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Design of an Energy-Saving Driving Strategy for Electric Buses

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ABSTRACT In recent years, fully electric vehicles (EVs) have accounted for a higher proportion of urban buses. On account of their relatively short cruising range, many technologies were used to improve the driving range, such as improving energy management strategies and promoting the performance of the battery and engine. The purpose of this study was to develop an energy-efficient driving strategy to save energy. The strategy consists of two parts: determining a velocity interval for lower energy and establishing an energy-saving acceleration mode. First, 30 velocity datasets were collected from an actual bus line. An electric bus model and energy consumption equation were established in the AVL CRUISE software to analyze the energy consumption. Next, the velocity interval was determined based on the actual data with the objective of maximizing engine efficiency and minimizing energy consumption. By considering uniform motion and traffic conditions, 30-40 km/h was determined as the velocity interval of lower energy for the electric bus mentioned in this paper. The acceleration characteristic parameter β represents the curve of velocity versus time in different acceleration processes, which was chosen to describe the acceleration mode; we found that when β is greater than 0.2, the lower the β value, the lower the energy consumption per kilometer was. Finally, the energy-saving driving strategy was verified by conducting a simulation. It was determined that the reduction in energy consumption per kilometer after implementing the energy-saving driving strategy was between 12.32% and 18.7% for short sections of acceleration and 2.47% for the entire bus trip.

INDEX TERMS Acceleration mode, bus modeling, driving strategy, energy-saving, velocity interval.

I. INTRODUCTION

Electric vehicles have recently received a lot of attention because they are zero-emission vehicles and are more energy-efficient than conventional vehicles. Electric buses have many advantages [1]–[4], including being locally emission-free, suffering no energy losses during idle operation, more energy-efficient than conventional buses, quiet, and able to recover braking energy. Due to the increasing oil crisis, an increasing number of electric buses have been put into operation in China. In Xi'an Shaanxi Province, the number of fully electric buses (often described as pure electric) has increased by more than 60% as of March 2019. Although electric buses have many advantages, the relatively short cruising range and long charging time are two major problems [5]. The fact that drivers worry about the range of the bus is a critical issue. According to a survey, when the battery state of charge (SOC) is about 40%, 80% of bus drivers will charge the vehicle instead of continuing to drive to prevent running out of battery power during the bus journey.

In recent years, much research has focused on developing more energy-efficient vehicles [6], [7]. The energy efficiency of a vehicle depends on a number of factors; one factor is the hardware of the vehicle, such as the battery characteristics [8], electric motor characteristics [9], powertrain system [10], and charging device [11]. Hybrid electric vehicles can save fuel consumption but the engine generates CO, HC, and NO_X [12], [13]. Holdstock et al. analyzed the impact of the transmission topology on the energy consumption of electric vehicles and found that multiple-speed mechanical transmission systems resulted in higher performance and efficiency of fully electric vehicles than single-speed transmissions when driven by a single electric motor [14]. Another factor influencing the energy consumption of electric vehicles is the energy management strategy (EMS). Liu et al. put forward a rule-based energy management

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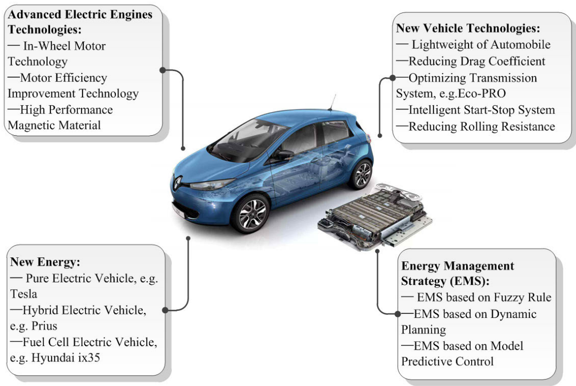


FIGURE 1. New technologies for improving vehicle energy economy.

strategy for hybrid electric vehicles based on operation-mode prediction; the results showed that the control strategy significantly enhanced the performance of the EMS and provided 9.6% improvement in real fuel consumption [15]. It was estimated that the efficiency improvement of advanced electric engines and vehicle technologies (as indicated in Fig. 1) was only about 4-10% and 2-8% respectively [16]–[18]. However, the implementation of a driving strategy is relatively low-cost and immediate and the improvement in fuel efficiency can reach 30%-45% [19], [20]. Bingham et al. computed an optimal velocity profile that was provided to the driver by the Eco-Driving Assistance System (EDAS). It was revealed that better driving behavior could increase the range of electric vehicles by 30% [21]. It was observed that the energy efficiency of electric vehicles improved when they moved at a constant cruising velocity; this is the reason why most energy-saving control strategies in the literature are focused on minimizing acceleration and deceleration of vehicles [22]–[25].

In this study, a driving strategy is developed to improve the energy efficiency of electric buses in Chinese cities. Driving strategy refers to the combination of acceleration mode and velocity values chosen by the driver to traverse a given distance. It is known that constant velocity is part of an energy-saving driving strategy to reduce energy consumption under various road conditions [26], [27]. Research on the use of cruise control to improve energy efficiency has shown that an ecological adaptive cruise control system (EACC) is a suitable approach [28], [29]. Some scholars have shown that the EACC provides optimal velocity for optimal fuel economy for internal combustion engine (ICE) vehicles [30], [31]. The fuel consumption rate first decreased with the increase in velocity, reached the optimal point, and then increased at high velocity due to high friction losses [32]. The curves of the fuel consumption versus driving velocity were U-shaped. This curve also applies to electric vehicles but the optimal velocity is much lower for electric vehicles. Wang and Rakha [33] found that the energy consumption per unit of time was positively correlated with the cruising velocity. The optimum cruising velocity was 40-50 km/h for diesel vehicles, 60-80 km/h for light gasoline vehicles, and 45-56 km/h for electric vehicles [34]. In real-world conditions, the driving velocity cannot be maintained at a constant value because the velocity limit and traffic flow have to be considered. The traffic environment is very complex and changeable in Chinese cities. The bus transit lanes are often occupied by other vehicles and non-motorized vehicles. In addition, buses need to stop at fixed stations for passengers to get on and off, making it impossible for buses to maintain a fixed velocity. Therefore, a better solution is required that provides a velocity interval for bus drivers to choose from depending on the actual traffic conditions in order to lower energy consumption.

Another important factor influencing the energy consumption of electric bus is acceleration. Eco-driving usually encourages drivers to minimize the use of the accelerator and brake pedal by looking ahead at the traffic flow [35], [36]. Pelkmans et al. found that acceleration was the dominant factor affecting the fuel consumption of a bus in real-city traffic; acceleration accounted for 35% of the driving time but was responsible for 70% of fuel consumption and 60-80% of CO, HC, and NO_X emissions during a driving cycle [37]. Yan also concluded that the main reason for differences in the energy consumption of electric buses operating on the same bus line was the difference in how the acceleration pedal was used [38]. The adjustment of the accelerator pedal affects the acceleration; therefore, after selecting an optimal velocity, the manner in which the vehicle is accelerated to achieve the target velocity also has a great impact on energy consumption.

As a consequence of the limited driving range of full electric vehicles and the imperfect construction of charging piles, range anxiety is a potential barrier for the widespread adoption of full EVs. City buses are regarded as the largest application body of full electric vehicles. In order to reduce energy consumption during driving, increase driving range of bus, and improve operational efficiency, the objective of this study was to develop an energy-saving driving strategy integrating the velocity interval for lower energy and energy-efficient acceleration mode. The realization of this goal requires two steps; firstly, a velocity interval for lower energy is determined by evaluating actual operational data. Secondly, the energy-saving acceleration mode is determined so that the vehicle can reach the target velocity selected by the driver. The rest of the article is arranged as follows: The electric bus model is described in Section II, including the electric motor, battery, and vehicle. In Section III, an energy-saving driving strategy is described in detail. The simulation results and discussion are presented in Section IV, followed by the conclusion in Section V.

II. ELECTRIC BUS MODEL & ENERGY CONSUMPTION EQUATION

As shown in Fig. 2, the research object is a rear-motor rear-drive (RR) fully electric bus that is a centralized control type. The prototype is a 12-m fully electric bus in Xi'an. Based on

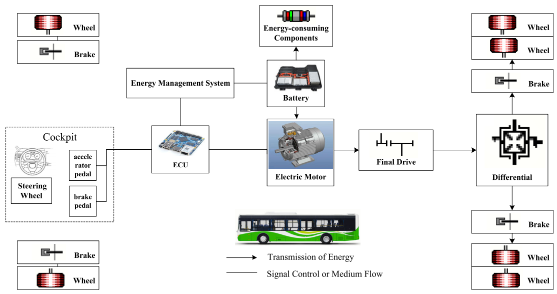


FIGURE 2. **Structure of an electric bus.**

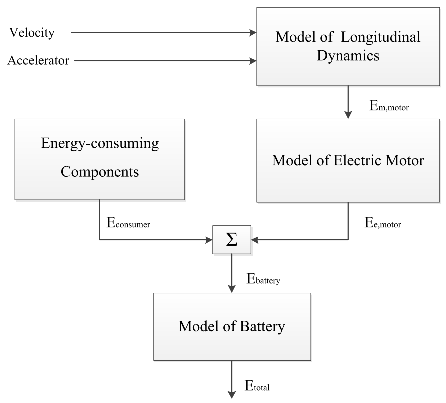


FIGURE 3. **Electric bus model.**

the theory of vehicle dynamics, a fully electric bus model was built that included four parts as shown in Fig. 3, namely, the model of the vehicle's longitudinal dynamics, the model of electricity consumption, the model of the electric motor, and the battery model.

A. MODEL OF LONGITUDINAL DYNAMICS

According to the principle of force balance, the resistance that has to be overcome so that the electric bus can move in a longitudinal direction consists of four components, namely, rolling resistance, uphill driving force, acceleration resistance, and aerodynamic drag. The combination of the four effects comprises the traction force, which is the basic force to propel the vehicle forward [39]. The resistance balance equation of the electric bus and the calculation formulas of the forces are as follows:

$$\begin{aligned} F &= F_f + F_i + F_j + F_w \\ F_f &= mgf \cos\alpha \\ F_i &= mg \sin\alpha \\ F_j &= \delta ma \\ F_w &= \frac{C_D A v^2}{21.15} \end{aligned} \tag{1}$$

where F is the traction force (N); F_f is the rolling resistance (N); F_i is the uphill driving force (N); F_j is the acceleration resistance (N); F_w is the aerodynamic drag (N); m is the electric bus's mass (kg); g is the gravitational constant (m/s^2); f is rolling resistance coefficient; α is the road gradient; δ is the coefficient that is related to the vehicle's mass; a is the acceleration (m/s^2); v is the vehicle velocity (km/h); C_D is the aerodynamic drag coefficient; A is the bus's frontal area (m^2).

The power balance equation can be obtained by multiplying the driving velocity v on both sides of the resistance balance equation.

$$\begin{aligned} P &= Fv = (F_f + F_i + F_j + F_w)v \\ &= mgfv\cos\alpha + mgv\sin\alpha + \delta mav + \frac{C_D A v^3}{21.15} \\ \delta &= 1 + \frac{1}{m}\left(\frac{\sum I_w}{r^2} + \frac{I_f i_g i_0^2 \eta_T}{r^2}\right) \end{aligned} \tag{2}$$

where P is the power of the driving resistance (N·km/h); r is the tire radius (m); I_w is the moment of inertia of the wheel (kg·m^2); I_f is the moment of inertia of the motor (kg·m^2); i_g is the transmission ratio (which is 1 in this study); i_0 is the final drive ratio; η_T is the efficiency of the transmission.

After unit conversion, the vehicle power balance equation is descried as follows. Where the unit of P_t is kw.

$$P_t = \frac{mgfv\cos\alpha}{3600} + \frac{mgv\sin\alpha}{3600} + \frac{\delta mav}{3600} + \frac{C_D A v^3}{76410} \tag{3}$$

The driving energy of the wheel is:

$$E_d = \int_0^t \left(\frac{mgfv\cos\alpha}{3600} + \frac{mgv\sin\alpha}{3600} + \frac{\delta mav}{3600} + \frac{C_D A v^3}{76410}\right) t\,dt \tag{4}$$

where t is time (h); E_d is the energy of the wheel (kWh).

Additionally, it is known that energy recovery in the braking mode plays an important role during the operation of an electric bus. When the bus brakes, part of the kinetic energy can be recovered by operating the motor drive as a generator so that the battery can be charged. As a result, the regenerated energy depends on the velocity and deceleration, the structure of the brake and generator, and the ability of the battery to absorb energy [40]. The recovered energy can be calculated according to the law of energy conservation:

$$E_{\text{recovery}} = \eta_{\text{battery}} \eta_{\text{motor}} \eta_T \eta_{\text{recovery}} \left(\frac{1}{2} m v_1^2 - \frac{1}{2} m v_0^2\right) \tag{5}$$

where η_{battery} is the efficiency of the battery; η_{motor} is the efficiency of the electric motor; η_{recovery} is the efficiency of energy recovery; v_1 is the final velocity of braking (km/h); v_0 is the initial velocity of braking (km/h).

B. MODEL OF THE ELECTRIC MOTOR

The traction force F of the bus is provided by the electric motor and is expressed as:

$$F = \frac{T_{tq} i_g i_0 \eta_T}{r} \tag{6}$$

From Eqs. (1) - (5) the output torque of the electric motor T_{tq}(Nm) is determined as:

$$T_{tq} = \frac{r}{i_g i_0 \eta_T}\left(mgf\cos\alpha + mg\sin\alpha + \delta ma + \frac{C_D A v^2}{21.15}\right) \tag{7}$$

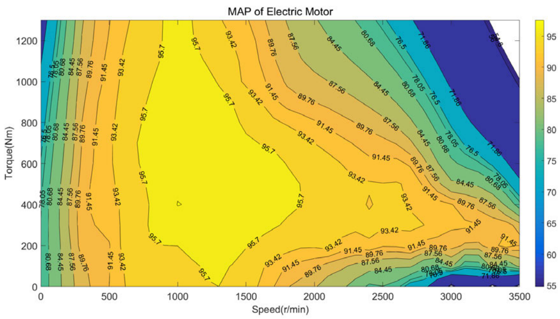


FIGURE 4. Torque versus speed map of the electric engine.

The speed of the electric motor n_{motor} (r/min)is:

$$n_{motor} = \frac{\omega_{motor}}{2\pi} \tag{8}$$

The output power of the electric motor $P_{\text{m,motor}}$ (kW) is:

$$\begin{aligned} P_{m,motor} &= \frac{T_{tq}n}{9550} = T_{tq}\omega_{\text{motor}} \\ \omega_{motor} &= \frac{vi_g i_0}{r} \end{aligned} \tag{9}$$

The output energy of the electric motor $E_{\text{m,motor}}$ (kWh) is:

$$\begin{aligned} E_{m,motor} &= \int_0^t P_{m,motor}tdt = \int_0^t T_{tq}\omega_{motor}tdt \\ &= \int_0^t \frac{v}{\eta_T}(mgf\cos\alpha + mg\sin\alpha + \delta ma + \frac{C_D A v^2}{21.15})tdt \\ &= \frac{1}{\eta_T}E_d \end{aligned} \tag{10}$$

The electric engine of the fully electric bus serves two functions; the first function is as an electric motor, which converts the electric energy transmitted by the battery into mechanical energy to drive the bus, and the second function is as a generator to recover the mechanical energy when the bus brakes or decelerates and convert it into electrical energy to charge the battery. The torque versus speed map of the electric engine is shown in Fig. 4; the motor efficiency is a function of the speed and torque.

The electric energy of the electric motor mode and the generator mode is calculated as follows:

$$\begin{aligned} \text{Electric motor mode}: E_{e,motor} &= \frac{E_{m,motor}}{\eta_{motor}} \quad (T_{tq} \geq 0) \\ \text{Generator mode}: E_{e,motor} &= E_{m,motor}\eta_{motor} \quad (T_{tq} \leq 0) \end{aligned} \tag{11}$$

C. ELECTRICITY-CONSUMING COMPONENTS

The energy-consuming components of the electric bus include the air-conditioning system, the steering system, the electric engine cooling water system, the entertainment information system, and the lighting system; the electric

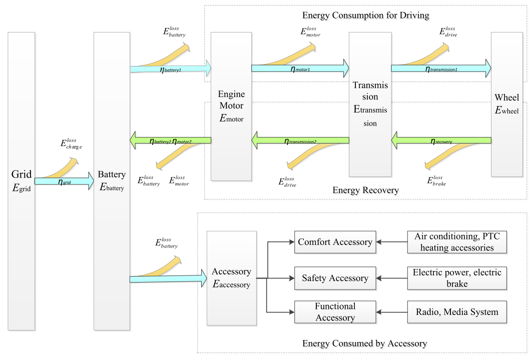


FIGURE 5. Energy flow path of the fully electric bus.

energy consumed is:

$$E_{consumer} = \int_0^t \frac{UIt}{1000}dt \tag{12}$$

D. MODEL OF THE BATTERY

The output power of electric bus battery can be calculated based on the output voltage U(V) and current I (A):

$$P_{battery} = UI \tag{13}$$

The output energy of the battery E_{battery} (kWh) is:

$$E_{battery} = \int_0^t P_{battery}tdt \tag{14}$$

Since the internal resistance of the battery also consumes energy, if the internal resistance of the battery is $R(\Omega)$, the total battery energy can be calculated as Eq. (15). E_{total} refers to the energy contained in the battery itself. This part does not include the energy charged into the battery during the process of energy recovery.

$$E_{total} = E_{battery} + I^2 R \tag{15}$$

As described above, the fully electric bus energy consumption equation based on vehicle dynamics and the energy flow direction of the electric vehicle is simplified as Eq. (16). As presented in Fig. 5, the energy flow has two directions. One direction is the energy consumption from the battery to wheel, where the energy of the battery is transmitted to mechanical energy to drive the wheels. The other direction is energy recovery, that is, excess mechanical energy is converted into electric energy by the generator to charge the battery during braking. Therefore, from the view of energy flow, the total energy E that actual consumed during the operation of the electric bus can be expressed by the sum of the energy contained in battery (E_{total}) and the recovered energy (E_{recovery}). From the view of vehicle dynamic, the total energy E can be expressed by some driving parameters, such as velocity and acceleration. So the Eq.(16) established a connection from two different view to express the actual energy consumed during the operation of the electric bus.

TABLE 1. Relevant bus model parameters.

Name and Unit	Value
Vehicle—Length×Width×Height (mm):	12000×2550×3360
Curb Weight (kg)	12400
Gross Weight (kg)	18000
Frontal Area (m^2)	7.6
Transmission Ratio	6.33
Rotation Mass Conversion Factor δ	1.08
Maximum Velocity (km/h)	69
Gravitational Acceleration (m/s^2)	9.81
Drag Coefficient C_D	0.67
Rolling Resistance Coefficient f	0.012
Tire Radius (m)	0.485
Battery—Lithium Iron Phosphate	
Energy Density (Wh/kg)	150
Monomer Voltage (V)	3.2
Monomer Capacity (Ah)	200
Number of Cells in Series	156
Monomer Mass (kg)	4.28
Total Voltage (V)	500
Number of Cells in Parallel	3
Battery Capacity (kWh)	300
Electric Motor—Permanent Magnet Synchronous Motor	
Nominal Power (kW)	90
Nominal Speed (rpm)	900
Nominal Torque (Nm)	1000
Total Mass (kg)	250
Maximum Power (kW)	190
Maximum Speed (rpm)	3500
Maximum Torque (Nm)	2100
Nominal Voltage (V)	480

The calculation result of this variable will be an important basis for analyzing the effects of energy-saving driving strategies.

$$\begin{aligned} E &= E_{total} + E_{recovery} \\ &= \frac{1}{\eta_{battery}}(E_{consumer} + \frac{1}{\eta_{motor}\eta_T}E_d) \\ &= \frac{1}{\eta_{battery}}[E_{consumer} + \frac{1}{\eta_{motor}\eta_T}(\int_0^t(\frac{mgfv\cos\alpha}{3600} \\ &\quad + \frac{mgv\sin\alpha}{3600} + \frac{\delta mav}{3600} + \frac{C_D A v^3}{76410})tdt)] \end{aligned} \tag{16}$$

The bus parameters [41] are provided in Table 1. The energy consumption model shows that the factors affecting the energy consumption of fully electric buses include the driving velocity, acceleration, vehicle mass, rolling resistance coefficient, drag coefficient, road gradient, frontal area, rotation mass conversion factor, motor efficiency, battery efficiency, transmission efficiency, and time. The key components that affect the simulation performance of the software are the map of the motor, the torque versus speed characteristic map, and the charge and discharge curves of the battery.

III. ENERGY-SAVING DRIVING STRATEGY

For a given electric bus, the basic parameters such as mass, drag coefficient, and frontal area are determined. Motor efficiency is a function of torque and speed. The efficiency of the battery is determined by its charge and discharge curve. Velocity and acceleration are the most important driving behavior factors affecting energy consumption.

A driver typically drives the bus based on experience to judge the surrounding traffic environment and choose a velocity and acceleration. This driving strategy is random rather than optimal and does not take advantage of the electric power of the battery. Perhaps the driver chose the optimal velocity and acceleration at certain times but he did not realize it. Therefore, it is necessary to determine the energy-saving driving strategy from the operating data of the bus.

As shown in Fig. 5, the energy flow path of the fully electric bus has two directions. The first direction is energy consumption, where the energy is flowing from the battery to the wheels. In detail, the electric bus obtains electric power from the battery, which is charged by the grid. In this mode, the energy loss of the battery mainly includes the energy that is used to drive the vehicle and the energy that is consumed by accessories. The energy of the battery is transmitted to the motor in the form of a current so that the motor generates torque. The output torque is transferred from the motor to the transmission system to drive the wheels. During the transfer of energy from the battery to the wheels, energy loss occurs due to battery efficiency, motor efficiency, and transmission system efficiency. Therefore, these three types of efficiencies are important factors influencing the driving energy, especially the motor efficiency. The second direction is energy recovery, in which energy is flowing in the opposite direction. When the electric bus is braking, the excess mechanical energy of the wheel is converted into electric energy. In other words, the wheel drives the motor to rotate and the motor control system turns the induction motor into an alternator to generate a current; the alternating current (AC) is converted into direct current (DC) to charge the battery. Similarly, in the energy recovery mode, the three types of efficiencies are also important.

Due to the important influence of motor efficiency, battery efficiency, and transmission efficiency on energy consumption, it is meaningful to achieve a reduction in energy consumption by maximizing efficiency. Vaz et al. proposed a multi-objective approach to obtain the optimal velocity by maximizing the electric motor efficiency and minimizing power consumption [42]. In this study, a similar approach is used to find the velocity interval for lower energy. It was calculated that the efficiency of the battery and mechanical system during the operation of the fully electric bus did not change much and did not require optimization. Therefore, it was assumed that in this study, the efficiencies of the battery and the transmission system were constant. In order to maximize the use of the battery's energy for vehicle driving and minimize the heat loss, the velocity interval for lower energy was chosen so that the electric motor efficiency was maximized and the energy consumption was minimized. In other words, the energy per kilometer was lowest at the optimal velocity. The range and trip time were calculated for the same energy at different velocities. The velocity interval for lower energy and the corresponding trip time and range were provided to the bus driver, who can select an optimal travel velocity according to traffic conditions.

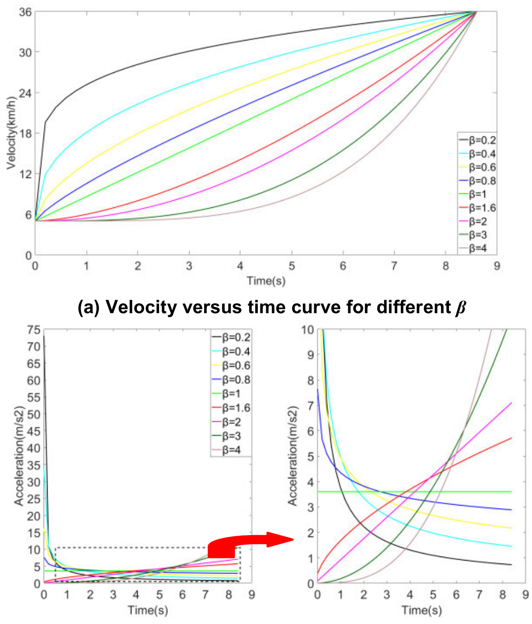
Once the drivers selected the optimal velocity according to the traffic environment, in order to achieve minimum energy consumption, the drivers accelerated to reach the optimal velocity in the shortest time, but rapid acceleration causes more energy consumption, which was contrary to the initial expectations. The second objective of this study was to find an acceleration mode that used less energy.

There are many ways for a bus to accelerate from one velocity to another. Vaz et al. had researched the effects of single acceleration and multiple accelerations on the energy consumption of an electric vehicle during acceleration process, and found that multiple accelerations had less energy consumption than that of a single acceleration in the same acceleration time [43]. Li proposed acceleration characteristic parameters to represent different acceleration modes of electric vehicles, and further studied the relationship between different acceleration characteristic parameters and electrical energy consumption [44]. With reference to this, in this paper, the acceleration characteristic parameter was used to represent different acceleration modes of a full electric bus. The general acceleration process of electric vehicles was analyzed. The time changed from t_0 to t, and the vehicle velocity accelerated from $v_0(t_0)$ to $v(t)$. The relationship between velocity $v(t, \beta)$ and travel time t is the acceleration mode of the vehicle. It is represented by the acceleration characteristic parameter β. Here, the acceleration characteristic parameter β was defined to indicate the relationship between the velocity of the bus and the travel time. In fact, this was derived from the calculation formula of final velocity about the uniform acceleration motion, that is $v = v_0+at$ or $\Delta v = a\Delta t$. Here we described a continuously varying acceleration process, and at the same time, different acceleration modes were indicated by the acceleration characteristic parameter β, and the bus had multiple accelerations in each mode.

$$v = v_0 + (v_f - v_0)(\frac{t - t_0}{t_f - t_0})^{\beta} \tag{17}$$

where t_0 is the initial time of acceleration ($t_0 = 0$), v_0 is the initial velocity during acceleration, v_f is the final velocity, t_f is the end time of acceleration, β is the acceleration characteristic parameter ($\beta \in (0, \propto)$,where $\beta = 0.2, 0.4, 0.6, 0.8, 1.0, 1.6, 2.0, 3.0, 4.0$.

Equation (16) demonstrates that the energy consumption of the vehicle is affected by the time, velocity, acceleration, and motor efficiency. In Section II, those equations showed that the efficiency of the motor is a function of its torque and speed, and the torque and speed can be expressed by the velocity. It is understood from Eq. (17) that the velocity and acceleration can be expressed by the acceleration



(a) Velocity versus time curve for different β

(b) Acceleration versus time curve for different β

FIGURE 6. Trends of velocity and acceleration as a function of time for different values of β.

characteristic parameter. Therefore, the energy consumption of the bus is related to the acceleration characteristic parameter and acceleration time. When the acceleration time is fixed, the energy consumption is determined by β. Therefore, the acceleration characteristic parameter β can be used to find the acceleration that uses the least amount of energy.

In this study, the same acceleration duration was used to research the effect of the acceleration mode on energy consumption. Fig. 6 shows the trends of velocity and acceleration as a function of time for different values of β.

As shown in Fig. 6, when $0 < \beta < 1$, the acceleration was large at the initial stage of acceleration and the velocity increased faster. At the end of the acceleration period, the acceleration was small, the change in the velocity was smaller, and the velocity curve had a convex shape. When $\beta = 1$, as shown by the green line in the figure, the acceleration remained unchanged throughout the process. When $\beta > 1$, the acceleration was small at the initial stage of acceleration and the velocity increased slowly. At the end of the acceleration period, the acceleration had a larger value, the velocity increased faster, and the acceleration curve had a concave shape.

In China, the operation of fully electric buses is affected by the complex traffic environment and stop-and-go conditions are common. Therefore, the velocity interval for lower energy and energy-saving acceleration mode are two important factors. In this study, we collected actual velocity and acceleration data from a fully electric bus in Xi'an. The bus route has 38 stations from the city center to the suburbs; this is a representative route because it runs through a bustling commercial district, urban expressway, residential areas, etc. The average running time from the starting point to the ending

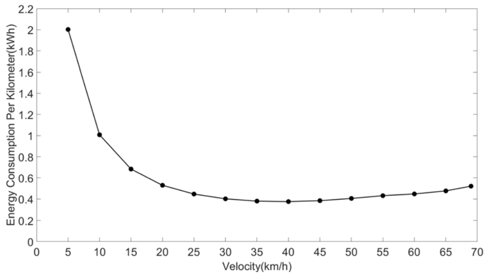


FIGURE 7. Energy consumption per kilometer at different velocities.

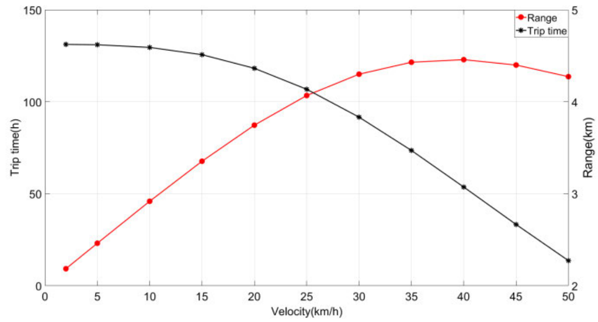


FIGURE 8. The range and trip time for different velocities and the same energy consumption.

point is 91 min. With a sampling frequency of 1 Hz, approximately 6000 rows of data were collected each trip and a total of 30 datasets were collected.

The AVL CRUISE software can be used to simulate the dynamic, fuel economy, and emissions performance of the vehicle. Its modular modeling concept allows users to easily build vehicle models with different layouts. The sophisticated and complete solver ensures the speed of calculations. The intelligent driving model can realistically simulate driver behavior. Additionally, the data output is detailed; almost all parameters of the vehicle, battery, motor, and driver can be exported to an.xls file for subsequent data analysis. In this paper, it was used to establish a simulation model for a fully electric bus, and the actual velocity values were input to simulate the bus operation. The output data included velocity, acceleration, accelerator pedal and brake pedal operating percentages, driving range, motor torque, speed, battery voltage, current, SOC, and many other parameters. Based on the operational data, the velocity interval for lower energy during the operation of the fully electric bus was determined.

IV. RESULTS AND DISCUSSION

A. VELOCITY INTERVAL FOR LOWER ENERGY

The first objective was to determine the velocity interval for lower energy based on the bus operational data. Based on the electric bus model and energy consumption equation established in Section II, a cruise control mission of the fully electric bus was set in the AVL CRUISE software. Since the maximum velocity of this electric bus was 69 km/h, 14 velocity points were selected in the range of 5-69 km/h with steps of 5 km/h. At each velocity point, the software supplied the total energy consumption and range. Energy consumption per kilometer can be obtained by dividing the two results. The energy consumption per kilometer at different velocities is shown in Fig. 7.

The range and trip time were calculated for different velocities and the same energy consumption based on a cruise control mission of the bus set in the AVL CRUISE software. The initial SOC was 100% and the final SOC was 85%. The results are presented in Fig. 8. As expected, the trip time decreased as the driver chose a higher velocity. The range increased as the velocity increased up to 40 km/h, after which the range decreased. The reason for this is that the optimal velocity where the energy consumption per kilometer was minimized was 40 km/h under the uniform motion task, as shown in Fig. 7. Naturally, the velocity that had the maximum range was 40 km/h, as shown in Fig. 8. This occurred because the efficiency of the motor increased with the increase in the velocity when the velocity was lower than 40 km/h; subsequently, as the velocity increased, the air resistance increased as did the energy consumption and, therefore, the range decreased. Therefore, the trip velocity that provided the maximum range was 40 km/h. However, if the driver desired a shorter trip time, a higher velocity can be chosen from Fig. 8. For example, at 45 km/h, the range decreased by about 2.38% but the trip time decreased by about 13.24%. If the driver had to choose a lower velocity because of the traffic conditions, the range would be reduced. At this time, due to external factors, the driver can only compromise and choose a velocity close to the maximum while maintaining safety.

Due to the traffic environment during actual operations, the probability of using long-term cruise control of the bus is very small. Furthermore, the traffic environment in China is relatively complex. During the operation of the bus, frequent entry and exit operations, road congestion, intersection traffic lights, etc. result in a go-stop-go operation of the bus; therefore, the optimal velocity obtained by using the cruise control is not practical in a real case and the optimal velocity extracted from the actual operation data will be closer to the actual conditions.

The energy consumption model was used to determine the energy consumption per second and per meter during the bus operation; several days of data were used. In steps of 5 km/h, the velocity was segmented into 9 intervals, i.e., 0-5 km/h, 5.001-10 km/h, etc. up to 45 km/h. For each interval, the average value of the velocity, energy consumption per second, and energy consumption per meter were obtained. A simulation was conducted to obtain the torque and speed of the motor and the motor efficiency at different velocities was calculated. In Fig. 9, energy consumption per meter and energy consumption per second were used to find the velocity for the lowest energy consumption. The curve of the energy consumption per second versus velocity was used as an auxiliary verification. The relationship between the two indexes is that they all expressed the energy consumption

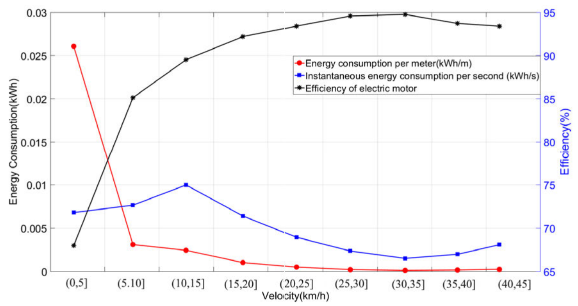


FIGURE 9. **Energy consumption per meter and per second and motor efficiency at different velocities.**

characteristic of electric buses, though they also exhibit some differences. The energy consumption per kilometer is equal to the total energy consumption divided by total range, denoting the energy that the vehicle driving 1 km consumed. It is a general energy economic evaluation index that is internationally used. However, the energy consumption per second is equal to the total energy consumption divided by total driving time. It represents the energy consumed per second during the driving of the bus. It is not a general indicator of energy economy, but, to a certain degree, it can also reflect the energy consumption characteristic of the bus.

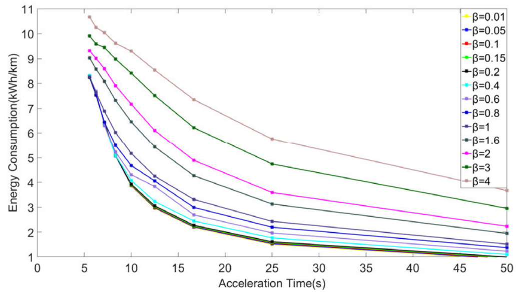
As shown in Fig. 9, at velocities less than 33.55 km/h, the engine speed was less than 1161 r/min. The engine was in constant torque operation mode prior to the base speed. According to the torque versus speed map, when the speed was less than 1161 r/min, the torque was constant and the efficiency increased with increasing speed but the energy consumption per meter decreased as the velocity increased. When the velocity was greater than 33.55 km/h, the engine efficiency decreased but the air resistance was higher at higher velocity; therefore, the energy consumption per meter increased. When the velocity was less than 12.47 km/h, although the motor efficiency increased, it was still inefficient. Also, according to the map of driving force, at low velocity, the driving force of the bus increased with the increase of velocity. Therefore, the resistance the vehicle needed to overcome increased. In order to overcome the driving resistance, the energy consumption per second exhibited an upward trend. When the velocity reached a certain value (12.47 km/h), the motor efficiency exceeded 90%, and the driving force decreased with the increase of velocity. The resistance that needed to be overcome also decreased, so the instantaneous energy decreased until 33.55 km/h, at which the energy consumption per second and per meter reached the minimum.

As shown in Figs. 8 and 9, at the point of minimum energy consumption, i.e., at 33.55 km/h, the range was 2.24% lower and the trip time was 16.53% higher than at 40 km/h. Fig. 9 shows that the velocity interval for lower energy was 30.001-35 km/h. Considering the velocity corresponding to the maximum range, as shown in Fig. 8, the velocity interval for lower energy was extended to 30-40 km/h so that the driver can flexibly select the travel velocity according to the traffic conditions. For other electric buses, because the actual bus data and technical parameters were different with the electric bus mentioned in this paper, but these parameters were pivotal to used to calculate the energy consumption and range of bus, so the velocity interval for lower energy maybe have a difference due to the replacement of technical parameters of the vehicle. In detail, the technical parameters and the performance of electric motor and battery for different electric buses will be different, and the characteristic of energy consumption will also be different. As mentioned in the introduction, although the curves of the energy consumption versus driving velocity for electric vehicle were U-shaped, the velocity with the lowest energy consumption of different vehicles will be different, and the driving range used the same energy by electric vehicles will have a difference due to different technical parameters. This will cause a change in the velocity interval for lower energy.

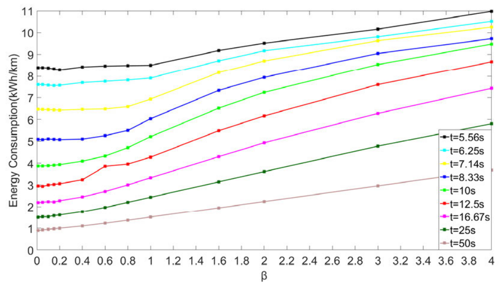
B. ENERGY-SAVING ACCELERATION MODE

The second objective was to determine the energy-saving acceleration mode that uses the least amount of energy during acceleration. The rule of eco-driving states that greater acceleration consumes more energy [35], [45]. Theoretically, regardless of the loss of energy, the energy consumed by a vehicle to accelerate from 0 to v is $E = 1/2\, mv^2$, signifying that the energy is not related to the acceleration time. In other words, using 10 s to accelerate from 0 to v consumes the same amount of energy as using 1 min. However, in practice, energy loss occurs during the acceleration process as a result of transmission efficiency and other factors. In order to ensure the energy that vehicle used to increase kinetic energy, the battery would consume more energy. Meanwhile, the air resistance and rolling resistance increase with an increase in the velocity. Also, rapid acceleration results in higher torque, which increases the friction between the gears and, therefore, increases energy consumption. In addition, the motor current is higher during rapid acceleration, which increases the coil temperature and consumes more electric energy. Therefore, it is necessary to avoid sudden acceleration in actual driving; in this study, we determined how to accelerate from the current velocity to the optimal velocity.

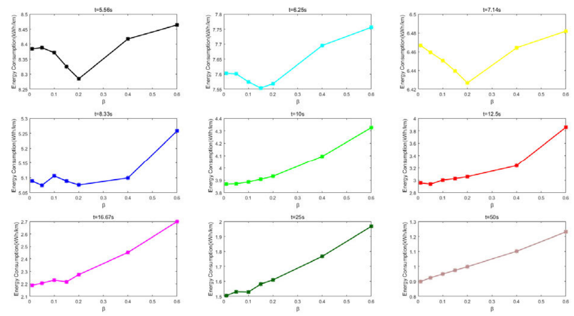
The velocity interval for lower energy determined by the bus driving parameters was 30-40 km/h. In order to facilitate the description of the acceleration mode, we selected 36 km/h (i.e.10 m/s) as the final velocity of the acceleration process. The final velocity of 36km/h is taken as an example, which does not mean that the acceleration strategy we proposed is only applicable to the case. As described earlier, the acceleration characteristic parameters β and the acceleration time are the main factors affecting the energy consumption of the vehicle. Here, the acceleration characteristic parameters β, the acceleration time, and the initial velocity during the acceleration process were selected as control variables and the influence of the three variables on energy consumption was discussed for two cases. Case 1: the acceleration time and initial velocity were kept constant and β was changed.



(a) Results for the 9 acceleration times with different β



(b) Curve of energy consumption per kilometer varying with different β using the same time from 0 km/h to 36 km/h



(c) The partial enlarged view of Fig. 10(b)

FIGURE 10. Effect of the acceleration characteristic parameters on energy consumption during the acceleration process.

Case 2: β was kept constant and the initial velocity was changed. The initial velocity values were $v_0 = 0$, 5, 10, 15, 20, 25, and 30 km/h and the acceleration time was selected as the time that the vehicle accelerated from the different initial velocities to 36 km/h using constant acceleration; The maximum acceleration was 1.8 m/s^2, the reason is that among the 30 datasets of actual bus operation data collected in this paper, the ratio of acceleration to more than 1.8 m/s^2 found in 28 groups (93.3%) is 0.

The two cases are discussed below.

Case 1: acceleration time and initial velocity were kept constant and β was changed.

Fig. 10 shows the energy consumption per kilometer with an initial velocity of 0 and the same acceleration time during the acceleration from 0 to 36 km/h. Fig. 10(a) shows the results for the 9 acceleration times with different β. Fig. 10(b) shows the curve of energy consumption per kilometer varying with different β using the same time from 0 km/h to 36 km/h. Fig. 10(c) is a partial enlarged view of Fig. 10(b), where β is from 0.01 to 0.6

When β is more than 0.2, the energy consumption per kilometer increased with the increase in the acceleration characteristic parameter β at the same acceleration time. But from Fig. 10(c), when β is less than 0.2, there is no uniform law of energy consumption per kilometer with the change of β, and the value did not change much. The average value of the difference is 0.07kwh/km. As shown in Fig. 6(b), when $\beta < 1$, the acceleration rapidly decreased from a large value to a small value during the initial stage of acceleration and the lower acceleration accounted for a larger proportion during the acceleration process. Due to the larger acceleration at the initial stage, the vehicle accelerated to a larger velocity in a short time and from this velocity, the target optimal velocity was achieved with a smaller acceleration. When $\beta > 1$, the acceleration was small in the initial stage and larger in the middle and late stages of acceleration. During the acceleration process, the vehicle was at a lower velocity most of the time and the operating efficiency of the engine was low until the end of the acceleration process; since the acceleration increased, the velocity of the vehicle quickly increased to the target velocity. These acceleration modes resulted in lower motor efficiency, which increased the energy consumption per kilometer of the acceleration process and the larger the β, the higher the energy consumption per kilometer was. In contrast, the convex acceleration mode consumed less energy than the concave acceleration mode and the linear acceleration mode was in between the two modes in terms of energy consumption. As shown in Fig. 10(a), the energy consumption per kilometer decreased with the increase in the acceleration time when β was constant.

Case 2: β was constant and initial velocity was changed.

Fig. 11 shows the velocity during the acceleration from 0 to 36 km/h for the same acceleration mode, and different acceleration times.

The acceleration values were not fixed but were changed for $\beta > 1$ or $\beta < 1$. The energy consumption per kilometer was determined during the acceleration from 0 to 36 km/h in the same acceleration mode with different acceleration times (Fig. 12, the black curve). The energy consumption per kilometer decreased as the acceleration time increased. Further, it was found that during the process of accelerating to the optimal velocity at different initial velocities, the closer the initial velocity was to the target velocity, the lower the energy consumption per kilometer was.

The analysis of the two cases indicated that the acceleration mode for energy saving was the convex mode, and when β is more than 0.2, the lower the β value, the lower the energy consumption per kilometer was. However, as shown in Fig. 6, the smaller the β was, the larger the acceleration at the initial stage of accelerating was, and the faster the velocity increased. In this process, the motor was required to provide a large torque in a short time. In actual situations, this is related to the capability of electric engine to provide high torque during the initial stage of accelerating. If the maximum torque of the motor is less than the required torque, the bus cannot complete the velocity increase in the initial

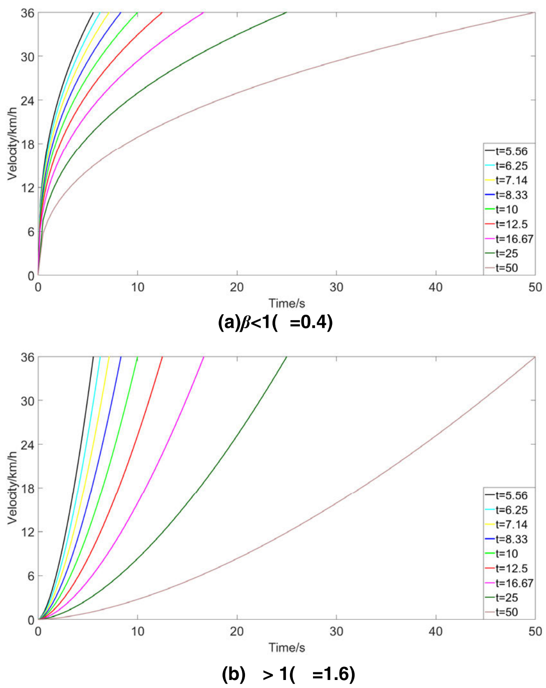


FIGURE 11. Velocity during the acceleration from v0 to 36 km/h for different acceleration times.

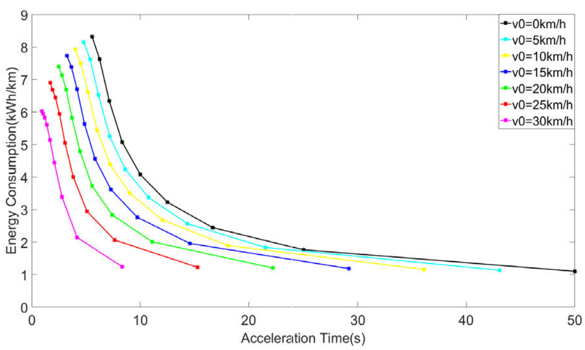


FIGURE 12. Energy consumption per kilometer for different initial velocities.

stage of accelerating according to the provided acceleration mode, and thus an energy-saving acceleration strategy cannot be achieved. Therefore, in future research, the acceleration strategy should not only consider minimizing the consumption using a smaller β, but also consider whether the performance of the motor can reach the required torque during the acceleration mode. This will be a point of follow-up research.

In daily driving, the driver does not know the value of β and cannot keep it at a small value. However, the driver can be provided with a velocity curve with a small β value so that the driver can track the velocity and save energy. The initial velocity of driving will also affect energy consumption during acceleration. It was found that the closer the initial velocity was to the target velocity, the lower the energy consumption per kilometer was. Therefore, during actual driving, if the surrounding traffic environment allows it, the driver can try to drive near the target velocity to reduce the energy consumption required for accelerating. With regard to the

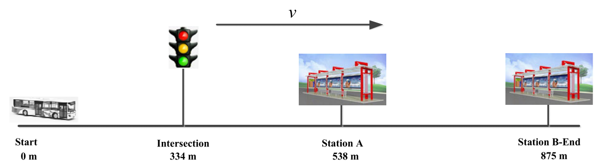


FIGURE 13. A continuous trip selected from the actual bus operation.

influence of the acceleration time on the energy consumption, since the acceleration time and energy consumption cannot be optimized at the same time, the reduction of the acceleration time will lead to an increase in energy consumption. This problem was not addressed or discussed in this article. Drivers can choose the appropriate acceleration time based on the surrounding traffic conditions and actual driving needs.

For others electric buses, it can be seen from Eq. (17), the parameters affecting the acceleration mode are mainly the acceleration characteristic parameter β, the initial velocity, the final velocity and the acceleration time. These are the driving parameters, which are independent of the technical parameters of the vehicle itself, so the acceleration mode can be applied to all buses even other electric vehicles. Li found that the energy consumption per kilometer decreased by 37.6% when β changes from 1.4 to 0.5 [44]. In fact, their research object was small-sized passenger electric vehicle.

C. VERIFICATION OF THE DRIVING STRATEGY

In order to verify the effectiveness of the energy-saving driving strategies, that is a velocity interval for lower energy (30-40km/h) and an energy-saving acceleration mode, a continuous trip in the actual bus operation was selected (Fig. 13) and the energy consumption of each small scene and of a continuous trip before and after the implementation of the energy-saving strategy were simulated and compared. Two typical traffic environments that the bus runs through are intersections and bus stations. The continuous trip shown in Fig. 13 consists of four small scenes: accelerating from the start point, accelerating after idling at the intersection, accelerating from a lower velocity to a higher velocity, and accelerating at the outbound station. The energy-saving driving strategies were applied to the four small scenes and the entire trip.

In order to verify the velocity strategy, 16 s of steady velocity data with velocities of 30-40 km/h and 20-30 km/h after implementing the strategy were selected. It was found that the energy consumption per kilometer at 30-40 km/h was half of that at 20-30 km/h.

As described above, the smaller the β, the lower the energy consumption was and the energy consumption of $\beta < 1$ was lower than that of $\beta > 1$. Therefore, in the verification of the energy-saving acceleration mode, we selected three acceleration modes with $\beta < 1$, i.e., $\beta = 0.6$, 0.2, and 0.1. In order to avoid the influence of the acceleration time and initial velocity on energy consumption, we used the same acceleration time, initial velocity, and final velocity as during actual driving. The velocity curves before and after optimization for the four small scenes are shown in Fig. 14. The black curve in

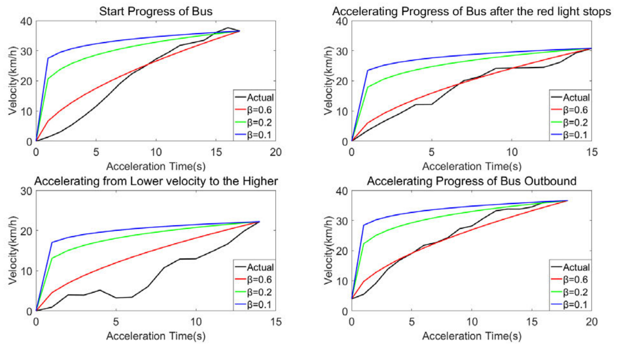


FIGURE 14. Velocities before and after optimization for the four small scenes.

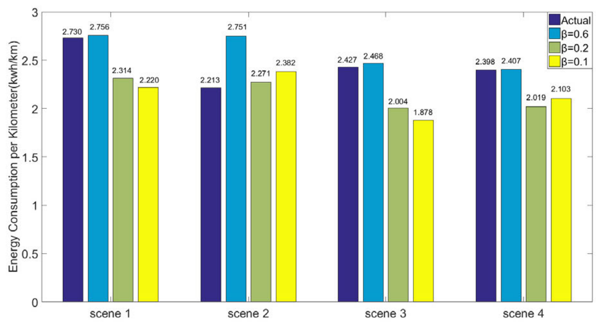


FIGURE 15. Energy consumption per kilometer before and after optimization for the four small scenes.

the figure represents the velocity curve before optimization, and the red, green and blue represent that after optimization, which are the velocity curves in the three acceleration modes of $\beta = 0.6$, 0.2, and 0.1 respectively.

The energy consumption per kilometer before and after implementing the acceleration strategy for the four small scenes are shown in Fig. 15. In the four scenes, when $\beta = 0.6$, the energy consumption per kilometer was higher after the optimization than the actual energy consumption. When $\beta = 0.2$ and $\beta = 0.1$, the energy consumption per kilometer was lower after the optimization. After using the energy-saving acceleration strategy, the energy consumption per kilometer decreased for Scenes 1, 3, and 4 and the percent decrease was between 12.32% and 18.7%. but in Scene 2, compared with actual data, the energy consumption per kilometer increased after optimization. This is a normal case, because the strategy adopted by the driver during the actual operation was random, and perhaps he unknowingly adopted a driving strategy with lower energy consumption. In Scene 2 and 4, we can see that "$\beta = 0.1$" is the smallest one, but its corresponding energy consumption per kilometer is not the smallest. It can be seen from Fig. 10 (b) and (c), when β is more than 0.2, the conclusion is that the smaller the β, the lower the energy consumption was. But when β is less than 0.2, the above conclusion is not applicative. There is no uniform law of energy consumption per kilometer with the change of β, and the value did not change much. Because when β is enough small, the acceleration was large at the initial stage of acceleration, this made some calculate error in

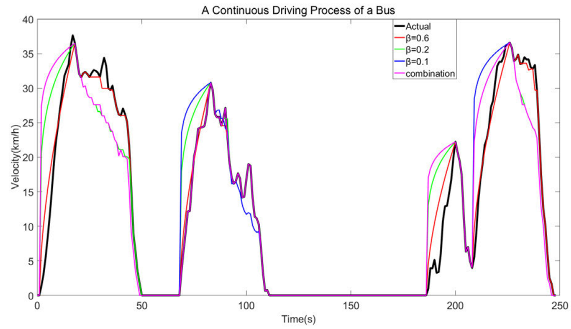


FIGURE 16. Velocity versus time before and after trip optimization for the entire trip.

simulation. In fact, it is not practical in actual driving when $\beta < 0.2$. From Fig. 10(c), for the cases of $\beta = 0.1$ and $\beta = 0.2$, sometimes the energy consumption per kilometer of $\beta = 0.2$ is greater than that of $\beta = 0.1$, but sometimes the result is opposite. Therefore, in Scenes 1 and 3 in Fig. 15, the energy consumption per kilometer of $\beta = 0.2$ is higher than that of $\beta = 0.1$, but in Scenes 2 and 4, that is opposite, both the two results are normal.

The energy-saving acceleration strategies reduced the energy consumption for the cases of the small scenes. Next, we evaluated the results for the continuous trip. Since the travel line was fixed (as shown in Fig. 13), the distance from the starting point to the intersection and the stations A and B was constant. The operation process of bus for each small scene contains three processes: the acceleration process, the deceleration process, and the velocity adjustment process between the two. In this paper, the optimization of acceleration process was predominantly considered, but for the same acceleration time, initial velocity, and final velocity, the distances were different for the different acceleration modes. Furthermore, the deceleration process affects the energy recovery when the vehicle brakes. In order to ensure that the effect of the deceleration on the energy consumption did not affect the energy-saving strategy, we ensured that the deceleration process was consistent with actual driving and only changed the velocity of the velocity adjustment process. In the simulation, we set the distance between the bus to the intersection and the stations A and B, though the velocity of deceleration process was unchanged. The simulation made a slight adjustment to the velocity of the velocity adjustment process so as to guarantee that the distance was unchanged. Fig. 16 shows velocity versus time before and after trip optimization. The black curve in the figure represents the velocity curve before optimization, and the others are the curve of after optimization. The three cases were $\beta = 0.6$, 0.2, and 0.1. We also used a combined case, in which the optimal solutions of the single-scene optimizations were used.

The velocity versus the distance before and after optimization is shown in Fig. 17. It is evident that in the different energy-saving acceleration modes, the difference in the distances between the bus arriving at the intersection and the bus station was small, indicating that the optimization ensured that the bus route and stations were fixed.

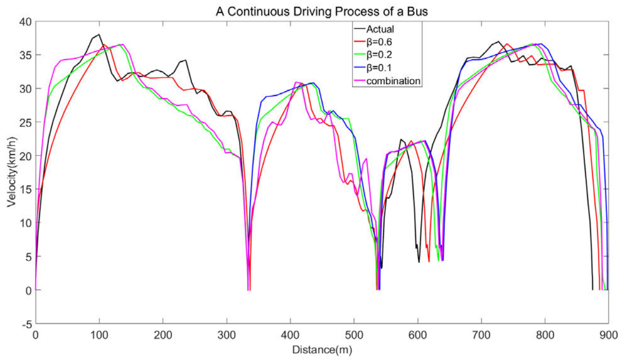


FIGURE 17. Velocity versus distance before and after trip optimization for the entire trip.

TABLE 2. The optimization results.

		Driving distance （km）	Difference in driving distance (%)	Energy consumption per kilometer (kWh/km)	Difference in energy consumption before and after optimization (%)
Before optimization		0.875		1.009	
After optimization	β=0.6	0.886	1.25	0.984	↓2.53
	β=0.2	0.896	2.41	0.983	↓2.56
	β=0.1	0.898	2.64	0.991	↓1.86
	Combination	0.889	1.70	0.994	↓1.51

The results before and after optimization are shown in Table 2.

As shown in Table 2, the difference in the total distance for the continuous trip before and after optimization was less than 3%, indicating that the optimization did not change the characteristics of the fixed distance of the bus. After optimization, the energy consumption per kilometer was lower than the actual driving data for the four cases but the percent decrease was lower (1.51%-2.56%) than that of the single small scenes. As described in the section on the energy-saving acceleration mode, the smaller the β, the lower the energy consumption was. When β decreased from 0.6 to 0.2, the energy consumption per kilometer was reduced but the difference was not large. When $\beta = 0.1$, since the acceleration in the initial stage of acceleration was very large, more energy was consumed; therefore, the energy consumption of the entire trip increased by 0.81% compared with $\beta = 0.2$. For the combination case, the combination of local optimal did not achieve the global optimal. On account of the different acceleration modes traveling different distances, and each small segment of the bus trip being fixed owing to the existence of stations and intersections, the driver will reach the intersection or station at a fixed distance after the acceleration process is finished. This will affect the velocity curve after the acceleration, thus affecting the energy consumption of the entire trip. The energy-saving acceleration mode may deteriorate the energy consumption of the deceleration process, ultimately leading to the result that the "local optimum cannot achieve global optimization".

After using the same verification method to implement the energy-saving driving strategy for the actual bus operation data, the average of the percentage difference in energy consumption was calculated; it was found that the proposed energy-saving driving strategy reduced the energy consumption per kilometer by 2.47%. This result was significantly lower than the energy savings of each small scene. The reason for this was that it included not only the acceleration process, but also the deceleration process and the approximate uniform velocity process during the operation of the bus. Since this paper does not involve the optimization of the deceleration strategy, as already discussed in the text above, in order to ensure that the bus reaches the intersection and the station at a fixed distance, we certified that the deceleration process was consistent with actual driving, only smoothing the process of velocity fluctuations between the acceleration and deceleration phases. Compared with the result obtained from before optimization, the change of velocity will also affect the energy consumption of the whole trip. This is the shortcoming of this study. Subsequent research will optimize the deceleration process and the transition process of acceleration and deceleration during bus operation to further verify the optimization results for the entire trip.

V. CONCLUSION

The main goal of this study was to determine an energy-saving driving strategy for a fully electric bus in Xi'an. By considering uniform motion on the platform of AVL CRUISE, it was found that the lowest energy consumption per kilometer occurred at 40 km/h. Naturally, the same energy was consumed at different velocities but at 40 km/h, the maximum driving range was obtained. These findings were further validated by the daily operational data. The velocity interval for lower energy, at which the engine efficiency was maximized and the energy consumption was minimized, was 30.001-35 km/h. Taking into account the uniform motion and traffic conditions, we expanded the interval to 30-40 km/h. The recommendation to the driver was to maintain the bus velocity as close to 30-40 km/h as possible depending on the traffic environment.

After finding the velocity interval for lower energy, there were different acceleration modes from the current velocity to the optimal velocity. We analyzed two cases; the acceleration characteristic parameters β, the acceleration time, and the acceleration initial velocity were chosen as variables of interest and the impact of different acceleration modes on the energy consumption were determined. It was found that the convex acceleration mode consumed less energy than the concave mode; when β is more than 0.2, the smaller the acceleration characteristic parameter β, the lower the energy consumption per kilometer was. when β is less than 0.2, there is no uniform law of energy consumption per kilometer with the change of β. Therefore, the energy-saving driving strategy was to maintain the velocity close to the velocity interval for lower energy. If acceleration and deceleration are unavoidable due to changes in the traffic environment, the convex acceleration mode should be chosen to accelerate from the current velocity to the optimal velocity. In the actual application, the implementation of driving strategy for driver is to track an optimal velocity curve, and try to keep the driving velocity consistent with the optimal velocity curve as much as possible.

After verifying the proposed energy-saving driving strategy, it was found that for the local acceleration process, the reduction in the percentage of energy consumption per kilometer was between 12.32% and 18.7% after optimization. For the entire trip, the energy consumption per kilometer was reduced by 2.47% after optimization. One limitation of this study is that the energy-saving driving strategy only considers the velocity interval for lower energy and the energy-saving acceleration mode. In actual driving, the decelerating process involves energy recovery during braking, which also affects energy consumption. In a future study, we will investigate this aspect, and adopt some intelligent algorithms (such as NSGA-II algorithm [46], Dual-objective Program [47], [48]) to solve the optimization problem.

The method of designing the energy-saving driving strategy mentioned in the paper applies to all buses. Owing to the fact that the actual bus data and technical parameters were used to calculate the energy consumption and range of bus, the velocity interval for lower energy mentioned in the conclusion may show a difference because of the replacement of technical parameters of the vehicle. However, the acceleration mode can be applied to all buses, namely, when β is more than 0.2, the smaller the acceleration characteristic parameter β, the less energy consumption per kilometer. When the readers are driving a different kind of bus, they need to obtain a new velocity interval to replace that in this paper's energy-saving driving strategy, but do not need to replace acceleration mode. In detail, they can obtain the velocity interval for lower energy by a simple method, that is to establish the model of other buses in simulation platform and set a cruise control mission of different velocity to get energy consumption per kilometer in each velocity, then they will draw a U-shaped curve of energy consumption varying with velocity. With the lowest energy consumption, they can obtain an optimal velocity. If they want to obtain a more practical velocity interval, some operational data are needed to collect and to analyze them by referencing the method in Section IV-A. According to this method, combined with the simulation results, they can obtain an velocity interval for lower energy close to the actual. For acceleration mode, they can directly use Eq. (17) to obtain the velocity curve of different acceleration mode. They only need to change initial velocity, final velocity and acceleration time according to actual demand. To obtain a lower energy consumption, they can take a smaller value of β. However, when β is less than 0.2, the initial acceleration is too large to be realized, which can not be considered in practice.

In China, during the operation of electric buses, the bus lanes are commonly occupied by other vehicles and non-motor vehicles. This results in frequent stop-and-go events and velocity changes. So the percentage of uniform velocity mode is too low during the entire trip. This results in high energy consumption. In order to reduce the energy consumption during the operation of electric buses and to increase the driving range, it is important to optimize the driving behavior but sometimes the driver cannot avoid accelerating and decelerating due to traffic conditions. Another effective method is to improve the management of the bus lanes and prohibit other vehicles and non-motor vehicles from driving in the bus lanes. This would improve the efficiency of bus operations, minimize frequent velocity changes, and increase the proportion of the uniform velocity mode, thereby reducing energy consumption and increasing the driving range.

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