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Recent Advances and Applications of AI-Based Mathematical Modeling in Predictive Control of Hybrid Electric Vehicle Energy Management in China

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Abstract: Artificial intelligence is widely used in mathematical modeling. The technical means in mathematical modeling are more and more diversified, especially the application of artificial intelligence algorithm greatly promotes the development of mathematical modeling. In recent years, because of its great influence on the fuel consumption, output power and exhaust performance of automobiles, the control strategy has become a research hotspot and focus in automobile R&D industry. Therefore, based on the relevant research results in recent years, after studying and analyzing the typical control strategies of hybrid vehicles, this paper finally puts forward the energy management strategy of hybrid vehicles based on model predictive control (MPC), and strives to contribute to the academic research of energy management strategies of hybrid vehicles.

Keywords: model predictive control; hybrid electric vehicle; energy management; control policy; mathematical modeling; artificial intelligence

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1. Introduction

Artificial intelligence is an important branch of computer science, which aims to understand the essence of intelligence and produce intelligent machines similar to human responses. Hybrid electric vehicle (HEV) is one of the strategic emerging automobile industries that China and many developed countries in the world are promoting and encouraging, and it is gradually becoming the main competitor of the old automobile market [1]. At the same time, its unique advantage is that the system state of hybrid vehicle is very complicated. As the main core part of hybrid vehicle research, energy management strategy directly affects the reliability of hybrid vehicle. Therefore, energy management strategy is being widely studied by relevant experts all over the world [2].

Since 1886, machinery, electronics, chemistry and other industries related to the automobile industry have also made great progress. Moreover, cars have become indispensable means of transportation, but at the same time, people and society are also faced with many big problems such as energy, environment and climate change [3]. At present, 11% of global energy consumption comes from China, and about 60% of oil is mainly consumed by the transportation sector. The automobile sector alone accounts for as much as 34% of oil consumption [4].

In addition, the contradiction between the explosive growth of car ownership and the rise of international oil prices is a serious threat to economic stability. Secondly, the rapid increase of the number of cars also leads to the increase of exhaust gas in the air, which seriously threatens the air quality in the environment, especially in large and medium-sized cities [5]. The pace of building a wealthy society has slowed down as a whole because of the rising economic and environmental costs and the increasing harm to public health. The vigorous development of the automobile industry has also brought a large number of greenhouse gases to the earth's environment. The daily greenhouse gas emissions are increasing rapidly, which seriously endangers the overall ecological environment system, and cannot provide people with a good social and environmental security. Today, mankind is facing arduous suffering and huge problems in the environment and development. Statistics on the number of new energy vehicles in China from 2016 to 2021 are shown in Figure 1 [6]:

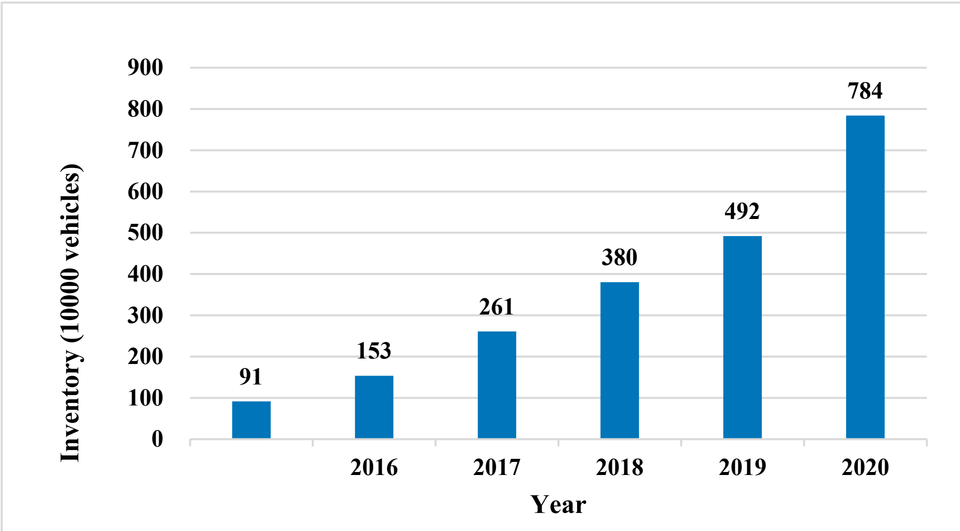

Figure 1. Statistics on the number of new energy vehicles in China from 2016 to 2021.

With the rapid development of Internet technology, the powerful computing power of AI algorithms makes it possible to build complex mathematical models. AI algorithms have gradually become an essential tool in the process of mathematical modeling.

2. Current Situation of Hybrid Electric Vehicles

2.1. Domestic Development Status of Hybrid Electric Vehicles

Pure electric vehicles can achieve no pollution and zero emission, which is undoubtedly the most effective way to solve the problem. However, due to the energy density, life and price of batteries, the further development and promotion of pure electric vehicles are hindered [7]. Therefore, hybrid electric vehicles with the advantages of both internal combustion engine vehicles and electric vehicles were born. The prototype of hybrid electric vehicle originated in the early 20th century, and it is mainly used to assist diesel locomotives with low power or extend the cruising range of electric vehicles [8]. In the 1990s, people gradually realized that the performance of pure electric vehicles was low, so the world's major automobile manufacturers paid close attention to hybrid vehicles, which made a lot of fruitful research results and improved the economic benefits of the whole industry [9]. The classification of new energy vehicles is shown in Table 1:

Table 1. Classification of new energy vehicles.

Classification	Trait
Pure electric vehicle	It is a car powered by rechargeable batteries, with a long history of 86 years, but has been limited to some specific applications, and the market is very small. The main reason is that various types of batteries have problems such as high price, short service life, large volume and weight, and long charging time.
Hybrid Electric Vehicle	This kind of vehicle can use both the internal combustion engine of traditional vehicles and the electric motor of fully electric vehicles for hybrid drive, reducing the demand for fossil fuels, improving fuel economy, and achieving the effect of energy conservation, emission reduction and greenhouse effect mitigation.
Fuel cell electric vehicle	It uses hydrogen as fuel and reacts with oxygen in the atmosphere in the fuel cell installed on the vehicle to generate electricity to start the motor and drive the vehicle. In addition to electric energy, this chemical reaction only produces water. Therefore, fuel cell vehicles are called "authentic environmental vehicles".

FAW is the first automobile company in China to enter the field of hybrid vehicles, and has made considerable achievements in the field of hybrid vehicles [10]. As one of the major automobile manufacturers in China, FAW has gradually entered the research and development of plug-in hybrid vehicles and pure electric vehicles from the research and development of hybrid vehicles [11]. At the same time, it also helps the research plate of vehicle kinetic energy research and transmission development. The hybrid design structure of the vehicle's overall unpowered terminal transmission is adopted, and the excellent sports performance is realized while considering the fuel consumption [12]. The best Pentium B50 hybrid vehicle, which is the first hybrid model after the "Blue Way Strategy" was released, inherits the dual-motor hybrid structure of the Pentium B70 hybrid vehicle, and has complete external plug-in functions [13]. The vehicle power system consists of a 1.5 L engine, a permanent magnet synchronous motor with an output power of 40 kw, and a lithium-ion battery with a capacity of 30 Ah. Besides, the hybrid version of Hongqi H7 is also an important product of "Blue Way Strategy". Statistics of China's new energy vehicle production/sales from 2016 to 2021 are shown in Figure 2 [14]:

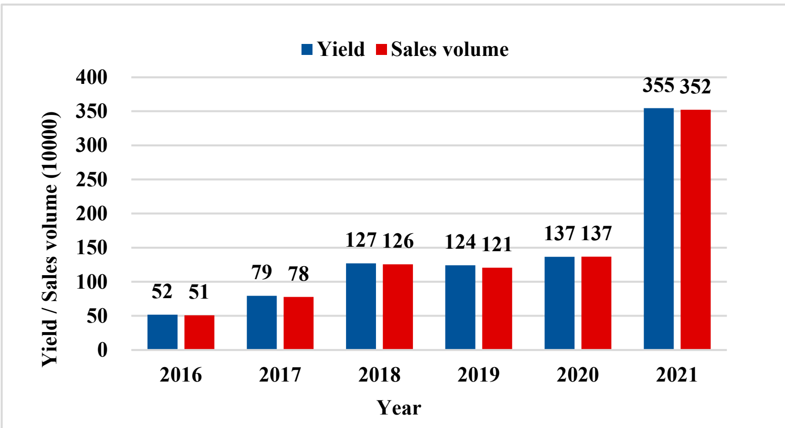

Figure 2. Production/Sales statistics of new energy vehicles in China from 2016 to 2021.

In the research and development of SAIC's new energy vehicle, it broke the three major electrical technical barriers of battery, motor and electronic control technology, and formed three major electrical technical systems [15]. From 2009 to 2016, many new energy models came out one after another. Roewe e550 went public in 2014. This model, which relies on Roewe 550 product platform, is equipped with 1.5LVTiTec engine, dual motors and EDU intelligent electric drive gearbox [16]. It has a cruising range of 500 km and only consumes 2.3 L of fuel. Subsequently, the intelligent electric drive unit was optimized and upgraded, so that the comprehensive mileage of Roewe 550 reached 600 km, and the comprehensive fuel consumption decreased to 1.6 L In addition, Changan Automobile mainly develops medium-sized and large-sized hybrid vehicles, which occupies a dominant position in China's medium-sized hybrid technology [17]. Chery was the first automobile company to realize mass production of BSG hybrid, and later developed A-class ISG hybrid which basically met the demand of private cars. The hybrid version of Chery Arrizo 7e, which went on the market at the end of July 2016, is the first plug-in hybrid model built by Chery, using a simple single-motor parallel mechanism. The cruising range of pure electricity is 50 km, that of fuel and electricity is 930 km, and the fuel consumption is 1.9 L per 100 km [18]. However, this model is not a performance car, and the acceleration time per 100 km is 10.9 s. Compared with BYD Qin, which is equipped with a 1.5 T engine with an output of 110 kw, the acceleration time per 100 km is negligible, and the acceleration performance of 5.9 s is quite poor. BYD is a product that develops BYD's dual-mode technology DMI. Since it came out in 2012, it has attracted much attention for its excellent acceleration performance of 100 km and its fuel consumption of 1.6 L per 100 km [19]. In fact, 70 km of pure electric driving range can make office workers very satisfied. Its biggest technical highlight is to solve the problem of difficult charging and let the household power supply charge, thus making plug-in hybrid vehicles really practical and creating a new era of hybrid vehicle technology [20]. The penetration trend of China's new energy vehicle market from 2016 to 2021 is shown in Figure 3:

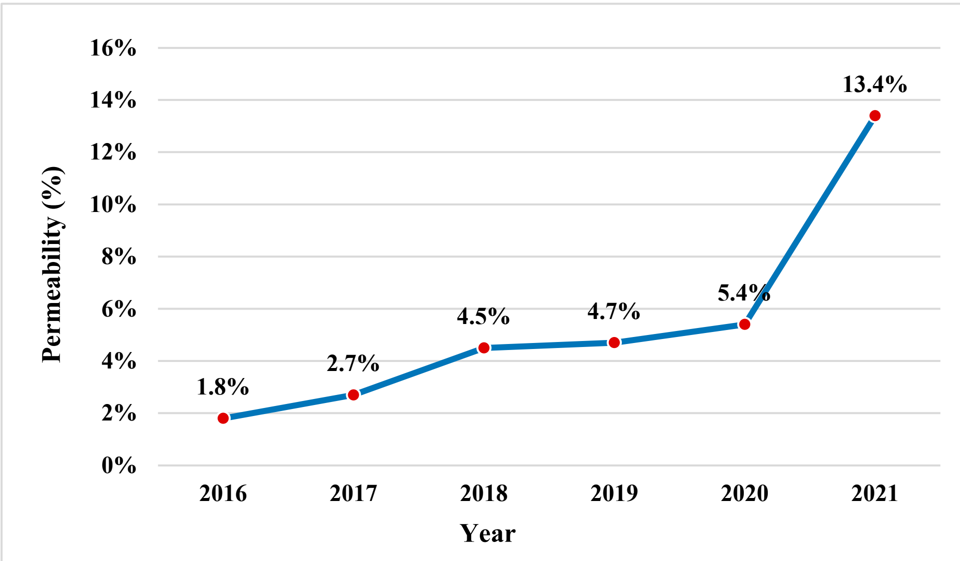

Figure 3. Trend of China's new energy vehicle market penetration rate from 2016 to 2021.

2.2. Research Status of Hybrid Electric Vehicle Control Strategy

Hybrid electric vehicles have two or more power sources. If you want to drive a hybrid vehicle, you need to get the best fuel efficiency and exhaust performance while ensuring the overall performance of the vehicle power components during the whole driving process, and then solve many problems through energy management and control strategies [21]. Nowadays, with the development of science and technology, as the key technology of hybrid electric vehicle development, the quality of energy management control strategy determines the success or failure of hybrid electric vehicle development. Therefore, it is necessary to understand the control purpose and control form of energy management before formulating the control strategy of energy management [22]. Energy management control strategies are mainly divided into two categories, one of which is based on the rules, and the other is based on the optimization. Strategies based on rules will be further divided into strategies based on clear rules and strategies based on fuzzy rules about decision theory. The strategies based on optimization are further divided into global optimization and short-term optimization [23]. Classification of control strategies is shown in Figure 4:

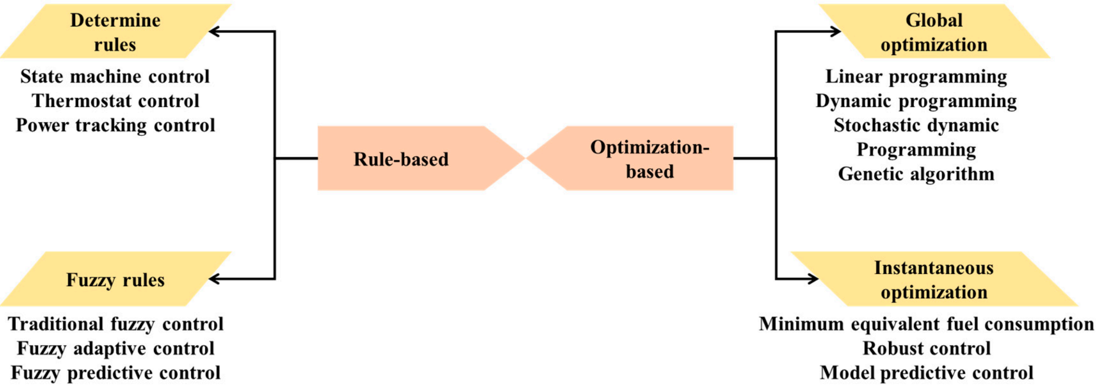

Figure 4. Classification of control strategies.

3. Concepts Related to Energy Management Strategy of Model Predictive Control

3.1. Concept of Model Predictive Control

Model predictive control, also known as rolling time domain control, is a control method based on rolling optimization. In essence, it still belongs to the category of solving optimal control [24]. Model predictive control is not a new method. Compared with traditional optimization methods such as global optimization algorithm, the biggest advantage of model predictive control optimization algorithm is to limit the optimization process to a finite time domain, thus reducing the amount of calculation and having the potential of real-time control. After using the prediction model to obtain the system state values in the prediction interval, the control sequence must be optimized according to the performance indicators set in the finite time domain and within the reachable range of the predicted state variables, so that the sequence can reach the local optimum [25]. Every optimization process is an exact copy of behavior, and the format of performance indicators is exactly the same, but the change of current information may lead to different performance indicator parameters. When the optimal control is executed, it can be optimized at k time, and after the optimal control in the prediction time domain Hp is obtained, the value u(k) before the optimal control sequence [U (k), U (k+2 | k), . . . , U (k+p | k)] will be applied to the system to detect the output of the system under control. At the time k+1, the future dynamic of the system is predicted again based on the actual output detected, and the optimal solution is carried out again, so that a new optimal control sequence [u(k+ 1), u (k+2 | k+1), u (k+3 | k+1),..., u (k+p+1 | k)] is obtained and applied.

3.2. Control Strategy Based on Optimization and Driving Conditions

(1) Optimization-based control strategy: based on the optimized control strategy, there are two kinds of control strategies: global optimization algorithm and real-time optimization algorithm [26]. Simplify the number of optimization targets to find the best optimization method. At this time, the energy loss time of the vehicle at any time point will be minimized. This optimization method can achieve the goal of optimizing the power train of hybrid vehicle under specific working conditions, and can get the timing optimal working point. (2) Control strategy based on driving condition prediction: Hybrid electric vehicles make control strategy when the driving condition of the vehicle is clear [27]. Now, the methods to predict the driving condition of the vehicle include the method to predict the past driving condition. In addition, the future driving condition can be obtained from GPS and other positioning systems. Adjust the battery level according to the road condition forecast, and choose whether to use electric motor to drive the vehicle or engine to drive the vehicle under various driving conditions.

3.3. Energy Management and Control Strategy of Hybrid Vehicle Based on Model Predictive Control

One of the cores of predictive control is the prediction of the future driving state of automobiles, and the key point is how to build a reference model. In recent years, scholars have established reference models by means of generalized exponential change, Markov chain model, Behrman's optimality principle, neural network and Kalman filter principle. Some experts have used the prediction of the specific placement position of the accelerator pedal to distribute the future state of the accelerator pedal as a probability, and established a Markov model reflecting the future torque demand of hybrid vehicles [28]. Secondly, using the dynamic programming method, the minimum value of the objective function is solved in the limited prediction time domain, and the optimal engine torque and motor torque are obtained. Considering the probability distribution of the future state of the accelerator pedal, the stochastic prediction model based on Markov chain can more accurately predict the power demand of the future vehicle. Compared with the rule-based control strategy, the fuel economy of the vehicle can be significantly improved, and the fuel consumption can be saved by 13%. Therefore, the stochastic prediction model based on Markov chain has a good application prospect in model predictive control, which is worthy of further analysis and research.

4. Hybrid Electric Vehicle System Analysis and Vehicle Model Establishment

4.1. Overview of Hybrid Electric Vehicle Power System

The forms of hybrid structures are often different. The hybrid power system is mainly used for urban public transport. It can realize six working modes of pure electric drive, engine drive, hybrid drive and battery charging, including engine type drive, braking energy regeneration and battery charging mode [29]. The main advantages of the hybrid system are as follows: ① The engine can work at any point of its universal characteristic map, so the control technology can ensure the overall low fuel consumption of the vehicle and always operate in a high-efficiency area. ② There is no mechanical connection between the motor and the engine, and the degree of freedom of layout of the vehicle body structure is high. ③ There is no mechanical connection between the engine and the driving wheel, so the control mode is relatively simpler compared with other complicated structures. The mechanical kinetic energy generated by the engine will be converted into electric kinetic energy by the generator, and then converted into a plurality of converted mechanical kinetic energy by the motor, so energy loss will occur, and the energy utilization rate will be very low. ② Battery is also the most important power source in the automobile, which not only meets the requirements of driving force, but also meets the requirements of braking torque, so the requirements of vehicle power are relatively low. And the increase of motor capacity leads to the gradual increase of the cost and weight of automobiles [30]. Common vehicle rolls stability indicators and their advantages and disadvantages are shown in Table 2:

Table 2. Common vehicle roll stability indicators and their advantages and disadvantages.

Roll Stability Index	Advantage	Disadvantage
Lateral acceleration (roll threshold) or roll angle	Simple, intuitive and easy to implement.	The early warning performance is poor. It is impossible to predict the risk of vehicle rolling in the future.
Roll protection reserve energy (RPER)	Suitable for road vehicles.	It is a static indicator, and the threshold is difficult to determine.
Roll index (RI) combining roll energy and roll energy rate	Several indexes including roll angle, roll angle speed, yaw rate, lateral acceleration and vehicle speed are considered.	It is closely related to the index vehicle speed, and it is difficult to select an appropriate threshold for vehicles with large changes in center of gravity.
Collision time (TTR)	Suitable for dynamic analysis, simple and easy to implement.	The evaluation index is single and the early warning performance is insufficient.
Transverse load transfer rate (LTR)	Strong applicability, able to cope with various rolling conditions; Easy to implement and high in real time.	Tire load is difficult to calculate and measure.

Parallel hybrid power system is widely used, which can realize all working modes of series hybrid power trains [31]. The power source can choose not only the electric motor, but also the motor with smaller power and the battery with smaller capacity, so as to control the cost. However, there are still many disadvantages in the structure of the system: for example, the mechanical connection between the engine and the driving wheels limits the selection of a better working point for the engine. This will also affect the optimization function of the engine's working energy consumption. The power system structure of hybrid electric vehicle is complex, and the output power of the engine and the start and stop of the motor can be flexibly controlled according to the driving conditions. However, the complex structure is not only costly, but also the difficulty of formulating the correct control strategy for the hybrid power system. The hybrid electric vehicle power system model is shown in Figure 5:

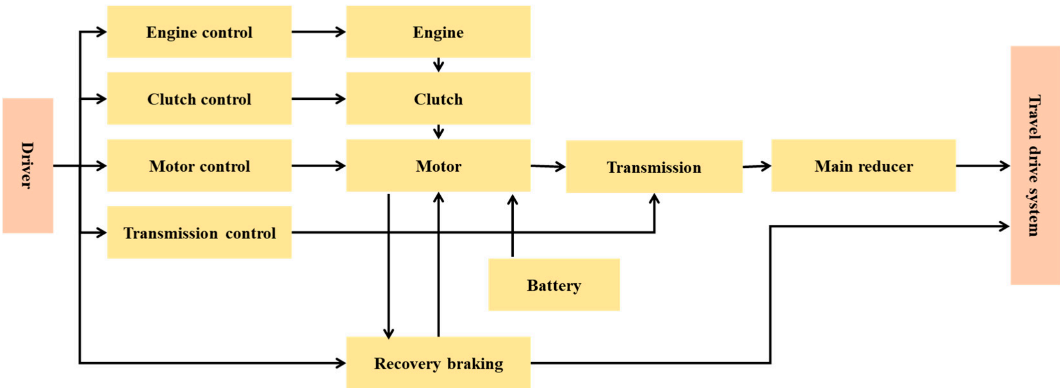

Figure 5. Hybrid electric vehicle power system model.

4.2. Principles of Modeling and Control Strategy for Hybrid Vehicles

The basic principles used to formulate the control strategy of logic gate limits are as follows [32]: ① Adopt pure electric mode at the beginning; ② Motor drive at high power, engine drive at low power, single-shaft drive at low load and double-shaft hybrid at high load; ③ In pure electric mode, the rear drive motor starts first. Based on the above ideas, the working conditions of each working mode and the corresponding torque distribution are as follows: (1) Pure electric drive mode. This mode is suitable for start-up and high-power state. When the hybrid vehicle starts, it needs low speed. If the engine provides the necessary torque and the engine torque exceeds the optimal efficiency range, the engine running rate will decrease and the fuel consumption rate will increase. When starting, pure electric drive is adopted. When the electric power is higher than the set reference value, in order to restrain fuel consumption and maximize the use of electric power, pure electric drive is adopted to drive the vehicle. In the pure electric driving mode, the rear wheel driving motor is driven first, and the ISG motor is used as the auxiliary power supply for driving. The hybrid vehicle has the pure electric mode of rear wheel drive. The torque distribution of the hybrid system in this mode is shown in Formula (1):

$$\begin{cases} T_e = 0 \\ T_m = min\left(T_{mmax},\ T_q/i_{gr}\right) \\ T_{isg} = min\left(T_{isgmax},\ \left(T_q - T_m i_{gr}\right)/\left(i_{gr} i_g\right)\right) \end{cases} \tag{1}$$

In Formula (1), *Te*, *Tm* and *Tg* are the torques provided by engine, rear drive motor and ISG motor respectively, $N{\cdot}m$; *ig*, *igr* and *igf* are CVT transmission ratio, rear axle final drive ratio and front axle final drive ratio respectively. T_{isgmax} and T_{mmax} are the maximum allowable output torques of ISG motor and rear drive motor respectively.

(1) Engine independent driving mode. When the battery power is lower than the preset reference value, the required torque is within the optimal working range of the

engine, and the engine will provide all the required driving force for the automobile, as shown in Formula (2):

$$\begin{cases} T_e = T_q / \left(i_{gf} i_g \right) \\ T_{isg} = 0 \\ T_m = 0 \end{cases} \quad (2)$$

(2) ISG motor single drive mode. Even if the battery balance is lower than the set reference value, when the required torque can't reach the optimal working range of the engine, the vehicle is still driven by ISG motor, as shown in Formula (3):

$$\begin{cases} T_{isg} = T_q / \left(i_{gf} i_g \right) \\ T_e = 0 \\ T_m = 0 \end{cases} \quad (3)$$

(3) Front axle hybrid mode. If the required torque exceeds the optimal working range of the engine, the torque will be too high when the engine is running alone, the fuel consumption rate will also be high, and the working efficiency of the engine will be greatly reduced. Therefore, the set functional work of the engine will be driven by ISG motor to supplement the required torque. According to different required intervals, there are two different torque distribution schemes for front axle hybrid, as shown in Formula (4):

$$\begin{cases} \begin{cases} T_e = T_{eopt} \\ T_{isg} = T_q / \left(i_{gf} i_g \right) - T_e \\ T_m = 0 \end{cases} \text{Front axle hybrid mode 1} \\ \begin{cases} T_e = T_q / \left(i_{gf} i_g \right) - T_{isgmax} \\ T_{isg} = T_{isgmax} \\ T_m = 0 \end{cases} \text{Front axle hybrid mode 2} \end{cases} \quad (4)$$

(4) Four-wheel drive hybrid mode. In the mode of single-axle drive or pure electric drive, if the single-axle power source can't provide a large amount of driving force needed by the current vehicle, or the required torque is greater than the maximum driving force of the double-axle drive, the motor drive and all power sources will participate and switch to the hybrid mode. According to the participation of the engine in running mode, it can be divided into mild hybrid power and full hybrid power, as shown in Formula (5):

$$\begin{cases} \begin{cases} T_e = T_{eopt} \\ T_{isg} = min\left(T_{isgmax}, T_q / \left(i_{gf} i_g \right) - T_e \right) \\ T_m = min\left(T_{mmax}, T_q / i_{gr} - \left(T_e + T_{isg} \right) i_{gf} i_g / i_{gr} \right) \end{cases} \text{Light hybrid four} - \text{wheel drive mode} \\ \begin{cases} T_m = T_{mmax} \\ T_{isg} = T_{isgmax} \\ T_e = min\left(T_{emax}, T_q / i_{gf} i_g - T_{isg} - T_m i_{gr} / i_{gf} i_g \right) \end{cases} \text{Full hybrid four} - \text{wheel drive mode} \end{cases} \quad (5)$$

(5) Engine driving and charging mode. When the electric quantity is lower than the set low limit, the battery stops discharging, the rear drive motor is turned off, and the engine provides all the driving force [33]. At the same time, in order to make the battery state of charge reach the set reference value, the output torque of the engine should be larger than the required torque, and the surplus torque should be used to drive the ISG motor to generate electricity, so as to charge the power battery and maintain the balance of the state of charge. According to the optimal working area of the engine and the current required torque range, the hybrid vehicle follows four different driving charging rules. In addition, in the low charge state, if the required torque exceeds the maximum torque that the engine

can provide, the engine will output the maximum torque and give a warning at the same time, as shown in Formula (6):

$$\begin{cases} T_e = \begin{cases} T_{el} if\ 0 < T_q \le T_{el} \\ T_{eopt} if\ T_{el} < T_q \le T_{eopt} \\ T_{eh} if\ T_{eopt} < T_q \le T_{eh} \\ T_{emax} if\ T_q > T_{eh} \end{cases} \\ T_{isg} = \begin{cases} T_q / \left(i_{gf} i_g\right) - T_e if\ T_q \le T_{eh} \\ 0\ if\ T_q > T_{eh} \end{cases} \\ T_m = 0 \end{cases} \tag{6}$$

(6) Braking mode. In the process of driving, when the torque required by the car is lower than 0, the hybrid car will switch to braking state, which can be divided into two modes: mechanical stopping and regenerative stopping. If the torque is lower than the set upper limit value, the ISG motor and rear wheel drive motor is used to regenerate braking energy to supplement the power consumption of the battery. When the torque exceeds the upper limit value, the mechanical brake is used. When the energy is regenerated, the braking torque required by the motor is shown in Formula (7):

$$\begin{cases} T_{isg} = max\left(T_{isgmin}, T_q / \left(i_{gf} i_g\right)\right) \\ T_m = max\left(T_{mmin}, T_q / i_{gf} - T_{isg} i_{gf} i_g / i_{gr}\right) \\ T_e = 0 \end{cases} \tag{7}$$

4.3. Modeling and Control Strategy Formulation of Hybrid Electric Vehicle

Whether the engine model is completed and the modeling method is appropriate has an important influence on the formulation of energy management strategy for hybrid vehicles [34]. From the particularity of the power train structure of hybrid vehicles, it can be seen that the engine model is different from that of previous vehicles. In addition, the fuel consumption and emissions are obtained by the difference look-up table method. This paper does not go into the details of the internal work of the engine, but only considers the characteristic relationship between the input and output of the engine. Compared with the common electric vehicle, the hybrid vehicle has two independent driving sources: engine +ISG motor and rear wheel drive motor, so it can realize the selection of multiple working modes and the development of control strategies [35]. Performance parameters of main components of the whole vehicle are shown in Table 3:

Table 3. Performance parameters of main components of the whole vehicle.

Parameter Item	Unit
Unladen mass	kg
Frontal area	m^2
Radius of tire	N·m
Peak engine torque	N·m
Peak torque of ISG motor	N·m
Peak torque of rear drive motor	N·m
Battery capacity	A·h
Battery rated voltage	V

Whenever at least two or more power sources are required to participate in the vehicle driving work at the same time, the torque provided by each power source must be reasonably distributed according to the current required torque, which is combined with the characteristics of each power component. In order to determine when each power component will participate in the drive, it is necessary to set open conditions for each working mode. When the working conditions meet the set rules, the hybrid system will have the opportunity to enter the working mode specified in advance by the system. Besides, the driving modes can be divided into seven types: rear wheel drive pure electric, ISG motor drive mode, engine drive mode and charging, front wheel hybrid and pure electric wheel drive. The working states of components corresponding to different modes are shown in Table 4.

Table 4. Working states of components corresponding to different modes.

Operational Mode	Engine	ISG Motor	Rear Drive Motor	Power Source
After-drive pure electricity	Close	Close	Drive	Rear drive motor
ISG motor drive	Close	Drive	Close	ISG motor
Engine drive	Open	Close	Close	engine
Front axle hybrid	Open	Drive	Close	Engine +ISG motor
Engine driving +charging	Open	Generate Electricity	Close	engine
Pure electric four-wheel drive	Close	Drive	Drive	ISG motor +rear drive motor
Hybrid four-wheel drive	Open	Drive	Drive	Engine +ISG motor +rear drive motor

This paper develops an MPC strategy based on Markov model, which is also called Stochastic Model Predictive Control (SMPC) strategy. In order to verify the fuel economy optimization effect of SMPC strategy, this paper selects Frozen time MPC (FTMPC) and Present MPC (PMPC) to predict the future acceleration of hybrid electric vehicles in finite time domain. The SMPC, FTMPC and PMPC strategies are simulated based on three typical conditions in the same prediction time domain. Table 5 shows the comparison of fuel consumption per 100 km of each control strategy.

Table 5. Comparison of fuel economy results.

	NEDC	UDDS	CUDS	Mean Value
SMPC	4.3988	3.6966	2.9286	3.6637
FTMPC	4.5936	3.8814	3.1942	3.8939
PMPC	4.2763	3.5250	2.7091	3.4927

It can be seen from Table 5 that the average fuel economy of SMPC control strategy proposed in this paper is 5.91% higher than that of FTMPC. Among them, it increased by 4.24% under NEDC condition, 4.76% under UDDS condition and 8.32% under CUDS condition, which is close to the fuel economy of PMPC control strategy. The control strategy based on SMPC predicts the acceleration in the time domain by analyzing various cycle conditions, which can basically reflect the change of the vehicle's future acceleration. The control strategy based on FTMPC believes that the predicted acceleration in the time domain remains unchanged, which is greatly different from the actual acceleration of the vehicle. In contrast, the SMPC strategy based on Markov acceleration prediction model is feasible.

5. Conclusions and Prospect

With the continuous progress of artificial intelligence technology, more and more problems need to be solved by combining various intelligent algorithms. Artificial intelligence algorithms will play an increasingly important role in mathematical modeling. Facing the reform, development and transformation of the automobile industry, major domestic brands have responded positively. After years of accumulation and exploration, all automobile companies are exploring their own development paths and strategic plans for new energy vehicles. However, there is still a big gap between the achievements of various automobile companies and the target effect of China's new energy development strategy, which means that China's automobile industry companies still have a long way to go.

Through the recent research, the model control predictive control strategy can improve the practicability, safety, economy and emission performance of hybrid electric vehicles, which has more obvious advantages than the previous control strategies. However, due to the various states of hybrid electric vehicles, the accuracy of the prediction model is also the most important part of the predictive control strategy of model control. Just because of this, it is necessary to establish a relatively accurate vehicle prediction model, and combine it with an advanced traffic system with advanced sensors.

Author Contributions: Q.Z.: establish vehicle model and analysis the hybrid electric vehicle, preparation and writing of the draft. S.T.: analysis the current situation of hybrid vehicles. X.L.: preparation of the dataset, investigate the Concepts related to energy management strategy of model predictive control. All authors have read and agreed to the published version of the manuscript.

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Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

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