

RESEARCH ARTICLE

Modeling and Simulation of a Regenerative Braking System for Pure Electric Vehicles Using MATLAB

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ABSTRACT – The birth of electric vehicles has solved the problems of excessive energy consumption and environmental pollution caused by the use of traditional cars. The implementation of policies has led to an increase in the number of individuals who have opted to purchase pure electric vehicles, but these types of cars are limited by battery capacity, and currently, most of their range is not high. To address the issue of insufficient endurance that affects the development of electric vehicles, this study proposes a modeling and simulation of a pure electric vehicle braking system based on MATLAB. This model first matches the power parameters of the pure electric vehicle braking system, and then establishes a simulation model for the wheels, driving motors, and battery energy. The matching simulation results are analyzed using MATLAB software. The results showed that the set matching parameters were compared with the matched simulation results, and the set targets were basically consistent with the simulation results. The power battery has shown good discharge performance, with most efficiency exceeding 90%. The battery state of charge value of the research model was higher than that of non-braking energy recovery and the optimal braking sensation strategy. This model improves the discharge efficiency of electric vehicle power batteries and optimizes the endurance of vehicles.

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1. INTRODUCTION

Since its inception, cars have brought great convenience to people's lives, but the use of traditional cars requires a large amount of oil resources, and the exhaust emissions have a negative impact on the environment [1-2]. With the proposal of the "dual carbon" goal and the promulgation of policies to support new energy vehicles (NEVs), consumers' acceptance of NEVs is gradually increasing, and public charging facilities are also constantly improving. Therefore, NEVs have shown strong development momentum in recent years and have become a highlight of China's automotive industry development [3-4]. One of the main drawbacks of electric vehicles (EVs) is their insufficient range. Although modern battery capacity and charging technology have made great progress, they still cannot compare with traditional fuel vehicles in terms of range [5]. The automotive braking system is the entire mechanical arrangement process of transmitting the power generated by the engine through a series of power transmissions to the wheels, which affects the power and endurance of the vehicle [6]. MATLAB, as a powerful programming and numerical computing platform, plays an important role in the modeling, simulation, and optimization of electric vehicle braking systems, providing strong support for the optimization design of electric vehicle braking systems. It supports the entire data analysis workflow, including directly collecting data into MATLAB, analyzing and visualizing this data, and exporting results [7]. Therefore, to improve the endurance of electric vehicles (EVE), this study proposes modeling and simulation (M&S) of pure EV braking systems (PEVBS) based on MATLAB.

This study analyzes the results of PEVBS M&S using MATLAB software. It innovatively uses power matching parameters to establish simulation models for wheels, drive motors, and battery energy, and analyzes the simulation results using MATLAB. The main contribution is to effectively improve the performance of electric car power batteries and optimize the EVEs. This study conducts research from four aspects. Firstly, it reviews the current research condition of PEVBS M&S based on MATLAB, and secondly, it conducts in-depth research on it. Then, the proposed research method is experimentally validated, and finally, the research content is summarized.

2. RELATED WORKS

Pure electric vehicles (PEVs) have problems such as low range, slow charging speed, and low energy recovery efficiency [8]. Jamadar et al. proposed regenerative braking systems and energy management systems to address the issue of mechanical braking causing friction in vehicles, which in turn reduces the EVs efficiency. This method has successfully improved the braking efficiency of EVs and reduced heat loss [9]. Mondal et al. proposed an improved parallel regenerative braking system to address the issues of weak endurance and low energy utilization of EVs. The system improved energy recovery rate through a constant brake pedal sensation, with a high regeneration ratio and reduced energy

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consumption [10]. He et al. proposed a model predictive control method for the anti-lock braking (ALB) system of PEVs, aiming to deal with the matter of wheel lock-up when transitioning from high to low adhesion road surfaces. This method had good performance in the process of ALB and was particularly suitable for low adhesion road conditions [11]. Biao et al. developed a regenerative braking strategy based on an optimization allocation algorithm to address the serious suppression of promotion and application of EVs due to their limited range. This strategy optimized the braking force distribution on the front and rear axles based on the variable ratio of braking intensity, improving the braking energy recovery efficiency by more than 51.9% while maintaining braking stability [12]. Zhang et al. designed a predictive regenerative braking control strategy based on swarm intelligence to solve the problem of current regenerative control systems being unable to recover braking energy as much as possible and improve economic benefits. This scheme took particle swarm optimization as the main strategy part, and improved the recovery rate of braking energy while ensuring vehicle safety [13].

MATLAB provides rich data import and export functions, which can easily handle various formats of data files [14]. Abdullah et al. designed a simulation model for variable and constant speed controllers of DC servo motors based on MATLAB to improve the optimal values of control unit parameters for improving the performance of DC servo motors. This model altered the system rise time and up/down bypass ratio [15]. Niu et al. proposed an electric vehicle modeling method and a fuzzy logic-based PID controller gain tuning method for the design and performance analysis of hybrid electric vehicles, considering a set of parameters that affect system performance. The model was developed in MATLAB/Simulink, and the feasibility of the proposed method was verified through simulation results [16]. Chukwunweike et al. analyzed the impact of network attacks on the power electronics hardware of electric vehicles to ensure their safety, and conducted simulations in MATLAB/Simulink. The results indicate that with appropriate preventive measures, the electrical hazards of electric vehicles can be significantly reduced [17]. Vinh et al. used sliding mode control technology to improve the torque ripple of electric vehicle switched reluctance motors and conducted simulation analysis in MATLAB/Simulink. The results show that the proposed sliding mode control technology has good torque control performance, and the constant sliding mode controller can reduce motor torque ripple and compensate for its nonlinear torque characteristics [18]. Ha introduced a control method for an electric vehicle permanent magnet synchronous motor based on a fuzzy logic controller, and evaluated the performance of the proposed method using MATLAB/SIMULINK simulation results. The results indicate that the proposed method can meet the output stator voltage required by the controller [19].

In summary, the impact of endurance on PEVs is still significant. Many scholars and scientists have designed a large number of improved models to solve the problem of EVE and improve the energy recovery efficiency of braking systems. However, these models take longer to solve during execution. Therefore, to address this issue, this study proposes PEVBS M&S based on MATLAB.

3. PEVBS MODELING AND SIMULATION

3.1 Power Parameter Matching of PEVBS

The power drive system of EVs is the link between the energy storage system (ESS) and the wheels. Its role is to convert the energy output by the ESS into mechanical energy, driving the vehicle to overcome various rolling, air, acceleration, and hill-climbing resistances [20-21]. The driving characteristics determine the main performance indicators of a car, which convert kinetic energy into electrical energy during braking and feed it to the ESS. The entire EV system has two parts: an electric motor drive system and a mechanical transmission mechanism. The tram system mainly consists of an electric motor, a power converter, a controller, various detection sensors, and a power supply, as shown in Figure 1.

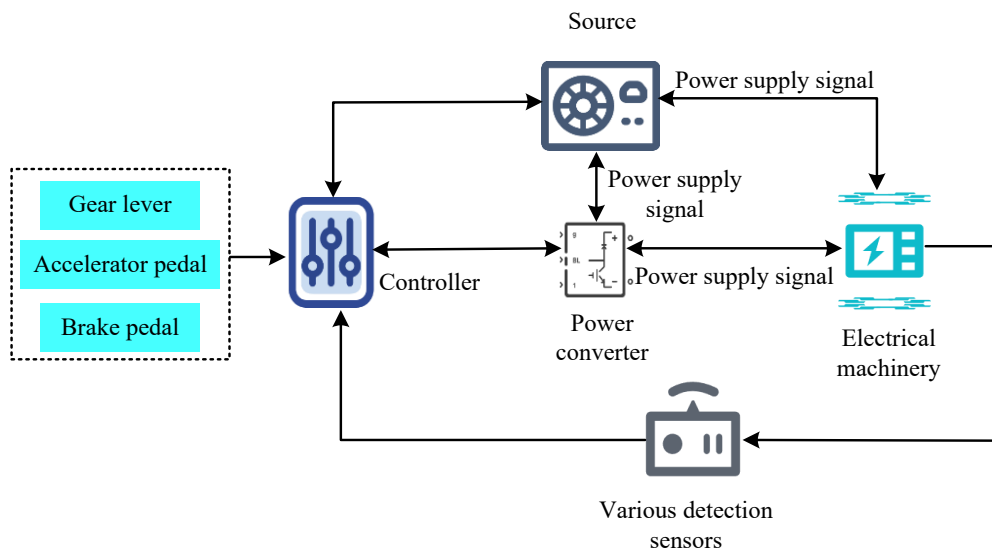


Figure 1. Basic composition diagram of electric motor drive system

The power performance of an EV is the mean driving velocity that a vehicle can achieve when driving in a straight line on a good road surface, determined by the longitudinal external force it is subjected to [22]. It is mainly evaluated by three elements: maximum speed, acceleration performance, and climbing ability (MS-AP-CA). Power parameters mainly include motor selection and parameter matching, as well as battery selection and parameter matching. The former should consider factors such as the speed, efficiency, mass size, and cost of the electric motor, which are influenced by MS-AP-CA. The latter is affected by climbing ability. The research roadmap for matching the power parameters of the braking system is shown in Figure 2.

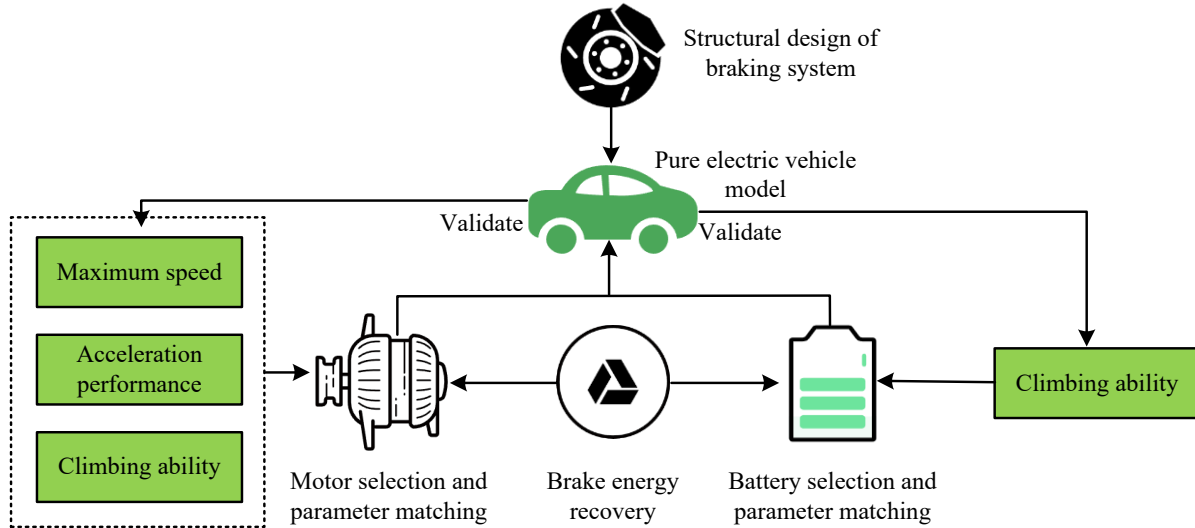


Figure 2. Roadmap for research on power parameter matching of braking systems

In EVs, the drive motor replaces the engine and generator in traditional cars. The driving motor can convert the energy from electrical into mechanical to drive the car, or act as a generator to convert mechanical into electrical and store it in the power battery [23]. Therefore, the driving motor has greatly affected the various performance of EVs. The basic parameters of EV drive motors include rated torque, starting torque, maximum torque, locked rotor torque, etc. When an EV is traveling at a constant speed on the road at its highest speed, the power of the motor at its highest speed is selected as the motor parameter. The calculation of motor power P_1 is given in Eq. (1).

$$P_1 = \frac{1}{\eta_T} \left(\frac{Gfu_{a\max}}{3600} + \frac{C_D Au_{a\max}^3}{76140} \right) \tag{1}$$

In Eq. (1), η_T represents transmission efficiency. The research is based on an SUV electric vehicle produced in China, and according to the official basic parameters of the vehicle, its transmission efficiency is 0.9. $u_{a\max}$ is the maximum speed. f is the rolling friction coefficient. G means the gravity of an EV. C_D is the air resistance coefficient. A denotes the windward area. When the construction is carried out on this section of the road, if the EV cannot travel at a uniform speed, the acceleration performance of the car is selected as the motor parameter. At this time, the power P_2 of the motor is expressed in Eq. (2).

$$P_2 = \frac{1}{\eta_T} \left(\frac{Gfu_{a\max}}{1.5 \times 3600} + \frac{C_D Au_{a\max}^3}{2.5 \times 76140} + \frac{\delta m}{2 \times 3600} \frac{u_m^2}{t_m} \right) \tag{2}$$

In Eq. (2), m represents the quality of the car. t_m and u_m are the acceleration time and final speed of the car. δ represents the rotational mass conversion coefficient. When driving on uphill roads, the climbing performance of the car serves as a motor parameter. Assuming that the speed of the car is constant when climbing, the power P_3 of the EV at this time is given by Eq. (3).

$$P_3 = \frac{1}{\eta_T} \left(\frac{Gf \cos \alpha}{3600} u_a + \frac{G \sin \alpha}{3600} u_a \right) \tag{3}$$

In Eq. (3), u_a represents the vehicle speed, $\alpha = \arctan i$, i is the slope of the car when going uphill. However, to satisfy the design needs of the car, the selection of the driving motor must simultaneously meet the three indicators of MS-AP-CA. At this time, the power of the motor is given by Eq. (4).

$$P_m = \max \{P_1, P_2, P_3\} \tag{4}$$

Motor speed is an important parameter during motor operation, which is meaningful for the performance and application of the motor. As the speed of the motor increases, its output power also increases. However, when the speed exceeds a certain value, the output power will begin to decrease. The rated speed calculation is Eq. (5).

$$n_e = \frac{n_{max}}{\beta} \tag{5}$$

In Eq. (5), n_{max} is the maximum rotational speed. β is the ratio of n_{max} to the rated rotational speed. As the power source of NEVs, the power battery is the most important system in the entire vehicle, which directly determines the vehicle's range. This study selects the number of batteries as the main parameter for battery matching. The premise for calculating the battery capacity of EVs is that the EV is traveling at a uniform velocity on a flat road surface. When the EV is driving at a uniform speed, all the power provided by the motor is in Eq. (6).

$$P = \frac{1}{\eta_r} \left(\frac{Gf}{3600} v + \frac{C_D A}{76140} v^3 \right) \tag{6}$$

In Eq. (6), v is the speed of the car when driving at a constant speed. When the car travels at a constant speed of l kilometers per hour, the energy required by the car is given by Eq. (7).

$$W = P \left(\frac{l}{v} \right) \tag{7}$$

In Eq. (7), P represents all the power provided by the motor. W represents the energy required for a car to travel l kilometers. The batteries used in EVs directly affect the capacity of the batteries, thereby affecting the vehicle's endurance. The batteries for EVs must meet the endurance requirements, as shown in Eq. (8).

$$W = N \frac{\eta_{DOC} E_0 C}{1000} \tag{8}$$

In Eq. (8), η_{DOC} is the depth of discharge, C is the capacitance of a single battery, E_0 is the operating voltage of a single battery, and N is the number of batteries.

3.2 Establishment and Simulation of PEVBS Model Based on MATLAB

After matching the dynamic parameters of PEVBS, the PEVBS model is established and simulated based on the matching results. MATLAB Simulink is a mathematical M&S software widely used in the fields of science and engineering. It provides rich tools and functions for solving various mathematical and engineering problems. In the research and development of PEVs, MATLAB Simulink is often used to establish dynamic models of EVs, design and simulate control strategies, and other aspects. To better study and master the power and economy of EVs, this paper constructs a model on the basis of the MATLAB Simulink platform, which includes modules such as battery, motor, vehicle longitudinal dynamics, control strategy, and driver. The method of editing the .m script files is adopted, making input data easier to manage. The constructed model is a completely open model, with no modules encapsulated. The electric vehicle simulation model is shown in Figure 3.

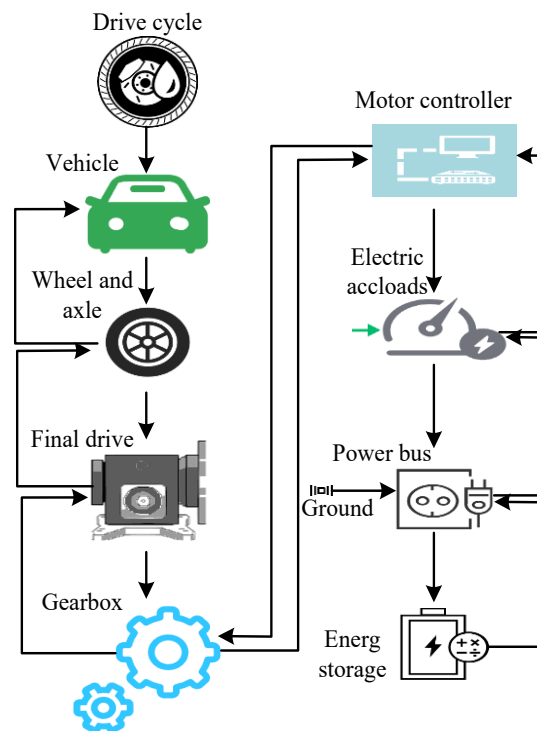


Figure 3. Electric vehicle simulation model

Figure 3 provides a detailed description of the main components of electric vehicles and their working relationships with each other. The entire system is connected through a power bus, ensuring that energy flows from the energy storage system to the motor controller, and then is transmitted to the wheels and axles through the electric actuators and final drive system to drive the vehicle. Meanwhile, the operational status and performance data of the vehicle can be simulated and evaluated through driving cycles. When conducting a simulation, the forces of vertical, longitudinal, and lateral, and return torque experienced by the tires are vital in the smoothness, handling stability, and safety of the car. As a result of the complex structure of tires and their nonlinear dynamic performance, selecting a tire model that is practical to utilize is the key to building a model and conducting dynamic simulations. The combination formula of trigonometric functions is used to fit tire test data, as shown in Eq. (9).

$$Y(x) = D \sin \left[C \arctan \left[Bx - E \left(Bx - \arctan(Bx) \right) \right] \right] \tag{9}$$

In Eq. (9), Y and x are the output and input variables. B , C , D , and E are the stiffness, shape, peak, and curvature factors. In practical applications, offset is caused by the turning effect of the ply, lateral force, or rolling resistance, and vertical offset S_y and horizontal offset S_h are usually introduced. The tire longitudinal force F_1 is given by Eq. (10).

$$F_1 = D \sin \left[C \arctan \left(Bx_1 - E \left(Bx_1 - \arctan(Bx_1) \right) \right) \right] + S_y \tag{10}$$

By Eq. (10), the tire lateral force is obtained as in Eq. (11).

$$F_2 = D \sin \left[C \arctan \left(Bx_2 - E \left(Bx_2 - \arctan(Bx_2) \right) \right) \right] + S_h \tag{11}$$

In Eq. (11), F_2 is the lateral force of the tire. Tires are the only parts in a vehicle that come into contact with the ground, bearing the weight of the entire body and providing power to the vehicle [24]. The goal of the power model is to simulate the working condition of the wheels, obtain the desired torque and speed, and use the main reducer to reduce and increase torque, finally obtaining the vehicle's speed and the driving torque of the wheels, thereby achieving the driving of the vehicle. The wheel power distribution model is shown in Figure 4.

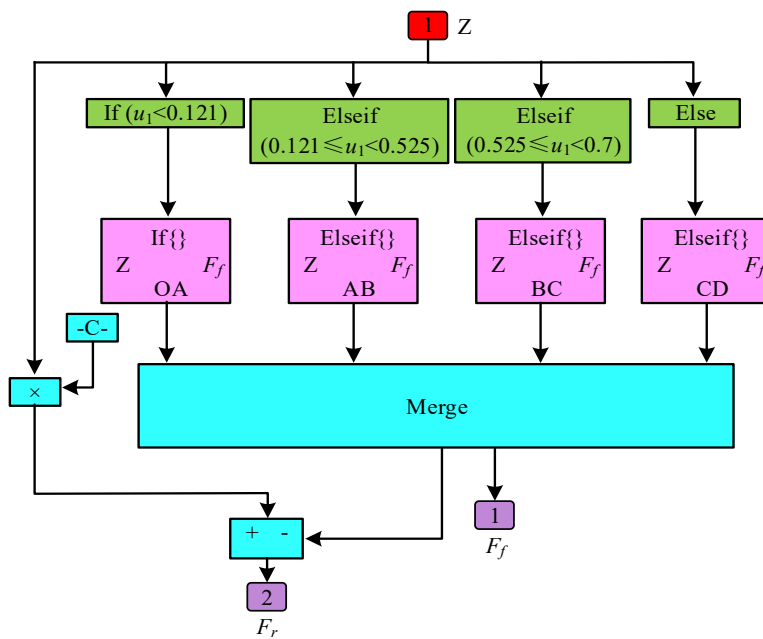


Figure 4. Wheel power distribution model

The drive motor is the heart of an EV, providing full body power to the EV, converting electrical energy into kinetic energy, driving the operation of the EV, and determining its performance. According to the performance of the battery itself, it is impossible to store all electrical energy in the battery, and kinetic energy cannot be fully converted into electrical energy. At this point, the maximum power P_{gen_max} generated by the motor is in Eq. (12).

$$P_{gen_max} = \frac{T_{reg_max} \cdot n}{9550} \cdot \eta \tag{12}$$

In Eq. (12), n is the motor speed. η represents the total power generation efficiency, and T_{reg_max} is the maximum braking torque. The max-braking force generated by the motor is given by Eq. (13).

$$F_{reg_max} = \frac{T_{reg_max} \cdot i_0}{r \eta_T} \tag{13}$$

In Eq. (13), η_r is the transmission efficiency. r is the wheel radius. i_0 is the main reduction ratio. The simulation model of the motor includes three modules: maximum torque and power, motor loss, and current. The input parameters include total battery pressure, motor speed, and motor requested torque. The output parameters include motor current and motor output torque. The architecture diagram of the motor simulation model is shown in Figure 5.

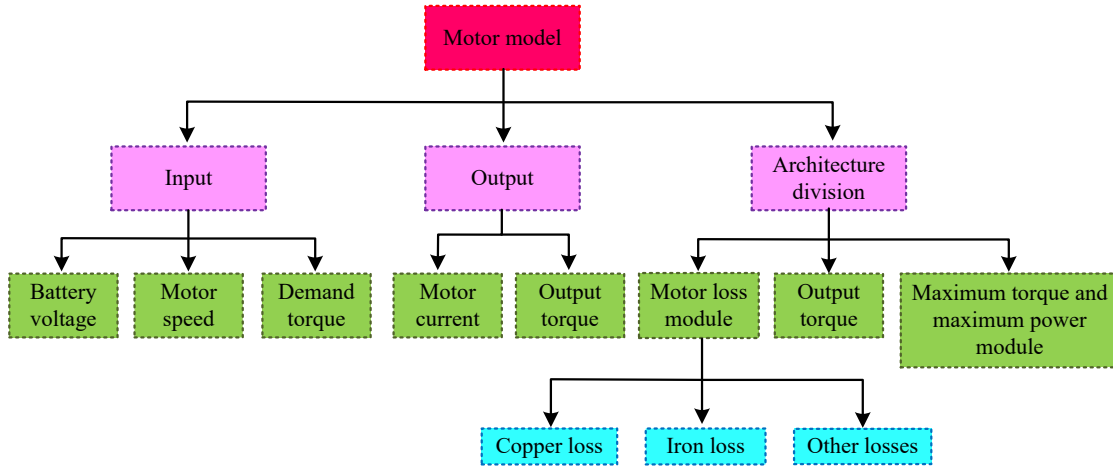


Figure 5. Architecture diagram of the motor simulation model

The battery is the core component of ESS in EVs, and accurately establishing a battery model is crucial for achieving precise energy management. Energy management strategy refers to the strategy of optimizing the distribution and utilization of energy during the operation of EVs. The optimized strategy can greatly enhance the performance and range of EVs. When the tram travels at a constant speed of S kilometres per hour, the energy required for the battery is given by Eq. (14).

$$W = \frac{P_4 S}{u} \tag{14}$$

In Eq. (14), P_4 and u are the power and speed of the tram at a constant speed. At this point, the capacitance of the battery pack is given by Eq. (15).

$$C = \frac{1000W}{U\eta_{bat}} \tag{15}$$

In Eq. (15), U is the voltage, η_{bat} is the discharge depth, and W represents the energy needed for the battery to travel S kilometres. The main steps in establishing a battery simulation model are four steps. Step 1 is to calculate the battery's charge level. Steps 2 and 3 are to calculate the battery's state of charge (SOC) and voltage. Finally, to calculate the correspondence between external parameters. The battery model diagram is Figure 6.

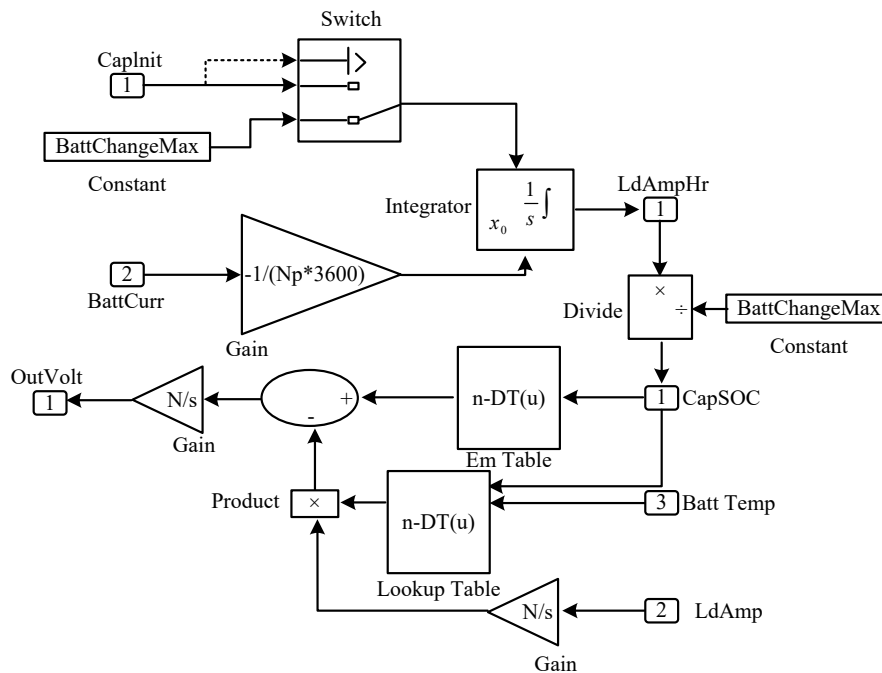


Figure 6. Battery energy simulation model

4. EFFECT ANALYSIS OF PEVBS MODELING AND SIMULATION BASED ON MATLAB

4.1 Experimental Parameter Setting and Efficiency Analysis

When establishing a wheel simulation model in this study, three parameters are used: wheelbase (m), wheel radius (m), and rolling resistance coefficient. When establishing a simulation model for the drive motor, three parameters are used: torque range (Nm), speed range (r/min), and motor mass (kg). When establishing a battery energy simulation model, four parameters are used: battery quantity, battery voltage (V), total battery mass (kg), and capacitance variation with temperature (Ah). To verify whether the power parameter matching of the electric vehicle braking system has achieved the expected design goals, a modular approach is adopted to design a simulation model. The software selected for the experiment is MATLAB Simulink. The experiment first imports Simulink simulation data, and then uses MATLAB to draw the curve of the model. In the experiment, the parameter settings for the electric vehicle wheels, drive motor, and power battery are shown in Table 1. As shown in Table 1, the study set the rolling resistance coefficient of the wheels to 0.016, the wheelbase to 2.67m, and the radius to 0.35m. Set the mass of the drive motor to 55kg, the torque to [-300300] Nm, and the speed to [06000] r/min. Set the battery capacity of the power battery to 95Ah, the number of batteries to 84, the total mass to 32kg, and the voltage to 3.5V.

Table 1. Parameter settings

Wheel simulation model		Drive motor simulation model		Battery energy simulation model	
Name	Variable	Name	Variable	Name	Variable
Rolling resistance coefficient	0.016	Motor mass (kg)	55	Capacitance varies with temperature (Ah)	[95 95 95]
Wheelbase (m)	2.67	Torque range (Nm)	[-300,300]	Number of batteries	84
Wheel radius (m)	0.35	Speed range (r/min)	[0,6000]	Total mass of battery (kg)	32
/	/	/	/	Battery voltage (V)	3.5

Figures 7 (a) and (b) show the statistical results of comparing the power of the driving motor with the change of acceleration time under different driving speeds and the same climbing slope. In Figure 7 (a), the power of the driving motor gradually decreases with time. Under the same acceleration of 10 seconds, when the tram accelerates from 0 km/h to 100 km/h, the driving power of the tram decreases slowly, from 100 kW to 89 kW. When the tram accelerates to 50 km/h, the driving power of the tram decreases rapidly, decreasing by 24 kW. In Figure 7 (b), the power of the driving motor grows with the continuous growth of the climbing slope. When the climbing slope increases from 0% to 30%, the power of the driving motor increases by 80 kW, from 5 kW to 85 kW. The speed of the tram decreases as the climbing slope increases. When the climbing slope is 0% and 30%, the speed of the tram is 178 km/h and 58 km/h.

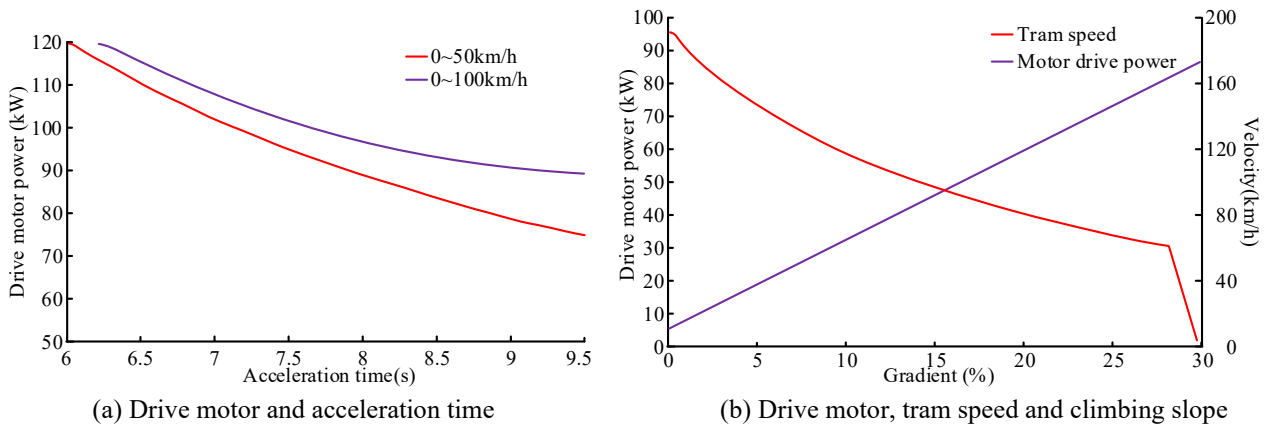


Figure 7. The variation of motor power over time and the variation of motor power and tram speed with slope

At different driving speeds, Figure 8 (a) shows the variation of driving resistance and driving force of EVs with vehicle speed, while Figure 8 (b) shows the variation of motor driving force and slope resistance with vehicle speed. In Figure 8 (a), the driving resistance of the EV increases continuously with the increase in car speed. When the speed is 0 km/h, the driving resistance of the tram is 240 N, and the driving force is 1780 N. When the speed increases to 137 km/h, the driving resistance is 830 N, and the driving force is 680 N. In Figure 8 (b), the driving force decreases continuously with the increase of vehicle speed, while the slope resistance rises with the rise of speed. When the speed is 0 km/h, the maximum driving force of the motor is 5350 N, the minimum resistance on a 5% slope is 2100 N, and the maximum resistance on a 25% slope is 4650 N. When the speed increases to 130 km/h, the motor driving force decreases to 2600 N, and the 5% and 25% slope resistance continue to increase, reaching 2350 N and 5000 N, respectively.

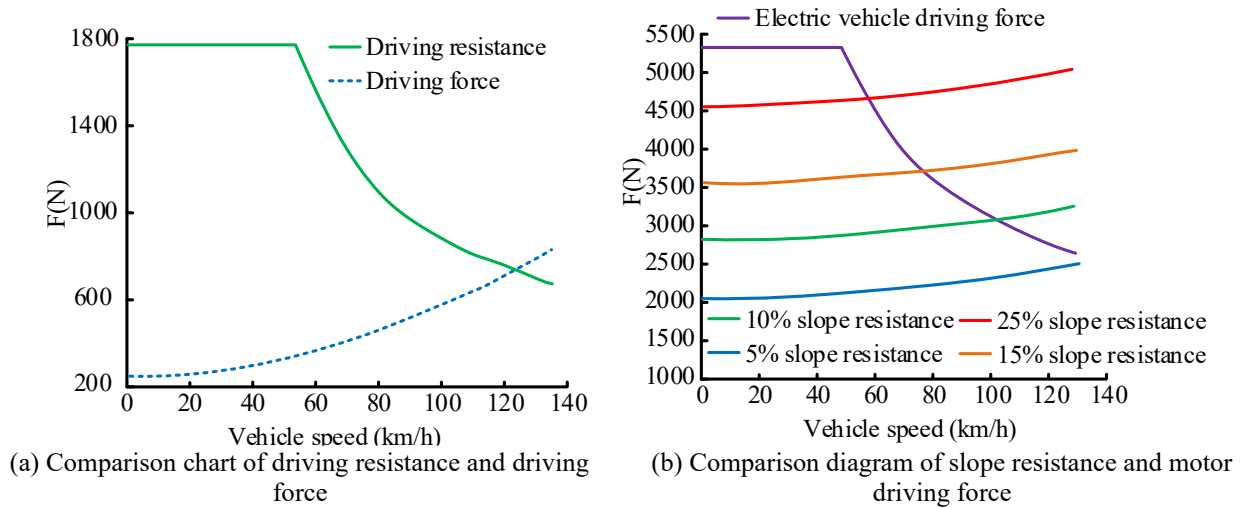


Figure 8. Changes in tram power and resistance over time

4.2 Quality Analysis of PEVBS Modeling and Simulation Based on MATLAB

This study sets three indicators for evaluating the power performance of EVs, namely MS-AP-CA. Table 2 compares the three indicators with the matched simulation results. In Table 2, the results of vehicle speed are basically consistent with the set indicators, meeting the design requirements. When the vehicle speed accelerates from 0km/h to 100 km/h or from 50 km/h to 100 km/h, the simulation results of the acceleration time are slower than the set acceleration time by 0.5 s and 2.9 s, respectively. When the vehicle speed accelerates from 0km/h to 50km/h, the simulation result of the acceleration time is 2.6 seconds faster than the set time. The simulation results of the vehicle's range and maximum speed are 203.3 km and 126.5 km/h, respectively, which meet the design requirements. The maximum climbing slope is initially set at 25%, and the simulated maximum climbing slope result is 24.1%. The vehicle's climbing ability is basically consistent with the set indicators.

Table 2. Comparison between target setting and simulation results

Name	Design objectives	Simulation result
Acceleration time s (0-100km/h)	18	18.5
Acceleration time s (0-50km/h)	8	5.4
Acceleration time s (50-100km/h)	10	12.9
Maximum speed (km/h)	200	203.3
Driving range (km)	120	126.5
Maximum Climbing Slope (%)	25	24.1

At different times, Figure 9 (a) shows the variation of the power battery of an EV over time, and Figure 9 (b) shows the result of the motor torque over time. In Figure 9 (a), the power battery exhibits good discharge performance. When the time is 230 s, the discharge efficiency is the lowest at 80%, and most of the other time efficiencies are above 90%. When EVs use regenerative braking force during braking, the torque is negative, and when climbing at a constant speed or acceleration, the torque is also negative. In Figure 9 (b), the torque of the driving motor continuously changes over time, showing a trend of linear fluctuations. When an EV is braking, the maximum torque of the driving motor is 297 Nm, and the maximum torque when climbing at a constant speed or acceleration is 49 Nm.

The results of comparing the battery state of charge (CBS) values of the research model with other strategies under different initial values of CBS are shown in Figure 10. In Figure 10 (a), when the initial CBS value is 60%, the CBS value of the study model is higher than that of the non-braking energy recovery (NBER) and optimal braking sensation strategy (OBSS). The CBS value decreases continuously with time, with the lowest CBS value of the research model being 57.3%, the lowest NBER being 56.6%, and the lowest OBSS being 56.9%. In Figure 10 (b), when the initial CBS value is 95%, the CBS value of the study model is higher than that of NBER and OBSS. The CBS value decreases continuously with time, and the lowest CBS value of the research model is 67%, NBER is 64%, and OBSS is 62%.

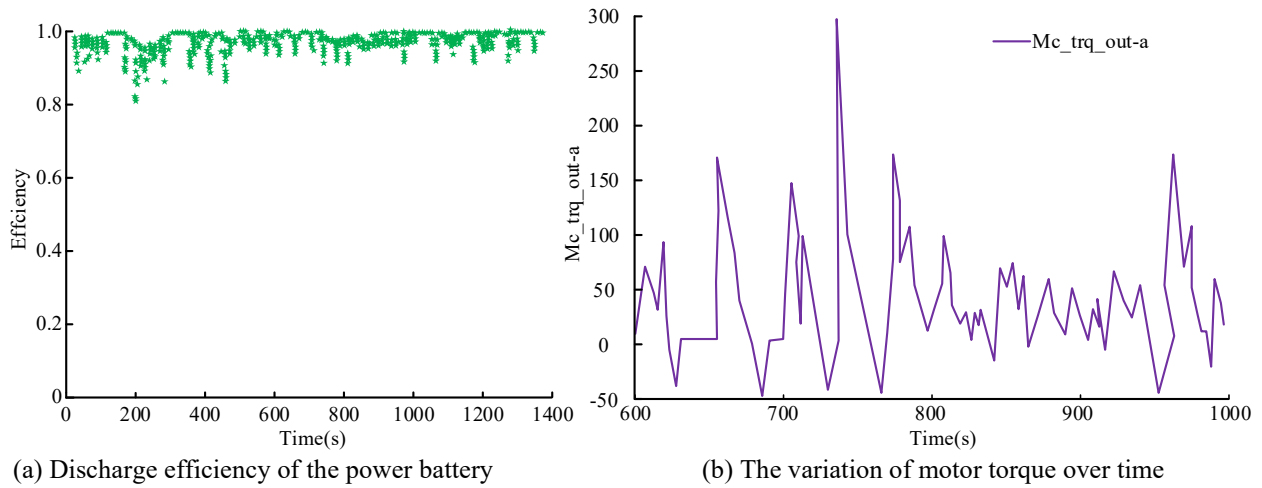


Figure 9. Diagram of the variation of discharge efficiency of power batteries and motor torque over time

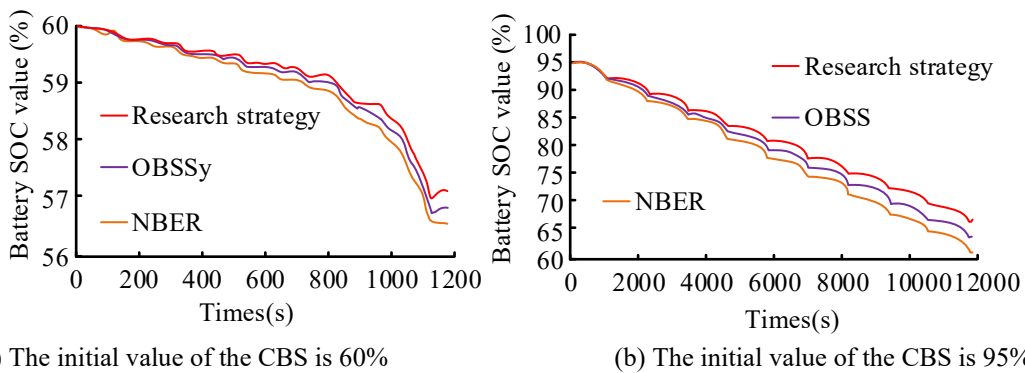


Figure 20. Comparison curves of CBS values for different initial batteries

5. CONCLUSION

To handle the issue that the use of traditional cars requires numerous petroleum resources and the negative impact of exhaust emissions on the environment, this study proposed PEVBS M&S based on MATLAB. This study first conducted dynamic parameter matching of PEVBS. The power performance of EVs was mainly evaluated by MS-AP-CA. Secondly, the PEVBS model was established and simulated based on the matching results. This study compared the three indicators for evaluating the power performance of EVs with the matched simulation results, and the set goals were basically consistent with the research results. The results were divided into 203.3 km/h, 126.5 km, and 24.1%. The power battery has shown good discharge performance. When the time was 230 s, the discharge efficiency was the lowest at 80%, and most of the other time efficiencies were above 90%. Compared with other strategies, the CBS value of the research model was higher than that of the NBER and OBSS models. When the initial CBS value was 95% and the time was 12,000 seconds, the lowest CBS value was 67%. The simulation results of the research model meet the design requirements, further improving the efficiency of EV power batteries, and the recovery of braking energy is higher than other methods. All variables in MATLAB are in vector form, but for a single element or when processing a vector as a single loop variable, the loop execution speed is slower. This is because MATLAB's vectorization operation can directly manipulate arrays using built-in functions, thereby reducing code execution time. But for individual elements in the vector, this advantage no longer exists, and each element needs to be processed separately, which increases the complexity of the calculation. Therefore, in future research, further exploration should be conducted on how to optimize MATLAB's vectorization operations or utilize parallel computing techniques to accelerate the individual processing of vector elements, in order to improve overall simulation and computational performance.

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CONFLICT OF INTEREST

The authors declare no conflicts of interest.

AUTHORS CONTRIBUTION

X.X.L. processed the numerical attribute linear programming of communication big data, and the mutual information feature quantity of communication big data numerical attribute was extracted by the cloud extended distributed feature fitting method. Y.J.W. combined with fuzzy C-means clustering and linear regression analysis, the statistical analysis of big data numerical attribute feature information was carried out, and the associated attribute sample set of communication big data numerical attribute cloud grid distribution was constructed. X.X.L. and Y.J.W. did the experiments, recorded data, and created manuscripts. All authors read and approved the final manuscript.

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