

Based on AVL-CRUISE Hybrid and Electric Vehicle Simulation and Highway Circle Power Consumption Factor Analysis

Xuanbo Liu

*Harbin University of Science and Technology, Harbin, China
15504529967@163.com*

Abstract: With the rapid advancement of science and technology and the gradual depletion of global energy resources, reducing energy consumption has emerged as a critical challenge. Hybrid and electric vehicles (HEVs and EVs) are playing an increasingly pivotal role in addressing this issue, necessitating further development and exploration. In this study, I employed AVL-CRUISE software to conduct vehicle simulations and data modeling, followed by a comprehensive performance evaluation of both hybrid and electric vehicles. Simulations were performed under the Highway driving cycle, revealing that the vehicle achieved a maximum speed of 134.88 km/h, a 0-100 km/h acceleration time of 11.49 seconds, and a maximum climbing capacity of 40.4%. These results demonstrate that hybrid and electric vehicles not only meet but also exceed performance expectations. Beyond the simulation outcomes, I also investigated key factors influencing vehicle performance, including vehicle mass, air resistance, and transmission ratio. Using MATLAB, I conducted a detailed analysis of the relationship between these factors and energy consumption, deriving correlation equations to describe these interactions. Through extensive data analysis and model fitting, this research has deepened our understanding of hybrid and electric vehicles. The findings not only contribute to the field but also hold significant potential for further advancements in the development of energy-efficient transportation solutions.

Keywords: AVL-Cruise, Simulation, hybrid and electric vehicles, cycle

1. Introduction

With the ongoing depletion of fuel resources and the escalating environmental pollution caused by conventional fuel vehicles, global awareness of these critical issues has significantly increased. Consequently, there has been a growing emphasis on the development of hybrid and electric vehicles (HEVs and EVs) as sustainable alternatives [1]. These vehicles not only enhance energy efficiency but also contribute to reducing air pollution, making research in this field indispensable [2]. Such studies provide essential insights for optimizing vehicle performance and energy consumption, offering viable solutions to pressing environmental and energy challenges [3].

Advanced simulation tools, such as AVL-CRUISE [4], play a pivotal role in modeling the dynamic performance of vehicles, enabling the simulation of driving cycles and vehicle operations under diverse environmental conditions. This study focuses on key performance metrics in vehicle dynamics, including top speed, acceleration time, and maximum hill-climbing ability. The simulation

results reveal that the vehicle achieves a maximum speed of 134.88 km/h, a 0-100 km/h acceleration time of 11.49 seconds, and a maximum climbing capacity of 40.4%. By integrating AVL-CRUISE with MATLAB, I developed a mathematical equation that elucidates the relationship between these parameters and the overall performance of hybrid and electric vehicles.

This research combines robust data analysis with advanced model fitting techniques to deepen our understanding of the factors influencing the performance of HEVs and EVs. Through this comprehensive approach, I aim to provide actionable recommendations that can guide the design and development of more efficient, energy-saving, and environmentally friendly hybrid and electric vehicles [5]. This work not only advances the field but also supports the broader goal of transitioning to sustainable transportation solutions.

2. Dynamic simulation

2.1. Vehicle Motion Equation

To analyze the dynamic performance of a vehicle, it is necessary to grasp the external force, driving force and driving resistance acting on the vehicle along the driving direction[6].

The driving force of the car is the torque generated by the car starting to pass through the drive train to the driving wheels. The relationship between the driving force of the car and the engine torque is as follows:

$$F_t = \frac{T_{tq} i_g i_0 \eta_T}{r} \quad (1)$$

Where F_t represents the driving force of the car, T_{tq} represents the engine torque, i_g represents the transmission ratio, i_0 represents the transmission ratio of the main reducer, η_T the mechanical efficiency of the drive train, and r is the wheel radius.

The working speed of the engine has an effect on the power and torque emitted by the engine, and their relationship is also an important basis for calculating vehicle performance. The power provided by the motor is stable in the unstable condition of the acceleration process, and the torque is stable in the stable condition of the low speed process. The relation between motor power and torque is as follows

$$P_e = \frac{T_{tg} n}{9550} \quad (2)$$

Where P_e represents the power of the motor, T_{tg} represents the torque of the motor, and n is the speed of the motor.

The relationship between engine speed and vehicle speed is as follows:

$$u_a = \frac{0.377 r n}{i_g i_0} \quad (3)$$

Where u_a is the speed of the car.

The resistance that cars generally need to overcome in the process of road driving is rolling resistance, air resistance, slope resistance and acceleration resistance.

The rolling resistance of the vehicle is the resistance caused by the contact between the tire and the road surface during the driving process.

$$F_t = mgf \cos \alpha \quad (4)$$

Where F_t is the rolling resistance of the car; m is the mass of the car; f is rolling resistance coefficient; α is the slope Angle.

The air resistance is the component of the air force in the driving direction when the car is driving in a straight line. It has an important relationship with the projected area of the driving direction of the car, the relative speed of the car and the air density. The relationship between the air resistance is as follows:

$$F_W = \frac{C_D A u_a^2}{21.15} \quad (5)$$

Where F_W is the air resistance of the car; C_D is the air resistance coefficient; A is the windward area; u_a is the relative speed, which is the speed of the car when there is no wind.

Slope resistance is the component force of gravity along the ramp when the car is driving uphill, and its relationship is as follows:

$$F_i = mgsina \quad (6)$$

Where F_i is the slope resistance of the car.

Acceleration resistance is the inertial force needed to overcome its mass acceleration when the car is driving, and its relationship is as follows:

$$F_j = \frac{\delta m du}{dt} \quad (7)$$

Where F_j is the acceleration resistance of the car; δ is the conversion coefficient of vehicle rotating mass; du/dt is the travel acceleration.

Therefore, the overall driving equation of the car is:

$$\frac{T_{tq} i_g i_o \eta_T}{r} = mgf \cos \alpha + \frac{C_D A u_a^2}{21.15} + mgsina + \frac{\delta m du}{dt} \quad (8)$$

The battery efficiency is the ratio of the total energy provided by the battery to the energy required for the battery to be fully charged, and the relationship is as follows [7]:

$$\eta_b = \frac{E_{dis}}{E_{chg}} = \frac{E - R_{int} i_b}{E + R_{int} i_b} \quad (9)$$

Where η_b is the cell efficiency; E_{dis} provides energy to the battery for the load; E_{chg} provides the energy needed for the battery from exhaustion to full charge; E is the electromotive force of the power supply; R_{int} is variable equivalent internal resistance; i_b indicates the battery current.

The efficiency of the drive motor system is the ratio of the output power of the motor to the input power, which includes two parts: motor controller efficiency and mechanical efficiency. The efficiency relation of the drive motor system is as follows:

$$\eta_m = \eta_{mj} \eta_{mc} = \frac{T_m \omega_m}{i_b U_b} \quad (10)$$

Where η_{mj} is the mechanical efficiency of the driving motor; η_{mc} is the drive motor controller efficiency; T_m is the motor output torque; ω_m is the angular speed of the motor rotor; U_b indicates the battery terminal voltage.

The energy consumption rate of electric vehicle under constant speed driving condition is:

$$C = \frac{Q_t}{s_t} \quad (11)$$

Where C is the energy consumption of the tram under constant speed conditions, Q_t is the electric energy consumed by the point drive system in constant speed conditions, and s_t is the driving range of the electric vehicle under constant speed conditions.

The total power relationship required for the engine and the drive motor [8].

$$P_h = \frac{1}{\eta_T} \left(\frac{Gfu_a}{3600} + \frac{Giu_a}{3600} + \frac{c_D Au_a^3}{76140} + \frac{\delta mu_a}{3600} \frac{du}{dt} \right) \quad (12)$$

Where P_h is the total power required by the engine and drive motor.

When the engine drives the motor to generate electricity, the electric energy generated is equivalent to the equivalent fuel consumption consumed by the engine according to the same load and efficiency, and the equivalent fuel consumption consumed by the drive motor is:

$$Q_C = \sum \frac{\alpha_i P_{hi} \eta_{gi}}{\eta_{ei} E_D} \quad (13)$$

Where Q_C is the equivalent fuel consumption consumed by the driving motor; α_i is the power distribution coefficient formulated by the energy management strategy; η_{gi} is the power generation efficiency of the drive motor; η_{ei} is the engine efficiency

The formula for the battery energy stored by the motor to drive the motor to generate electricity is:

$$W_c = \sum \alpha_i P_{hi} \eta_{gi} \eta_{ci} \quad (14)$$

The W_c is the battery electric energy stored by the motor to drive the motor to generate electricity; η_{ci} is the battery charging efficiency.

The electric energy relationship of the power battery stored by the drive motor through the braking energy recovery is as follows:

$$W_b = \sum \varphi_i P_{hi} \eta_{gi} \Delta t \quad (15)$$

In the formula, W_b is the power storage battery electric energy recovered by the drive motor through the braking energy; Proportional coefficient of braking energy recovery efficiency factor of φ_i drive motor.

Under the whole cycle condition, the fuel consumption of 100 km and the engine fuel consumption, the equivalent fuel consumption of the auxiliary drive of the drive motor and the equivalent fuel consumption of the net increase of electric energy of the battery are related as follows:

$$Q_Z = \sum Q_e + \sum Q_t + Q^\tau \quad (16)$$

Where $\sum Q_e$ is the sum of fuel consumption of all engines in the whole cycle; $\sum Q_t$ is the sum of the equivalent fuel consumption of all drive motor auxiliary drives in the whole cycle. Q^τ adds a net amount of energy to the battery's equivalent fuel consumption.

2.2. Select Hybrid and Electric Vehicle Parameters

The parameters pf the Hybrid and Electric Vehicle which is selected in this article and the model of it that is built by AVL Cruise are given below.

Table 1: Driving Parameters and Motor Battery

Driving Parameters	
Projects	Value
Curb Weight (kg)	2644
Gross Weight (kg)	3189
Friction Coefficient of Tire (η)	1.0
Air Resistance Coefficient (μ)	0.32
Front Area (m^2)	1.8
Wheel Base (mm)	3110.0
Reference Wheel Load (N)	3260.0

Table 1: (continued).

Static Rolling Radius (mm)	266.7
Dynamic Rolling Radius (mm)	119.25
Maximum Charge	120Ah
Initial Charge	95%

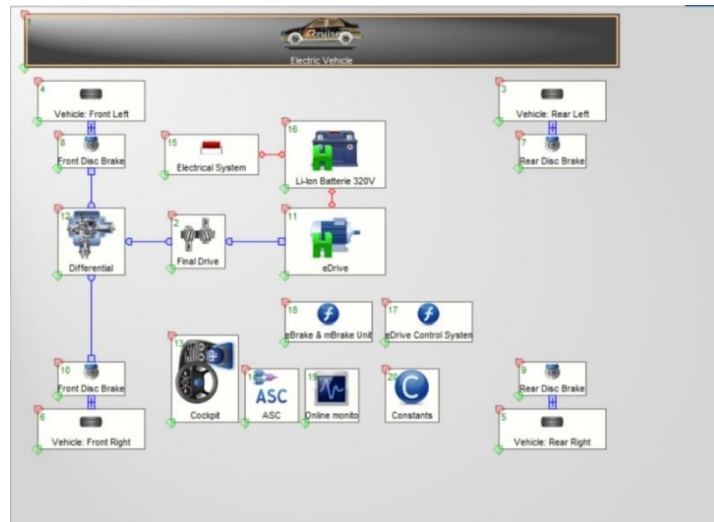


Figure 1: Urban Cycle Simulation of Distance, Velocity and Acceleration of Vehicle

2.3. Simulation results and analysis

In order to increase the understanding of vehicle performance, I simulated vehicle maximum speed, maximum acceleration and vehicle climb under appropriate vehicle conditions and environment.

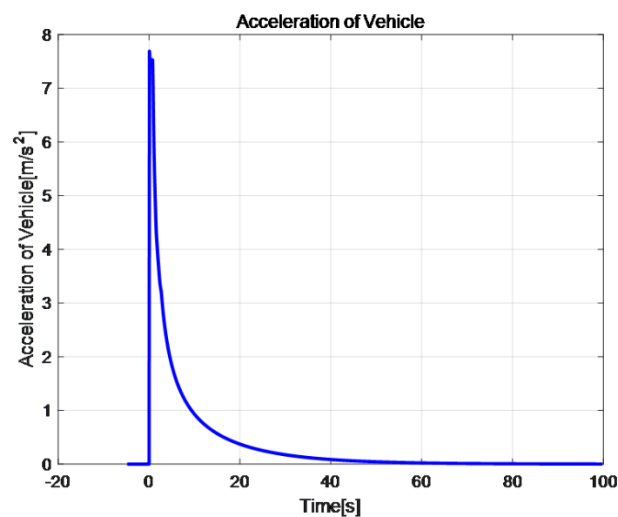


Figure 2: Simulation of Acceleration Performance

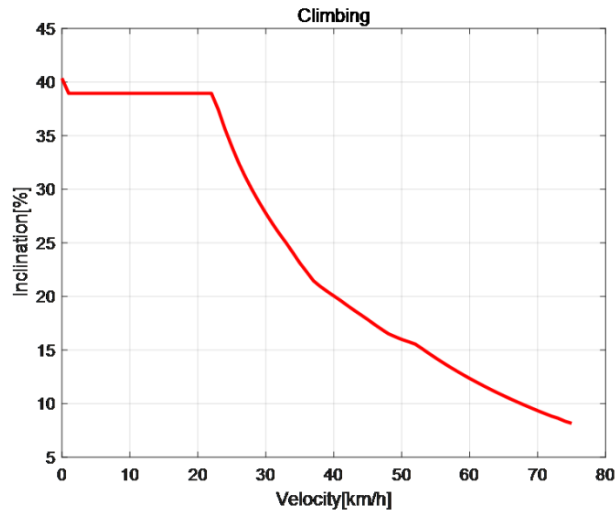


Figure 3: Simulation of Inclination Performance

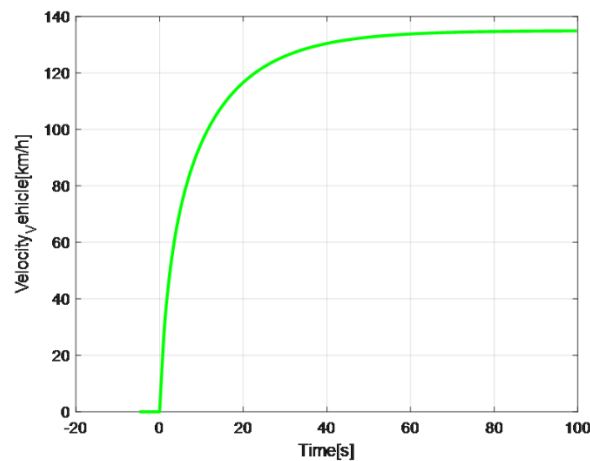


Figure 4: Maximum Speed Acceleration

According to Figures 2 and 4, the maximum acceleration of the hybrid and electric simulation vehicle is 7.7m/s^2 , the acceleration time of 100 km is about 11.49s, the acceleration time of the vehicle from rest to 50km/h is about 2.52 seconds, and the static acceleration response time at 50 to 80km is about 4.0s. According to Figure 4, we can conclude that the maximum speed of the vehicle is about 134.88km/h. As shown in Figure 3, the maximum climb slope of this vehicle is about 40.4%. In the speed range of 1km/h to 23km/h, the slope remains at about 39%, and then the climb rate decreases continuously to 8% as the speed increases to 75km/h. Therefore, the acceleration performance, maximum speed and climbing performance of the model meet the design standards.

3. Highway cycle performance simulation and optimization

3.1. Highway cycle performance simulation

In order to learn the consumption and process of the Highway cycle. I remain the above selected parameters and working conditions to conduct a simulation of the cycle. And the Highway cycle performance simulation shown below

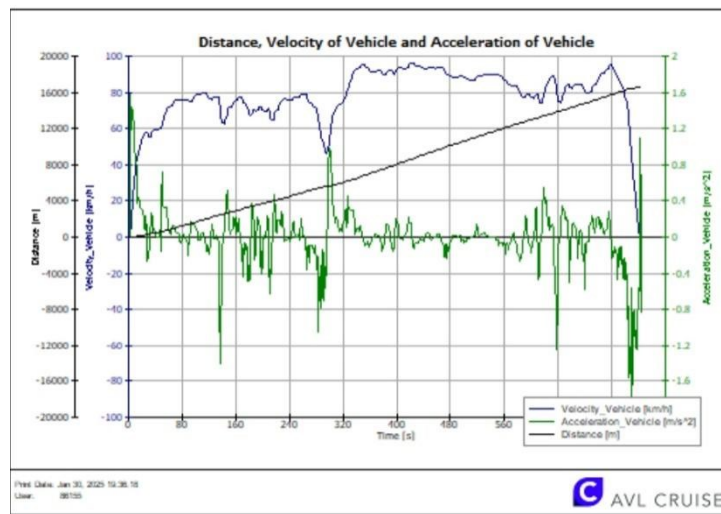


Figure 5: Highway Cycle Simulation of Distance Velocity and Acceleration

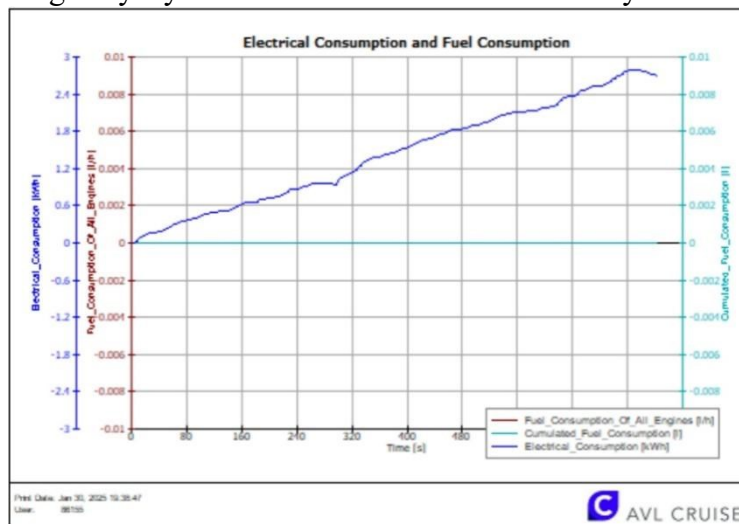


Figure 6: Highway Cycle Simulation of Electrical consumption and Fuel consumption

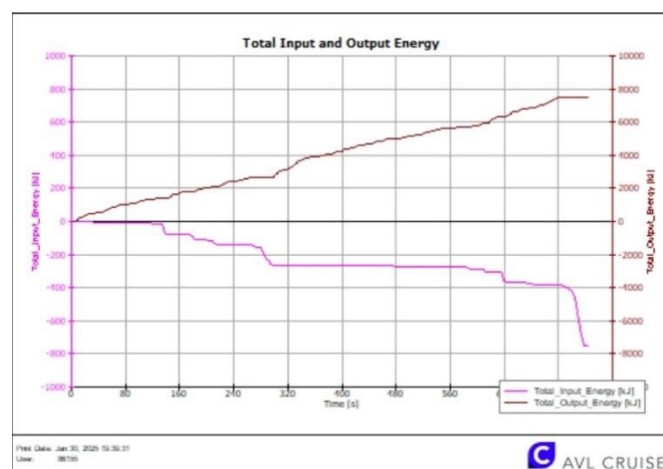


Figure 7: Highway Cycle Simulation of Electric Total Input and Output Energy

Below are the simulation data for hybrid and electric vehicle cycles based on AVL-Cruise. Figures 5, 6, and 7 illustrate the distance traveled, speed, acceleration, as well as power consumption and fuel consumption, as well as the total input and output of power, respectively.

As shown in Figure 6, the electricity consumption at the end of the urban cycle is about 2.77904 KWH. As shown in Figure 7, the final energy consumption of hybrid and electric vehicles is almost 7,500 kilowatts. In order to solve the energy consumption problem of most cars on the market, we must understand the factors of vehicle energy consumption.

3.2. Analysis on the influencing factors of energy consumption of hybrid and electric vehicle cycle condition

According to Figure 8, we can know that when simulation is carried out under appropriate conditions, we can explore the relationship of energy by changing the mass of the car. We cannot calculate an approximate linear correlation between mass and energy consumption. Through the relevant analysis using Matlab, the equation of quality and energy consumption is:

$$P = 0.0028M + 9.0364 \quad (17)$$

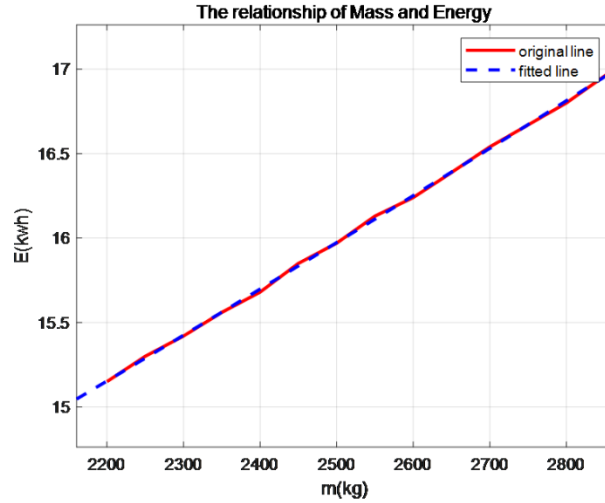


Figure 8: The relationship of Mass and Energy

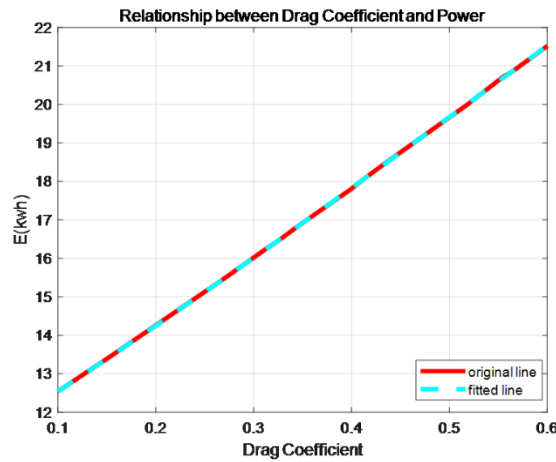


Figure 9: Relationship between Drag Coefficient and Power

Similarly, from Figure 9, by changing the drag coefficient, we can get the energy consumption in the appropriate environment. According to the fitting results, the relationship between the resistance coefficient and power consumption is as follows:

$$P = 1.8998C^2 + 16.6872C + 10.8439 \quad (18)$$

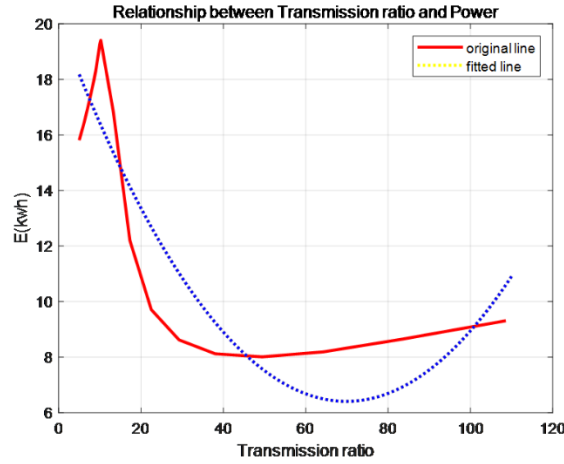


Figure 10: Relationship between Transmission ratio and Power

It can be seen from Figure. 10 that the energy relationship is obtained by changing the transmission ratio of the vehicle when simulation is carried out under appropriate conditions. According to the fitting results, when the transmission ratio is 10.238, the energy consumption is the largest, and with the increase of the transmission ratio, the energy consumption first decreases sharply and then increases slowly. The energy consumption is the least when the transmission ratio is 49.4325.

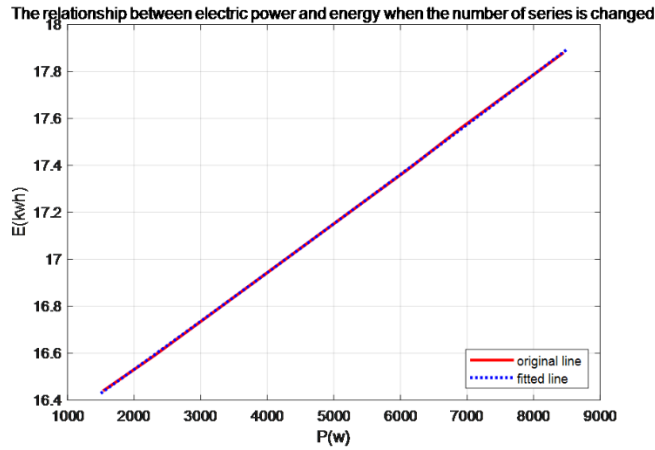


Figure 11: The relationship between electric power and energy when the number of series is changed

From Figure. 11, we can conclude that when we change the number of batteries in series, the electric power and energy consumption show a linear correlation, and the relationship is as follows:

$$P = 0.0002P + 16.1093 \quad (19)$$

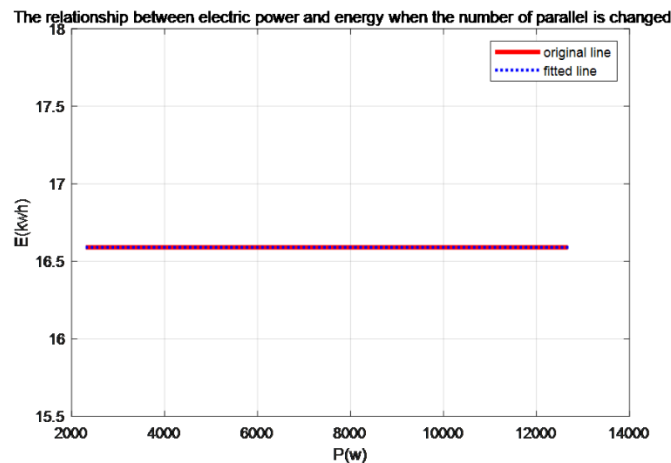


Figure 12: The relationship between electric power and energy when the number of parallel is changed

As shown in Figure 12, when we change the number of parallel batteries, the power consumption remains unchanged, so the power consumption is independent of the number of parallel batteries. So we can reduce the parallel number appropriately.

Table 2: The relationship between the number of batteries in series and parallel and the energy

Number of batteries in series and parallel	Energy
Two points are connected in series, and four batteries are connected in parallel	16.45
Four points are connected in series, and two batteries are connected in parallel	16.75
One point is connected in series, and eight batteries are connected in parallel	16.37
Eight points are connected in series, and one battery is connected in parallel	17.39

Finally, according to Table 2, I also found that when the output energy is the same, the energy dissipation will be different according to the number of series and parallel. In this regard, I also made a simple inquiry.

When one battery is connected in series and eight batteries are connected in parallel, this energy effect is the lowest consumption. So we can conclude that the more batteries in parallel, the less energy is dissipated. When we have a uniform spatial distribution, the number of batteries in series can be reduced to increase the number of batteries in parallel, so as to minimize energy consumption.

4. Conclusion

In conclusion, this paper presents a comprehensive process for developing and analyzing hybrid and electric vehicle (HEV and EV) simulation models using AVL-CRUISE software, with a focus on evaluating their performance across various dimensions. Initially, I constructed a motion model to capture the dynamic behavior of these vehicles, enabling an in-depth study of the factors influencing their dynamics. Subsequently, I conducted driving simulations under appropriate conditions and environments to assess key performance metrics. Based on these simulations, the fundamental performance characteristics of hybrid and electric vehicles were derived, including acceleration, top

speed, and hill-climbing ability. The results demonstrate a maximum speed of 134.88 km/h, a 0-100 km/h acceleration time of 11.49 seconds, and a maximum climbing capacity of 40.4%, underscoring the feasibility of these vehicles for real-world applications.

Furthermore, I analyzed the factors affecting vehicle performance during the Highway driving cycle. The electricity consumption at the end of the urban cycle was approximately 2.77904 kWh, while the total energy consumption of hybrid and electric vehicles reached nearly 7500 kJ. A linear relationship between vehicle mass and power consumption was observed, revealing that as vehicle mass increases, energy consumption rises correspondingly. Additionally, I investigated the relationship between the drag coefficient and power consumption, identifying a correlation that approximates a quadratic equation. As the drag coefficient decreases, energy consumption also diminishes, highlighting the critical role of aerodynamic efficiency.

Moreover, the study explored the relationship between the transmission ratio and energy consumption. At a transmission ratio of 10.238, energy consumption peaked, while it initially decreased sharply and then increased gradually as the transmission ratio changed. The lowest energy consumption was achieved at a transmission ratio of 49.4325. Finally, energy dissipation was examined by varying the number of series and parallel battery configurations. The most energy-efficient setup was observed with one battery in series and eight batteries in parallel, which minimized energy consumption. This analysis provides valuable insights into optimizing the number of cells in parallel for enhanced energy efficiency.

In summary, this research offers a detailed understanding of the factors influencing the performance and energy consumption of hybrid and electric vehicles, providing actionable recommendations for optimizing their design and operation.

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