Parameter Match of Powertrain and Economic Research for Electric City Bus

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Abstract

In order to improve the efficiency and reduce operating costs of electric vehicles, the powertrain parameters matching and economic analyses had been used as the point of research in this paper. The vehicle model was built in CRUISE, and used two kinds of Cycle Run in power consumption simulation, respectively were constant speed and Chinese typical cycle run. According to the matched electric city bus powertrain parameters, the vehicle model simulation results show the power consumption per kilometer was 1.02kWh under the Chinese typical cycle run conditions; the endurance mileage was more than 250km under constant speed 40km/h conditions. Compared with the traditional fuel vehicles in the 8-year service period of city bus, can save operating cost about 84108 $.

Keywords: *Electric City Bus; Parameter Match of PowerTrain; CRUISE; Power Consumption*

1. Introduction

As the society progresses ceaselessly, the contradiction between environmental protection and economic development has become increasingly prominent. Public transport as the main trend of city transport is increasingly obvious; the exhaust emission has brought a lot of pressure to the environment. With the increasing number of city buses, the pollution of city natural environment has become very severe. Compared to the other new energy vehicles, due to the characteristics of relatively simple structure, low noise, non-pollution, and zero release, the electric buses have become one of the major strategic initiatives to alleviate the energy crisis and achieve sustainable development all over the world. In China the development of electric city bus has become the national strategic decisions and major requirements.

There are variety of methods and software available to perform system simulation of vehicle propulsion. One of the standard methods to model the complete vehicle was matching the powertrain parameters based on electric city bus. Through building and modifying the model, the endurance mileage and power consumption had been given under driving cycles [1-3]. According to the electric bus dynamic indicators [4-6], established electric machine power calculation model, and combined with examples in the process of simulation. Through the electric machine efficiency map matched powertrain. The results showed it played an important role in optimizing power transmission system configuration and increasing energy efficiency for electric vehicle. Battery is an important part of powertrain, according to the analysis of the battery requirements of electric vehicles in steady-state and dynamic time, which including battery weight and the specific energy, deducing the vehicle model [7]. The

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literature [8] compared with the traditional fuel vehicles, proposed the economic comparative method for electric vehicles.

Among the built methods of electric city bus, the main researches had been focused on how to enhance the bus power and increase the endurance mileage [9-10]. The electric city bus mainly run in the city road, so this paper matches the powertrain parameters of electric city bus based on Chinese typical cycle run, and analyses economy.

2. The Vehicle Basic Parameters

The vehicle basic parameters were shown in Table 1. Reference the Chinese typical cycle run feature, this paper proposes the design specifications of the electric city bus, as shown in Table 2.

Table 1. Vehicle Basic Parameter

Curb Weight(kg)	13540
Gross Weight(kg)	18000
Frontal Area A(m^2)	7.5
Wheel Rolling Radius r(m)	0.536
Drag Coefficient C_d	0.75
Rolling Resistance Coefficient f	0.016
Transmission Ratio	9.4

Table 2. Design Requirements

Maximum Speed/(km/h)	≥80
Maximum Climbable Gradient /%	≥15
Acceleration Time/s	≤25 (0~50km/h)
Endurance Mileage /km	≥250(constant speed 40km/h)

3. Chinese Typical Cycle Run Analysis

Chinese typical cycle run is formulated by the result of a lot of statistical data according to China Automotive Technology Center, and combined with overseas codes, reflecting China's current actual bus working condition. Figure 1 shows the cycle run curve.

The cycle time is 1314s, driving distance is 5.899km. The vehicle idle time is rather long having 367s, idle ratio reaches 27.9%, and the number of stops occurs frequently, the mean speed is very low about 16.2km/h.

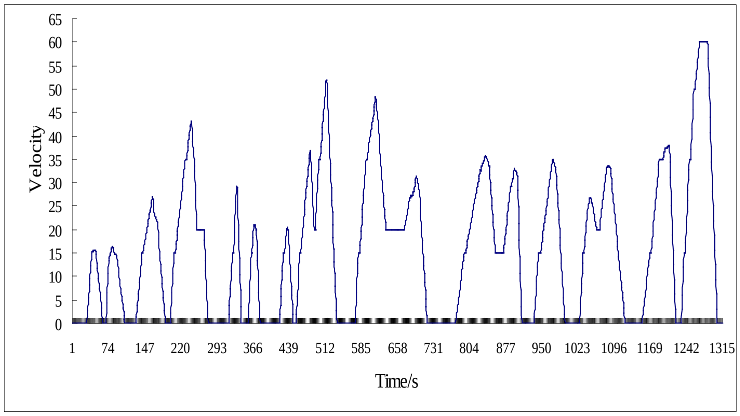

Figure 1. Chinese Typical Cycle Run

4. Power Train Parameter Matching

A. Electric Machine Parameters Matching

The power of electric bus is all provided by the electric machine, so the power must satisfy the requirements of the maximum speed, maximum climbable gradient and the acceleration time. It should ensure that the electric machine works at the high-efficiency area when city bus drive in cycle runs.

a) Electric machine rated and peak power matching: 1) The choice of electric machine rated power usually based on the bus expected maximum speed

$$P_N = \frac{v_{\max}}{3600\eta_T} \times (m \times g \times f + \frac{C_d \times A \times v^2{}_{\max}}{21.15}) \quad (1)$$

Where P_N is electric machine rated power, η_T is the transmission coefficient efficiency; m is vehicle weight, kg; f is Rolling Resistance Coefficient; C_d is the drag coefficient; A is frontal area; V_{max} is the maximum speed, km/h.

According to calculate P_N=99.81kW (integer 100 kW).

2) Maximum power-the instantaneous power requirements under climbable conditions

$$P_{N1} = \frac{v}{3600\eta_T} \times (m \times g \times f \cos\alpha_{\max} +$$

$$m \times g \times \sin\alpha_{\max} + \frac{C_d \times A \times v^2}{21.15} \quad (2)$$

Where climbing slope angle $\alpha_{\max} = \alpha rc\tan\frac{i_{\max}}{100}$.

3) The vehicle power when given full acceleration: When the vehicles run in the final moments of the accelerated process, the electric machine output power is maximum. Thus P_{N2} satisfy the equation:

$$P_{N2} = \frac{1}{3600 \cdot t_m \cdot \eta_t}(\delta \cdot m \cdot \frac{v_m{}^2}{2} + m \cdot g \cdot f\frac{v_m}{1.5} \cdot t_m + \frac{C_d \cdot A \cdot v_m{}^3}{21.15 \times 2.5} \cdot t_m) \quad (3)$$

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According to powertrain control strategy, the electric machine maximum power P_{max} must meet the power requirements when the bus in maximum speed; also must meet the power requirements when accelerating, climbing P_{N1}, P_{N2} requirements; namely $P_{max} \geq \max\{P_N, P_{N1}, P_{N2}\}$.

According to the results the electric machine peak power should be 150 kW.

b) The choice of electric machine rated speed and maximum speed: Due to the high cost, complicated technology and special requirements for bearings gears *etc.*, the electric machine speed over 6000r/min is generally used in electric cars, rarely used in electric city buses. Thus this paper takes the low-speed electric machine which maximum speed is not higher than 6000r/min.

$$n_{rated} = \frac{n_{\max}}{\beta} \tag{4}$$

Where n_{rated} is rated speed; $n_{\max}$ is maximum speed; β is electric machine enlarge constant power area coefficient, the value of β generally takes 2~4. According to the calculation result, the rated speed should be selected between 1500~3000r/min.

c) The choice of electric machine rated torque: the rated torque is determined by rated power/rated speed

$$M_e = 9554 \cdot P_N / n_e \tag{5}$$

Where M_e is rated torque, Nm; n_e is rated speed, r/min. According to the calculation result, the rated torque should be about 514 Nm.

d) The choice of electric machine rated voltage: Electric machine rated voltage is generally determined by the selected electric machine parameters, and considering the above results the electric machine rated voltage range should be chosen in 300-420V.

Table 3. Electric Machine Basis Parameters

Rated Power(kW)	100
Peak Power(kW)	150
Rated Speed(r/min)	1860
Maximum Speed(r/min)	4500
Rated Torque Nm	514
Peak Torque Nm	770
rated voltage V	300
Electric machine quality(kg)	320

B. The Choice of Battery Parameter

Battery is the energy source of the vehicle, which provides the vehicle driving power. Among many batteries, lithiumion battery has the advantages of high specific energy, long life, high rated voltage, light weight etc. So this paper selects lithium battery as the vehicle power battery [11].

a) The choice of battery parameter: Reference to lithium iron phosphate battery nominal voltage is 3.2V in the market, and the electric machine matched rated voltage range (300~400V) in this paper, so selecting battery pack voltage is 320V, requiring 100 lithium iron phosphate batteries in series.

b) The determination of battery pack energy: Electric bus mileage is s (km), the required energy in driving process can be calculated by the following formula [11] (formulas assumed to driving in 40km /h).

$$P = \frac{v}{3600\eta_T} \times (m \times g \times f + \frac{C_d \times A \times v^2}{21.15}) \tag{6}$$

$$W = P \times t = P \times (\frac{S}{v}) \tag{7}$$

Where *P* is the required power in electric drive, kW; *W* is the required energy in mileage *s* (km), kWh. According to calculate P=27.3kW, W=171kW. The battery energy in series W=180Ah×320V=57600Wh=57.6 kWh, thus the battery pack required 3 in parallel.

Comprehensive the above results, if expect the endurance mileage is 250km, the required battery parameters is shown in Table 4.

Table 4. Battery Parameters

Battery capacity (Ah)	180
Number of batteries in parallel	3
Single section voltage (V)	3.2
Battery voltage (V)	320
Battery section number in series	100
Total mass (kg)	2160

5. The Simulation of Pure City Bus and Power Consumption Analysis

A. The Establishment of the Whole Vehicle Model and Simulation of Power Consumption

The powertrain was constituted by battery, electric machine, clutch, transmission, gearbox and wheels [12]. The electric city bus powertrain did not use clutch and gearbox in this paper. The simple powertrain structure was shown in Figure 2.

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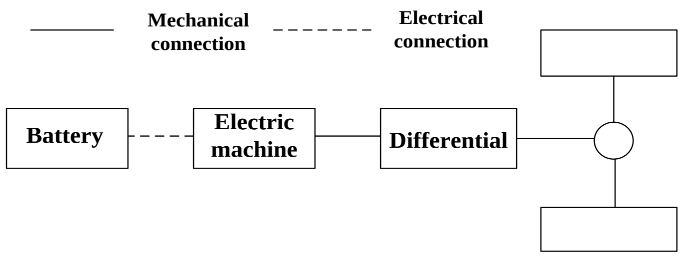

Figure 2. The Powertrain Structure

CRUISE uses modular concept, makes use of the modules provided by software, such as the engine, generator, battery, electric machine, main gear, vehicle, wheels etc. The Figure 3 showed the whole vehicle model built by CRUISE.

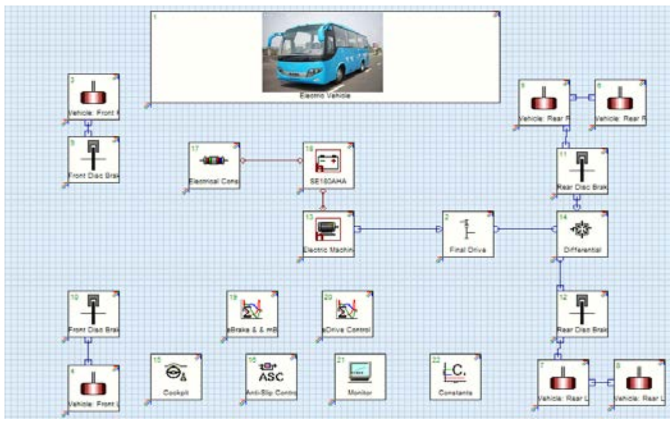

Figure 3. The Electric Bus Model

a. The power consumption of the Chinese typical cycle run: This paper mainly studied the electric city bus powertrain matching which based on the Chinese typical cycle run. In order to better reflect the real matching situation, established three cycle runs in the Cycle Run Task (in order to improve accuracy), the total time was 3942s, driving distance was 17.654km. Based on the simulation got the power consumption result, the curve was shown in Figure 4.

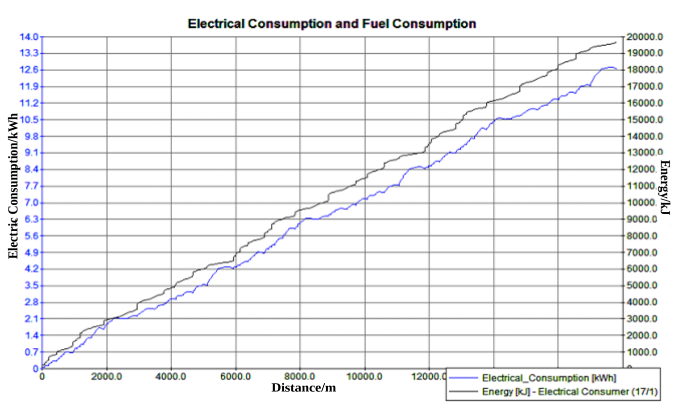

Figure 4. The Power Consumption Simulation Curve

The power consumption of whole vehicle and accessories was about 18.1 kWh, after equivalent to per kilometer was 1.02 kWh, and 100 km power consumption E_k=1.02×100=102 kWh.

On the basis of three cycle run, set 21 Chinese typical cycles run, the driving time was about 7.665h; the driving distance was 123.879km, the resulting curve was shown in Figure 5.

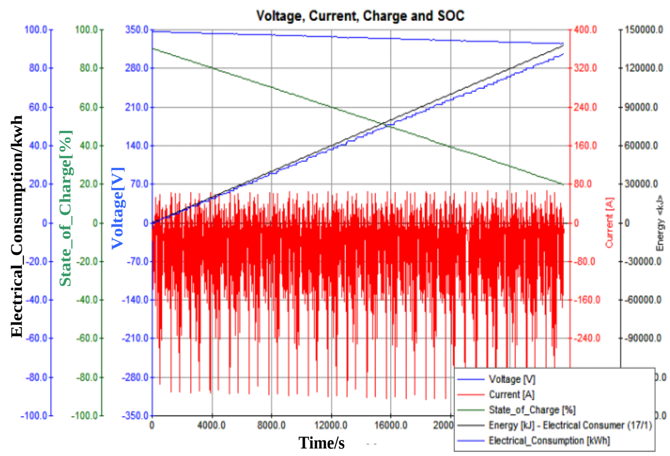

Figure 5. The Power Consumption Simulation Curve

The battery SOC down from 90% to 20%, and the total power consumption was 124.39 kWh during Figure 4. Equivalent to per kilometer was about 1.02 kWh.

b. The power consumption of Uniform motion cycle runs: Set a constant speed cycle run in computing tasks (speed was 40km / h), the driving distance was set to 300km. Figure 6 was the curve of SOC.

The initial charge of battery was 90%. If the SOC drops below a certain value, it will damage the battery, so selected the SOC=20% point of the abscissa as the electric city bus driving range, through simulation S=279km. Complied to the design target 250 km.

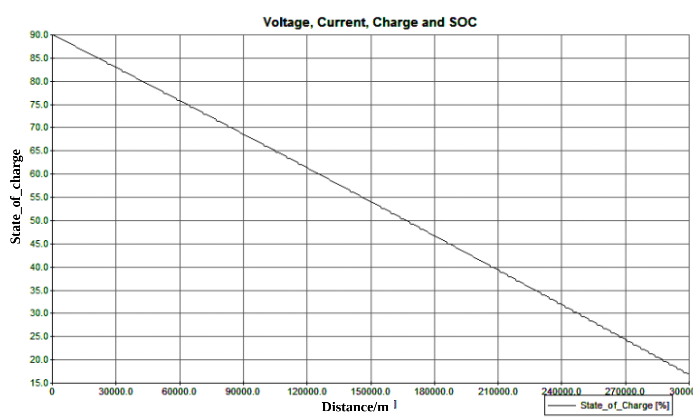

Figure 6. The Curve of SOC

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B. Economic Analysis

Reference to the national standards [13], the conversion equation between power consumption and fuel consumption is:

$$V_{fuel} = E_k \times 3600 / D_{fuel} Q_{fuel-low} \eta_{eng} \tag{8}$$

Where E_k is power consumption per 100 kilometers, kWh; D_{fuel} is fuel density, J/g; when in the power generation conditions, η_{eng} is the average power of engine; V_{fuel} is fuel consumption per 100 kilometers, L.

For diesel: D_{fuel}=0.85g/cm^3; $Q_{fuel-low}$=43000J/g; the average efficiency of diesel engine is about 36%, therefore after conversion the fuel consumption per kilometers is 27.9 L. For example, the diesel current price of Heilongjiang province is 6.76 Yuan/L, the industrial electricity price is 0.93 Yuan /kWh, and thus the electric bus and conventional bus running cost is compared in Table 5 in the same vehicle models.

Table 5. Cost Comparison

Comparison item	Pure electric bus	Diesel bus
Average daily mileage(m/day)	200	200
Attendance rate 95%	346day/year	346day/year
Running cost/km	0.15485$	0.30807$
8 years lifetime running costs/ $	86064	170172
Pure electric bus running saving cost / $	84108	

As shown in Table 5 the electric buses compared with the traditional fuel vehicles had a great saving in operating cost, and in the vehicle purchase price, in accordance with "the demonstration subsidy standards of more than ten meters city bus", after a one-time subsidies the electric bus on the price considerably with conventional buses.

6. Conclusion

The electric city bus is used as research object in this paper. After matching the powertrain parameters, and building whole vehicle model in CRUISE. The power consumption simulation was carried in two ways: constant speed and Chinese typical cycle run. According to the matched electric city bus powertrain parameters, the vehicle model simulation results show the power consumption per kilometer is 1.02kWh under the Chinese typical cycle run conditions; the endurance mileage is more than 250km under constant speed 40km/h conditions. Compared with the traditional fuel vehicles, the electric city bus saves operating cost about 84108 $ in the 8-year service period, which has a great advantage.

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References

[1] Z. Xiaohua, M. Haitao, X. Xing and W. Qingnian, "Parameter Design for Powertrain and Performance Simulation of Electrical City Bus", Vehicle Power and Propulsion Conference, **(2008)**, VPPC'08. IEEE, pp. 1-5.

[2] Z. Xiansheng and Z. Hongxiao, "Parameter Correction and Economic Research of Pure Electric Passenger Car Model Based on Cruise", Bus Technology and Research, **(2012)**.

[3] L. Zhi, Z. Rong and X. Xiao, "The Matching Research of Pure Electric Power Train Based on Driving Cycle", BAIC MOTOR, no. 2, **(2011)**.

[4] Y. Chen and Z. Wang, "Analysis and Comparison of Performance Evaluation Methods of Battery Electric Vehicle", proc IEEE, **(2011)**, pp.1-8.

[5] Z. Bo, Z. Whenzhang and Y. Jiantao, "Research on Electric Power Train System of Pure Electric Base on Automatic Transmission", The 25th World Battery, Hybrid and Fuel Cell Electric Vehicle Symposium & Exhibition EVS-25, **(2010)** November 5-9.

[6] Z. hongshan and W. Qinglong, "Matching Calculation and Simulation of Pure Electric Vehicle Power Train", Journal of Sun Yat-sen University, **(2010)**.

[7] W. Zhan, M. McDermott, B. Zoghi and M. Hasan, "Modeling, Simulation, and Analysis for Battery Electric Vehicles", Electrical Engineering, vol. 68, **(2010)**, pp. 227-241.

[8] Y. Feng and F. Jun, "Analysis and Comparison of the Economical Efficiency of Pure Electric Vehicles", Journal of Wuhan University of Technology, China, vol. 31, no. 2, **(2009)**.

[9] K. T. Chau, C. C. Chan and C. Liu, "Overview of Permanent-magnet Brushless Drives for Electric and Hybrid Electric Vehicles", IEEE Trans. Ind. Electron., vol. 55, no. 6, **(2008)** June, pp. 2246-2257.

[10] S. B. Han, Y. H. Chang and Y. J. Chung, "Fuel Economy Comparison of Conventional Drive Trains Series and Parallel Hybrid Electric Step Vans", International Journal of Automotive Technology, no. 10, **(2009)**, pp. 235-240.

[11] M. Ehsani, Y. Gao, S. E. Gay and A. Emadi, "Modern Electric Vehicles, Hybrid Electric Vehicles and Fuel Cell Vehicles - Basic Principles, theory and design", Beijing Chinese Journal of Mechanical Engineering, **(2008)**, pp. 288-289.

[12] C. C. Chan, B. Alain and K. Y. Chen, "Electric. Hybrid and Fuel-Cell Vehicles: Architectures and Modeling", IEEE Transactions on Vehicular Technology, **(2010)**.

[13] GB/T19754-2005Heavy Duty Hybrid Electric Vehicle Energy consumption, Beijing: China Technology Publishing house, **(2005)**.

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