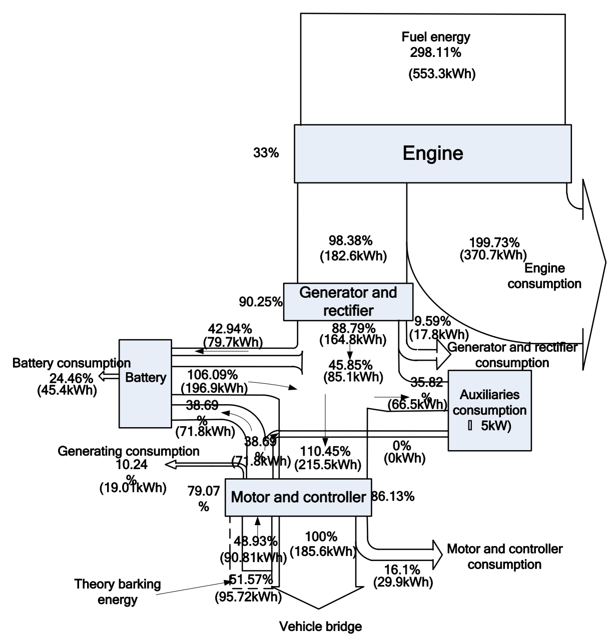

Figure 7. Powertrain Energy Follows in Zhuzhou City Driving Cycle with CD-CS Strategy

Figure 8 is the powertrain energy follow in Zhuzhou city driving cycle with Blended strategy.

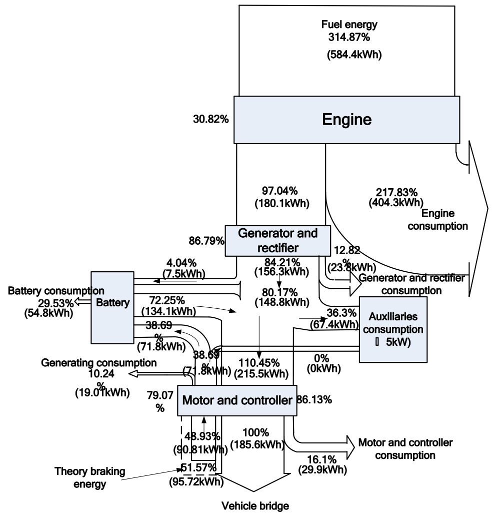

Figure 8. Powertrain Energy Follows in Zhuzhou City Driving Cycle with Blended Strategy

Table 4 is the economy comparison of the range-extended electric and the conventional fuel bus in the two driving cycles with daily trip mileage is 200km.

In the analysis of the utility cost saving, the calculation references the price of $0^{\#}$ diesel and commercial power of Beijing China 2013 June, $0^{\#}$ diesel is 1.225$/L, commercial power is 0.13$/kWh.

Table 4. The Comparison of the Economy Simulation Results in Different Driving Cycles

Driving cycle	Energy management strategy	Power consumption (kWh)	Fuel consumption (L)	Conventional fuel bus fuel consumption(L)	Utility cost saving (%)
Chinese city	CD-CS	36.7	49.76	79.86	32.81
	Blended	54.28	50.93		29
Zhuzhou city	CD-CS	45.4	46.65	70.4	26.89
	Blended	54.8	49.27		21.75

As is shown in Table 4, in different city road condition, with Blended strategy and confirmed road condition, the energy storage in battery can be fully used. With CD-CS strategy, as range extender uses thermostat control method in capacity maintaining part, at the end of the trip mileage of 200km, the final SOC may not reach the lowest set value, so the electric energy consumption is relatively low.

In addition, in Chinese bus driving cycle, with CD-CS strategy, the utility cost saving ratio of the range-extended electric bus is the maximum, 32.81%. While in Zhuzhou city driving cycle, the utility cost saving ratio only reaches 26.89%. The reason is that, in Zhuzhou bus driving cycle, the idle time ratio is low, for conventional fuel vehicle, the fuel consumption in idle part is low, so the fuel saving potential of the range-extended electric bus is relatively low.

4. Conclusion

The powertrain efficiency of the range-extended electric vehicle is compared in different driving cycles, energy management strategies, and range-extended control methods. With CD-CS strategy and the range-extender uses thermostat control method, the system efficiency is the maximum. The energy efficiency can reach 33%, the comprehensive efficiency of the generator and rectifier can reach above 90%.

The influence of the CD-CS and Blended strategy on the economy is compared in different driving cycles and daily trip mileage is 200km. Different driving cycles and control strategies have influence on the economy of the range-extended electric bus. In Chinese city driving cycle, with CD-CS strategy, the utility cost saving ratio can reach 32.81%.

Acknowledgements

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References

[1] W. Guihua, “Advanced vehicles: costs, energy use and macroeconomic impacts”, Journal of Power Sources, **(2011)**, pp. 530-540.
[2] K. Dominik, P. Sylvain and K. Jason, “Fair” comparison of powertrain configurations for plug-in hybrid operation using global optimization”, SAE, 2009-01-1334.
[3] V. Wieringen Matt and P.-L. Remon, “Development of a dual-fuelpower generation system for an extended range plug-in hybrid electric vehicle”, IEEE Transactions on Industrial Electronics, vol. 57, no. 2, **(2010)**, pp. 641-648.
[4] M. Roland, T. Lance and M. Horst, “VOLTEC Battery system for electric vehicle with extended range”, SAE International Journal of Engines, vol. 4, no. 1, **(2011)**, pp. 1944-1962.
[5] W. Jochem, R. Kevin and G. Davie, “Development of electric and range-extended electric vehicles through collaboration partnerships”, SAE International Journal of Passenger Cars-Electronic and Electrical System, vol. 3, no. 2, **(2010)**, pp. 215-219.
[6] C. Tae-Won, Q. V. Tran and H.-H. Lee, “Simulator for monitoring the operations of range extender electric vehicles”, Journal of Power Electronics, vol. 11, no. 4, **(2011)**, pp. 424-429.
[7] H. S. Hamut, I. Dincer and G. F. Naterer, “Exergy analysis of a TMS(thermal management system) for range-extended EVs(electric vehicles)”, Energy, vol. 46, no. 1, **(2012)**, pp. 117-125.
[8] R. Alfred and G. Bernhard, “NVH of electric vehicles with range extender”, SAE International Journal of Passenger Cars-Mechanical Systems, vol. 3, no. 1, **(2010)**, pp. 860-867.
[9] R. João, S. Carla and B. Francisco, “Analysis of four-stroke, Wankel and microturbine based range extenders for electric vehicles”, Energy Conversion and Management, vol. 58, **(2012)**, pp. 120-133.
[10] V. Scott, S. Adam and R. Jesse, “A numerical investigation on the efficiency of range extending systems using Advanced Vehicle Simulator”, Journal of Power Sources, vol. 196, no. 6, **(2011)**, pp. 3360-3370.
[11] P. Tuttle David and B. Ross, “The evolution of plug-in electric vehicle-grid interactions”, IEEE Transactions on Smart Grid, vol. 3, no. 1, **(2012)**, pp. 500-505.
[12] L. Xianjing, S. Yongzheng and D. Jun, “Optimization of Control Strategy for Engine Start-stop in a Plug-in Series Hybrid Electric Vehicle”, Automotive Engineering, vol. 33, no. 2, **(2011)**, pp. 112-117.
[13] Z. Su, N. Jigao and C. Fengxiang, “A Study on Powertrain Design and Simulation for Range-extended Electric Vehicle, Automotive Engineering, vol. 33, no. 11, **(2011)**, pp. 924-929.
[14] L. Xu, F. Yang and M. Hu, “Comparison of energy management strategies for a range extended electric city bus”, Journal of University of Science and Technology of China, vol. 42, no. 8, **(2012)**, pp. 640-647.
[15] X. Wu, J. Du and C. Hu, “The Economic Analysis of a Plug-in Series Hybrid Electric Vehicle in Different Energy Management Strategy”, Vehicle Power and Propulsion Conference, **(2013)**.