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The Influence Factor Analysis of Energy Consumption on All Electric Range of Electric City Bus in China

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Abstract

For the electric city bus demonstration operating in Chinese city, based on establishing the system model, this paper uses constant speed and Hefei of Anhui province of China as driving cycles, mainly analyses the influence of the vehicle mass and the average power of the electric auxiliary on the endurance mileage and energy consumption. Simulation results show that, the electric bus studied in this paper driving at the constant speed of 30km/h, if the vehicle mass increases per 1000kg, the power consumption increases about 3%～4%. If the auxiliary power increases per 5kW, the power consumption increases about 15%～55%. In Hefei city bus driving cycle, if the vehicle mass increases per 1000kg, the endurance mileage decreases about 1km, but the power consumption increases about 3.5%. If the auxiliary power increases per 5kW, the power consumption increases about 22%.

Keywords: electric bus, modelling, endurance mileage, energy consumption, influence factor

1 Introduction

As the energy and environment problem is increasing nowadays, the electric vehicle has become an important developing direction for the clean and using renewable energy.

The low endurance mileage limits the popularization of the electric vehicle, which is the main problem in the electric vehicle industry. A lot of researchers focus on the study of decreasing the battery capacity and cost at the premise of satisfying the endurance mileage. Literature [1-3] put forward that, using the range-extender to increase the endurance mileage for the electric vehicle. But that structure needs the parts of the internal-combustion engine and generator, so the room assigning of the vehicle is demanded. Literature [4-5] studied the problem of the low endurance mileage and estimated the charging method based on the demographic data and the limitation of the distribution network. Literature [6] put forward that, combining super-capacitor and ZEBRA battery to charge for the electric vehicle, so the endurance mileage is increased. Literature [7] studied the case of supplementing the induced power to increase the endurance mileage. Literature [8] studied the influence of driving behaviour on the energy consumption, SOC usable range, and the endurance mileage. Literature [9] studied the parameter calculation method of the influence of the vehicle mass, the mechanical efficiency of the transmission system, and rolling resistance coefficient on the dynamic and economy performance of the electric vehicle. Literature [10] used the collaborative optimization method to reach the optimal objective at the premise of satisfying the dynamic performance and the endurance mileage.

To sum up, aiming at the problem of the low endurance mileage, most solve methods adding the range-extender and enlarge the battery capacity, meanwhile the induction charging is developed to complement the endurance mileage. The literatures study the influence of vehicle mass, battery capacity, and electric auxiliary on the energy consumption and the endurance mileage are little. This paper studies the electric city bus demonstration operating in Chinese city, based on the system model, uses constant speed and Hefei of Anhui province of China as driving cycles, and analyzes the influence of the vehicle mass and the average power of the electric auxiliary on the endurance mileage and energy consumption.

2 The dynamic system modelling of the electric bus

In order to analyze the factors influencing the endurance mileage, this paper establishes the system simulation model shown in figure 1

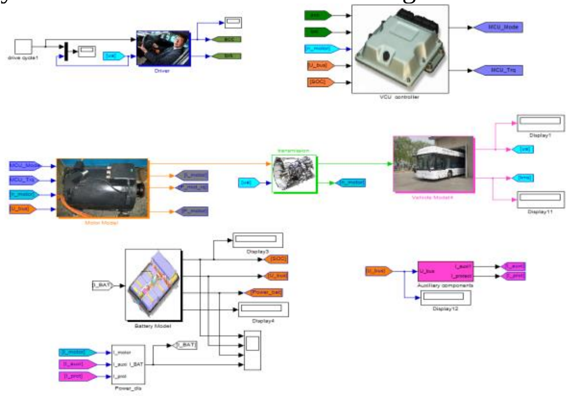

Figure1: The electric bus simulation model

The parameters used in model are shown in Table 1.

Table1: The calculation parameters in electric city bus model.

Kerb mass(kg)	14000
Full load mass(kg)	18000
Windward area A(m^2)	7.83
Rolling radius r(m)	0.512
Air resistance coefficient C_d	0.75
Rolling resistance coefficient f	0.0076+0.000056u_a
Air density ρ(kg/m^3)	1.23
Main reducer speed ratio i_0	6.2
Transmission efficiency η_T	0.96(one shift)

According to the electric bus basic configuration, the simulation system is divided into the following modules: driver module, power battery module, driving motor module, etc. Considering the driving motor, battery and other parts are highly complex. So before the modeling, the corresponding parts are made bench test. According to the bench test results, the MAP of the part is confirmed. In modeling, the simulation model is based on the MAP. Using the MAP to establish the system part model, instead of the complex mathematical model, the complexity is decreased and the credibility of the model is increased.

2.1 Drive motor module

The drive motor module consists of the drive motor and motor controller. The motor model is constituted of the steady state efficiency characteristics MAP and the one order inertial link. The main mathematical relation is shown as followings:

$$\eta_m = f_{m1}(n_m, T_m) \quad (1)$$

$$T_m = \min(T_r, T_{\max}) \cdot \frac{1}{\tau_m s + 1} \quad (2)$$

$$T_{\max} = f_{m2}(n_m) \quad (3)$$

Where, f_{m1} is MAP of the motor efficiency, f_{m2} is MAP of the motor maximum output torque, η_m is motor speed, T_m、T_r、T_{max} is respectively motor output torque, objective torque and maximum torque, ζ_m is time constant.

2.2 Power battery module

Power batter module uses internal resistance, equals to a variable voltage source and a variable internal resistance in series.

$$U_{oc} = E(SOC,T) - I \cdot R(SOC,T) \quad (4)$$

Where, SOC is the state of charge, T is the temperature. E is the battery open circuit voltage. The relationship between E and SOC and T is obtained in test. I is battery current, R is battery internal resistance.

2.3 Vehicle dynamic module

In simulation, the road load is idle. That is: air absolute speed is zero, well cement pavement. The vehicle driving on the road needs overcome driving resistance F_t including: rolling resistance F_f, air resistance F_w, slope resistance F_i, acceleration F_j.

$$F_t = F_f + F_w + F_i + F_j \quad (5)$$

$$F_f = fmg\cos(a\tan i) \quad (6)$$

$$F_w = \frac{1}{2} C_d A \rho u_a^2 \quad (7)$$

$$F_i = mg \sin(a \tan i) \quad (8)$$

$$F_j = 0.28 \delta m \frac{du_a}{dt} \quad (9)$$

$$F_t = 3.6 \eta_T P_{motor} / u_a \quad (10)$$

Where, f is rolling resistance coefficient, m is vehicle mass, g is gravity acceleration, i is road slope, C_d is air resistance coefficient, A is windward area, ρ is air density, u_a is vehicle speed, δ is rotating mass conversion coefficient, η_T is the transmission efficiency, P_{motor} is the traction motor output power.

3 The Influence Factors Analysis of the Energy Consumption and Endurance Mileage

This paper mainly focus on the driving cycles of constant speed and Hefei city bus, and analyzes the influence of the vehicle mass, battery capacity, and the electric auxiliary on the energy consumption and endurance mileage. And the influence law in different condition is summarized. In the calculation of the endurance mileage, the SOC ranges from 20% to 100%. The time-speed and speed distribution curve in the Hefei city bus driving cycle in simulation is shown in figure 2.

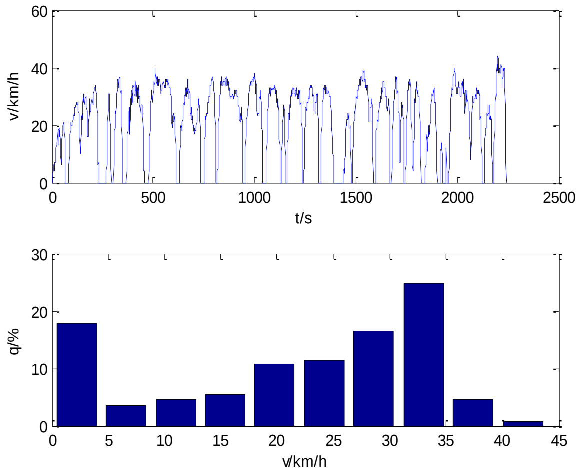

Figure2: The driving cycle and speed distribution curve of Hefei city

As is shown in figure 2, the speed is mainly under 5km/h and between 30km/h and 35km/h in Hefei city bus driving cycle.

According to the driving cycle, the typical eigenvalues of Hefei city bus driving cycle are shown in table2. As is shown in table 2, the idle speed ratio only reaches 15.83%, decreased by 12.92% than the Chinese city bus driving cycle of 28.75% [11]. And the energy recovery is low. So the electric vehicle energy efficiency analysis based on the actual data has the actual significance on the optimization of the electric vehicle configuration and the energy management strategy.

Table2: The typical eigenvalues of Hefei city bus driving cycle

Typical eigenvalue	Hefei city bus driving cycle
Cycle time/s	2242
Mileage/km	13.37
Maximum speed/km/h	44
Average speed km/h	21.48
Maximum acceleration /m/s^2	1.944
Maximum deceleration /m/s^2	-3.056
Average acceleration /m/s^2	0.52
Average deceleration /m/s^2	-0.59
Idle ratio/%	15.83

3.1 The analysis of the influence of the mass increase on the endurance mileage and energy consumption

3.1.1 The analysis of the influence of the mass increase on the endurance mileage

In order to analyze the influence factor of the vehicle mass on the endurance mileage, the battery is set 200Ah, the average electric auxiliary is 5kW. In simulation, the different vehicle mass influences on the endurance mileage in different constant speed are shown in figure 3.

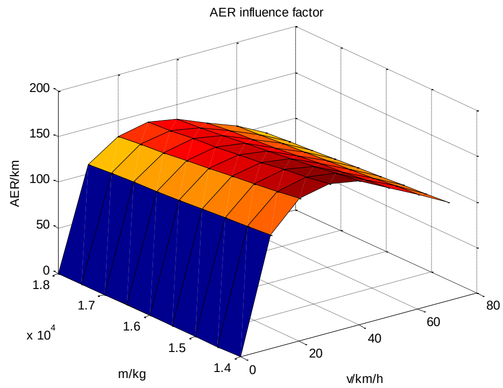

Figure3: The influence of the vehicle mass on the endurance mileage in constant speed driving cycle

As is shown in figure3, the vehicle bus studied in this paper drives with constant speed of 30km/h, the endurance mileage is the maximum. After calculation, if the vehicle mass is 14000kg, the endurance mileage is 163.5 km. If the speed is above 30km/h, with the increasing of the speed, the endurance mileage is decreased.

Figure 4 is the influence of different vehicle mass and battery capacity on the endurance mileage in Hefei city bus driving cycle. As is shown in figure 4, the relationship between the different vehicle mass, battery capacity and the endurance mileage is linearity.

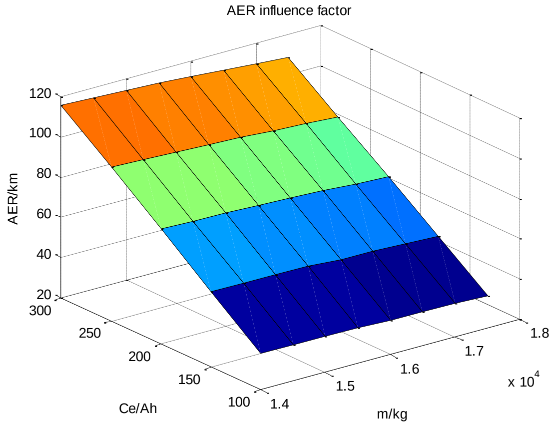

Figure4: The influence of the vehicle mass and battery capacity on the endurance mileage in Hefei city bus driving cycle

With the battery capacity is 300Ah, the relationship between the electric bus mass and the endurance mileage is shown in figure 5. As is shown in figure 5, if the vehicle mass increases per 1000kg, the endurance mileage decreases about 1km. If the vehicle mass increases to 3500kg, the endurance mileage decreases 6.7km, reaching 5.79% of the endurance mileage.

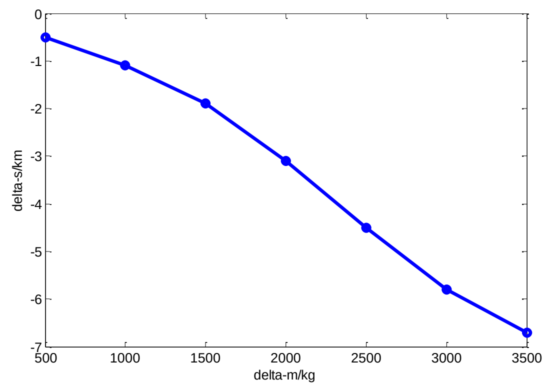

Figure5: The influence of vehicle mass on the endurance mileage in Hefei city bus driving cycle

3.1.2 The analysis of the influence of the mass increase on the electric bus power consumption

Figure 6 is the influence of the vehicle mass increasing on the power consumption in different speed. As is shown in figure 6, if the vehicle mass increases per 1000kg, the corresponding power consumption increases 0.03kWh/k～0.04kWh/km, which is 3% ～ 4% of the whole power consumption.

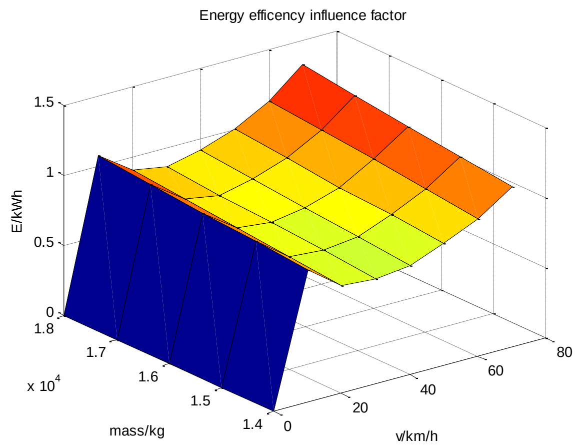

Figure6: The influence of mass increasing on power consmption with constant speed

Table 3 is the influence of the vehicle mass increase on the power consumption in Hefei of Anhui province of China. As is shown in table 3, the vehicle mass increases per 1000kg, the corresponding power consumption increases about 3.5%. If the mass reaches 18000kg, the power is 1.218kWh/km, increased by 16%.

Table3: The influence of the vehicle mass on the power consumption in Hefei city bus driving cycle

Mass(kg)	Drive energy (kWh)	Recovery energy (kWh)	Consumption energy (kWh)	Equal power consumption (kWh/km)
14000	21.12	7.024	14.1	1.05
15000	21.8	7.28	14.52	1.086
16000	22.68	7.605	15.075	1.128
17000	23.59	7.911	15.679	1.173
18000	24.53	8.241	16.289	1.218

3.2 The analysis of the influence of the electric auxiliary on the power consumption

Figure 7 is the power consumption with different auxiliary and constant speed. If the electric auxiliary increases per 5kW, the power consumption increases 15%～55%.

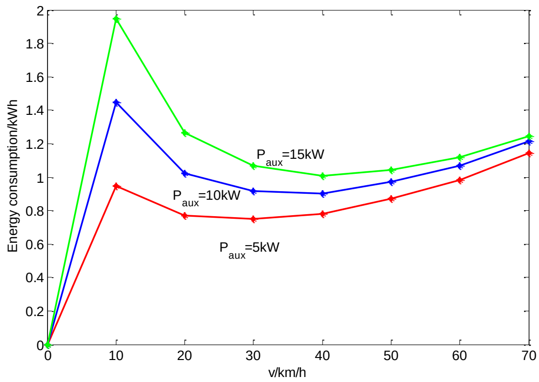

Figure7: The influence of auxiliary power on power consumption with constant speed

Table 4 is the influence of the different auxiliary power on the power consumption in Hefei city bus driving cycle. As is shown in table 5, the auxiliary power increases per 5kW, and the power consumption increases about 22%. If the auxiliary power reaches 15kW, the power consumption reaches 1.515kWh/km.

Table4: The power consumption with different auxiliaries in Hefei city bus driving cycle

Auxiliary power (kW)	Drive energy (kWh)	Recovery energy (kWh)	Consumption energy (kWh)	Equal power consumption (kWh/km)
5	21.12	7.024	14.1	1.05
10	23.29	6.106	17.184	1.285
15	25.55	5.292	20.258	1.515

4 Conclusion

Based on establishing the electric bus system model, this paper uses Chinese constant speed and Hefei of Anhui province of China city bus as the driving cycles, and analyzes the influence of different vehicle mass and auxiliary power on the endurance mileage. The simulation results are shown as follows:

(1) The speed is constant, if the vehicle mass increases per 1000kg, the power consumption increases about 3%～4%. If the auxiliary power increases per 5kW, the power consumption increases 15%～55%.

(2) In Hefei city bus driving cycle, if the vehicle mass increases per 1000kg, the trip mileage decreases about 1km, the power consumption increases about 3.5%. If the auxiliary power increases per 5kw, the power consumption increases about 22%.

Acknowledgments

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References

[1] Van Wieringen Matt, Pop-lliev Remon. *Development of a dual-fuel power generation system for an extended range plug-in hybrid electric vehicle*. IEEE Transactions on Industrial Electronics, vol.57, no.2, pp.641-648, 2010.

[2] Waldner Jeff, Wise Jeremy and Crawford Curran, et al. *Development and testing of an advanced extended range electric vehicle.* SAE 2011 World Congress and Exhibition, Apr.12, Detroit, United states, 2011.

[3] HU Mingyin, YANG Fuyuan and OUYANG Minggao, et al. *A research on the distributed control system for extended-range electric vehicle*. Automotive Engineering, vol.34, no.3, pp.197-202, 2012.

[4] David Steen, Le Anh Tuan and Ola Carlson, et al. *Assessment of electric vehicle charging scenarios based on demographical data*. IEEE Transactions on Smart Grid, vol.3, no.3, pp.1457-1468, 2012.

[5] Olle Sundstrom, Carl Binding. *Flexible charging optimization for electric vehicles considering distribution grid constraints.* IEEE Transactions on Smart Grid, vol.3, no.1, pp.26-37, 2012.

[6] Juan Dixon, Ian Nakashima and Eduardo F. Arcos, et al. *Electric vehicle using a combination of ultracapacitors and ZEBRA battery.* IEEE Transactions on Industrial Electronics, vol.57, no.3, pp.943-949, 2012.

[7] Swagat Chopra, Pavol Bauer. *Driving range extension of EV with On-Road contactless power transfer – a case study.* IEEE Transactions on Industrial Electronics, vol.60, no.1, pp.329-338, 2013.

[8] C Bingham, C Walsh and S Carroll. *Impact of driving characteristics on electric vehicle energy consumption and range.* IET Intelligent Transport Systems, vol.6, no.1, pp.29-35, 2010.

[9] CHENG Ming, GUO Lixin. *Parameters sensitivity analysis of dynamic performance and energy consumption economy of battery electric vehicle.*

Journal of Northeastern University (Natural Science), vol.33, no.5, pp.723-726, 2012.

[10] CHEN Yong, CHEN Xiaokai and LIN Yi. *Application of collaborative optimization to multidisciplinary design optimization of electric vehicles.* Automotive Engineering, vol.31, no.8, pp.709-714, 2009.

[11] OUYANG Minggao, LI Jianqiu and YANG Fuyuan, et al. *Automotive new powertrain: systems, models and controls.* Tsinghua University Press, 2008.

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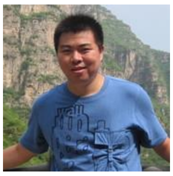

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