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Control of Fuel Lithium Battery Hybrid Vehicle Power Supply System and Vehicle Energy Management Strategy

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Abstract. The main research object of this article is the increasing number of new energy vehicles, focusing on the energy management issues of new energy vehicles. Firstly, a real car model was established: an engine mathematical model, an electric motor mathematical model, and a power battery mathematical model. Then, in order to achieve optimal management of vehicle energy management, an algorithm model for vehicle energy dynamic planning was established with the goal of minimizing energy consumption. Finally, simulation experiments were conducted to verify the performance improvement of the proposed algorithm in vehicle energy management.

Keywords: hybrid vehicle, energy management, dynamic programming

1 Introduction

The current urgent issue that the automotive industry must face is global environmental pollution and the depletion of proven oil resources. The increasing world car ownership further exacerbates the sharp contradiction between energy consumption and the increasingly limited supply of oil resources.

Developing hybrid vehicles can effectively solve energy and environmental pollution problems. Compared to pure electric vehicles, hybrid electric vehicles are not limited by battery life issues and outdated infrastructure construction such as charging stations. The research on new energy vehicles is gradually maturing and moving rapidly from laboratory to industrialization.

Fuel lithium battery hybrid vehicles charge the power battery through an external power grid, which can reduce the vehicle's dependence on fuel and usage costs, and significantly increase the vehicle's driving range. Currently, it is gradually receiving attention and technological research investment from the government, automotive companies, and research institutes.

For fuel lithium battery hybrid vehicles, the determining factor of their vehicle performance lies in the vehicle's energy management strategy. Therefore, the research on energy management strategies has always been a focus of PHEV development. In order to improve the energy management efficiency of fuel lithium battery hybrid vehicles, this article uses dynamic programming algorithms to optimize the energy management strategy of hybrid vehicles.

The work done in this article is as follows:

1) Firstly, establish a comprehensive mathematical model for hybrid vehicles, which includes an engine mathematical model, an electric motor mathematical model, and a power battery mathematical model;

2) Established and improved a dynamic planning model and planning algorithm for hybrid vehicles;

3) Build a simulation environment and conduct simulation experiments

In order to improve the description of the method used in this article, the structure of the article is as follows: Chapter 2 mainly describes the relevant research results, Chapter 3 is the process of establishing various mathematical models, Chapter 4 is the description of energy management strategies, Chapter 5 is the simulation experiment section, and Chapter 6 is the conclusion, summarizing the achievements and shortcomings of the article.

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2 Related Work

Domestic and foreign scholars have conducted extensive research on energy management issues in hybrid vehicles. Mechichi Oumaima proposed a fast initial estimation based method for energy control of PHEV models as an adaptive L-shaped control strategy. The control results were evaluated using a standard driving cycle evaluation method, and the expected results were achieved [1]. In China, many scholars have also achieved fruitful research results. Aiguo Han from Wuhan University of Technology proposed a hybrid energy management strategy based on a combination of rules and optimization algorithms for energy management of dual architecture plug-in hybrid vehicles. The simulation results show that the improved strategy can achieve a 4.7% reduction in fuel consumption [2]. Pengcheng Qu from Chang'an University's research object is urban buses, but its minimum value optimization method with the goal of optimal comprehensive economic use economy is also worth learning from. After simulation verification, this method can obtain the optimal battery configuration, optimal discharge depth, and SOC working area [3]. Xinliang Zhang introduced the idea of dynamic programming in energy control, simplifying the energy management strategy solving problem of the entire vehicle to an optimization problem of engine output torque, and using discrete particle swarm optimization algorithm to optimize gear selection, achieving a 9.42% reduction in fuel consumption [4]. Yaoxian Feng from Tongji University mainly studied the energy consumption of hybrid vehicles under starting and stopping conditions, and proposed intelligent control schemes for working modes under different starting and idling conditions, which can slow down the decay rate of batteries and improve the economy of hybrid vehicles [5].

3 Establishment of a Fuel Lithium Battery Hybrid Vehicle Model

The main parameters of the fuel lithium battery vehicle model, which is the research object of this article, are shown in Table 1.

Table 1. Main parameters of plug-in hybrid electric vehicles

Parameter	Data	Unit	Symbol
Overall dimensions	5030*1960*1760 mm	mm	
Curb weight	2300 kg	kg	M
Maximum total mass	2825 kg	kg	M_m
Air resistance coefficient	0.382		C_D
Tire rolling radius	0.345	m	R
Final drive ratio	3.43		i_0
Sending machine gift book	0.9		i_e
TM reduction ratio	2.47		$\mathrm{i_m}$

The vehicle object studied in this article adopts the form of a series connection between an engine and an electric motor. The electric motor can be used as an electric motor or a generator, and when used as an electric motor, the battery provides electrical energy [6]. When the engine is working, the engine provides electrical energy to the electric motor. The schematic diagram of the energy transfer structure of the vehicle is shown in Fig. 1. The mathematical model of hybrid vehicles includes the mathematical model of the car engine, the mathematical model of the power battery, and the mathematical model of the electric motor.

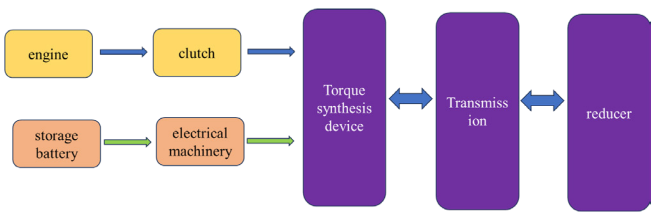


Fig. 1. Schematic diagram of parallel hybrid vehicle structure

3.1 Establishment of Engine Mathematical Model

The mathematical model of the engine only considers the input and output of the engine model, ignoring the internal structure of the engine. The engine output torque is calculated based on the throttle opening and engine speed. $T_{e\,\min}$ is the minimum torque of the engine, $T_{e\,\max}$ is the maximum torque of the engine, and the throttle opening command is represented by C_e. Therefore, the output torque T_e of the engine is expressed as:

$$T_e = T_{e\min} + C_e\left(T_{e\min} + T_{e\max}\right). \quad \textbf{(1)}$$

$$T_{e\min} = f_{e\min}\left(\omega_e\right). \quad \textbf{(2)}$$

$$T_{e\max} = f_{e\max}\left(\omega_e\right). \quad \textbf{(3)}$$

The fuel consumption calculation formula in the engine model is expressed as:

$$m_{fuel} = \int_0^t f_e\left(\omega_e, T_e\right) d_t. \quad \textbf{(4)}$$

$$V_{fuel} = \frac{m_{fuel}}{\rho_{fuel}} = \frac{1}{\rho_{fuel}} \int_0^t f_e(\omega_e, T_e) d_t. \quad \textbf{(5)}$$

In the formula, m_{fuel}, v_{fuel}, and ρ_{fuel} respectively represent the actual fuel consumption, engine fuel consumption, and fuel density.

3.2 Establishment of Mathematical Model for Electric Motors

The mathematical model of the electric motor in a hybrid vehicle can serve as a generator to charge the battery when the transmitter is working [7]. The motor controller and motor are considered as a whole, and only the input and output characteristics of the motor as a whole are considered during modeling. The output variable is the motor torque, represented by T_m, and I_m and J_m represent the motor current and moment of inertia. The expression is as follows:

$$T_m = \alpha T_{m\max}. \quad \textbf{(6)}$$

The maximum torque of the motor in electric mode is expressed as:

$$T_{m\max} = \min\left(h_i T_{mcont} + \left(1 - h_i\right) T_{mpeak}, \frac{UI_{m\max}}{\omega_m}\right). \quad \textbf{(7)}$$

The formula for calculating the maximum torque of the motor in power generation mode is:

$$T_{m\max} = \max\left(h_i T_{mcont} + \left(1 - h_i\right) T_{mpeak}, \frac{UI_{m\max}}{\omega_m}\right). \quad \textbf{(8)}$$

In the formula, $I_{m\,\max}$ is the maximum current of the motor, represented by $I_{m\max} = \frac{P_m}{U}$, P_m is the power of the motor, T_{mcont} is the maximum torque of the motor, T_{mpeak} is the peak torque of the motor, h_i is the temperature rise torque correction coefficient of the motor, U is the bus voltage of the electronic control system, and ω_m is the feedback speed of the transmission system. The power expression of the motor is as follows:

$$P_m = T_m \omega_m (\omega_m, T_m)^{-\sin(T_m)}. \tag{9}$$

3.3 Establishment of a Mathematical Model for Power Batteries

The charging and discharging process of power batteries is an electrical, chemical, and thermal process. In this paper, the internal resistance model method is used to model the battery. When modeling, the battery pack is considered as a voltage source, ignoring the complex electrochemical changes in the battery and only considering the input and output characteristics of the battery The terminal voltage expression method for power batteries is:

$$U_{b1} = E_{b1} - R_{b1} i_{b1}. \tag{10}$$

In the formula, E_{b1} is the electromotive force of the battery that varies with *SOC* in discharge mode, in units of *V*, and R_{b1} is the internal resistance of the battery that varies with *SOC* in discharge mode, in units of Ω. The formula for calculating the output power of the power battery in discharge mode is:

$$P_{b1} = i_{b1} U_{b1} (i_{b1} > 0). \tag{11}$$

In the formula, P_{b1} is the output power of the power battery, i_{b1} is the circuit current of the power battery, and U_{b1} is the terminal voltage of the power battery. The calculation formula for the circuit current in the power battery re discharge mode is:

$$i_{b1} = \frac{E_{b1} - \sqrt{E_{b1}^2 - 4R_{b1}P_{b1}}}{2R_{b1}}. \tag{12}$$

The calculation formula for *SOC* of power batteries in discharge mode is:

$$SOC = \frac{Q_r - \int_0^t i_{b1} dt}{Q_r}. \tag{13}$$

In the formula, Q_r is the rated capacity of the power battery. In charging mode, calculate the terminal voltage of the power battery:

$$U_{b2} = E_{b2} + R_{b2} i_{b2}. \tag{14}$$

In the formula, E_{b2} is the battery electromotive force *V* that varies with *SOC* in charging mode, in units of, and R_{b2} is the battery internal resistance that varies with *SOC* in discharge mode, in units of Ω.

4 Management Strategy Based on Vehicle Dynamic Planning

The principle of dynamic programming is based on the principle of optimality, which is defined as: if a decision satisfies optimality or optimality, any segment of the decision can be taken from the secondary decision, and still satisfies the decision optimality [8]. Starting from the endpoint of the decision, reverse inference is carried out, and each segment of the optimal decision is solved in segments until the starting point, and then the optimal solution is obtained by forward solving from the starting point to the endpoint. The principle of dynamic programming is shown in Fig. 2.

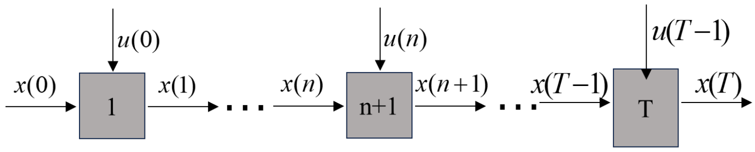


Fig. 2. Dynamic programming principle

4.1 Dynamic Programming Mathematical Modeling

The vehicle control strategy for hybrid vehicles aims to reduce fuel consumption while meeting power requirements. If a certain operating condition is given, the control strategy problem can be transformed into a dynamic programming problem. Given the known cycle conditions, the known cycle conditions are subdivided into multiple small stages, and the control amount of each stage is known. The cost or cost of each stage is calculated based on the state transition equation.

$$\begin{aligned} &x(m+1) = f\left[x(m), u(m), m\right] \\ &x(0) = x_0. \end{aligned} \quad \textbf{(14)}$$

In the equation, $x(m) \in X(m) \subset R^n$, $u(m) \in U(x(m), m) \subset R^k$, calculate the stage function values for each stage, and then accumulate all stage functions to obtain the performance index function of fuel consumption.

$$J = \min\left\{J_m\left(x(m+1), u(m+1)\right) + F_m(x(m), u(m), u_2(m))\right\}. \quad \textbf{(15)}$$

In the equation, $x(m)$ represents the state variable in state m, $u(m)$ represents the control variable in stage m, f represents the state transition equation in stage m, and J represents the performance indicator function.

4.2 Dynamic Planning Analysis

Dynamic programming algorithm belongs to the type of numerical algorithm, and this article studies the continuous function of time as the object [9]. Therefore, before using dynamic programming, it is necessary to discretize the research object into grid points, and then calculate from the endpoint to the starting point. The method is shown in Fig. 3.

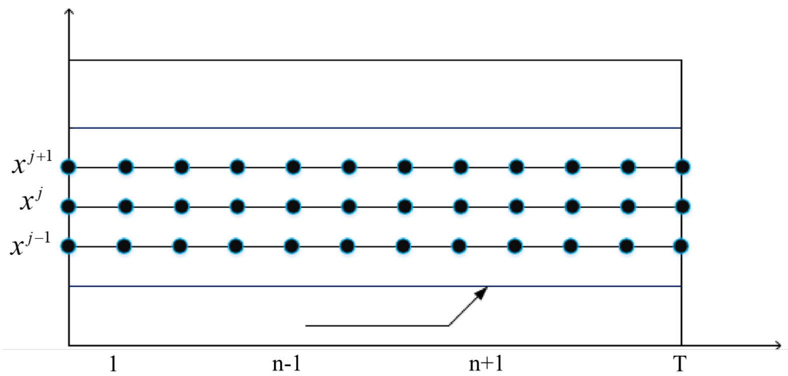


Fig. 3. Dynamic planning process

In space, dots represent intersections. The finer the discretization process, the denser the number of intersections in the graph, and the more accurate the calculated results are. Ultimately, the more likely it is to obtain the optimal solution. The more points obtained through discretization, the more points need to be calculated, and the amount of calculation will also increase significantly. It is particularly important to choose a reasonable number of discrete points. When using dynamic planning in plug-in hybrid vehicles, it is necessary to ensure that the vehicle power demand, battery *SOC* value, and motor power meet the actual demand, and calculate the set of *SOC* values that are the minimum fuel consumption of the entire vehicle under certain operating conditions. This article takes the *SOC* value as the state variable, and the torque distribution relationship between the engine and the driving motor as the control variable. First, the optimal stage function and corresponding optimal control variables for each stage of the entire continuous process are calculated in reverse, and then the optimal control variables for each stage are substituted in the forward direction to obtain the optimized results.

Given operating conditions such as WLTC or UDDS, the given operating conditions are discretized into N stages with a fixed time interval of Δt between stages. The state variables are discretized into Y segments along the coordinate axis with an interval of ΔSOC. In this paper, $N = 6$ and $Y = 5$ are taken, and the performance index function is expressed as:

$$\begin{aligned} J &= \sum_{\mathrm{k}=0}^{N-1} \left\{ L\left[x(k), u_1(k) \right] \right\} \Delta t \\ k &\in \{0, 1, \cdots, N-1\}. \end{aligned} \quad \textbf{(16)}$$

In the equation, $x(k)$ represents the state variable, i.e. the value of *SOC*; $u_1(k)$ represents the control variable, which is the torque distribution coefficient between the engine and the driving motor, and k represents the number of segments divided by the cycle conditions; J represents the new energy indicator function; L represents the fuel consumption per stage.

4.3 Dynamic Programming Solution

The reverse solution of dynamic programming first needs to complete the preparation work of discretizing the determined cycle conditions into segments and the state variable *SOC* into Y segments. Then, starting from the endpoint of the given cycle conditions, the optimal solution for each stage is calculated with the starting point as the target endpoint. Based on the given cycle conditions, calculate the required torque, and then search for the characteristic curves of the driving motor and engine, in order to reduce fuel consumption as the principle, select an appropriate torque distribution ratio.

Calculate from the endpoint of the cycle working condition to the starting point of the working condition, and complete the reverse calculation process. The next step is to start the forward solving process. Forward solving starts from the initial stage, and when the optimal solution is not at a given discrete point, interpolation is used to solve the optimal control for each stage until the endpoint of the discretized stage. The detailed steps are as follows:

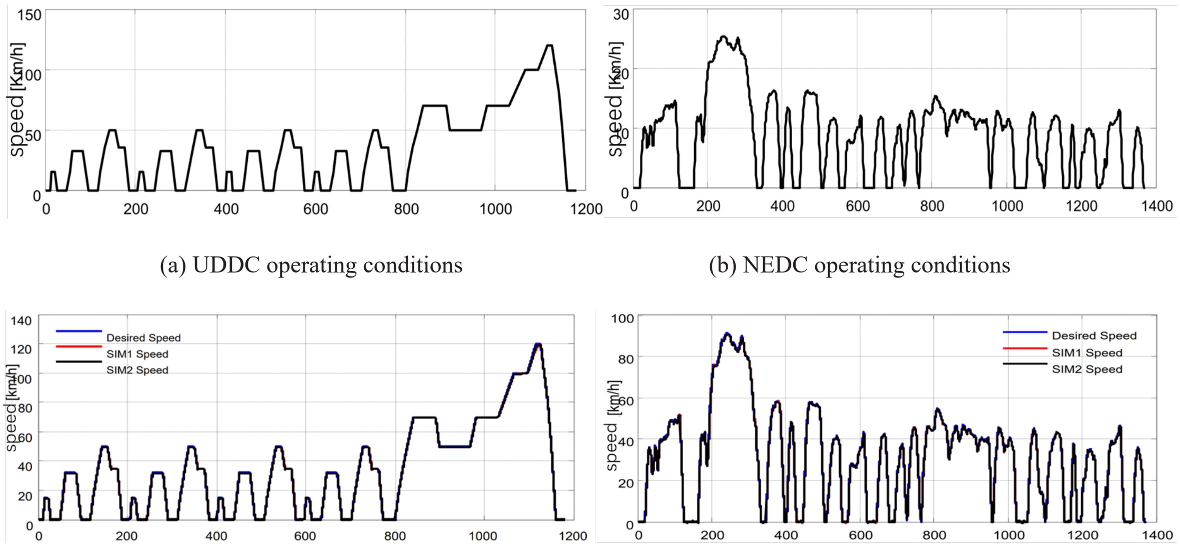
(1) Starting from the discrete initial point, the initial *SOC* value is known, and the value obtained from the reverse solving process is used as a known condition to obtain the optimal solution of the initial point.

(2) The second step is to use the state transition equation and obtain the optimal control for the second stage through interpolation method. Follow this step to solve the optimal control for each stage in sequence.

(3) Determine whether the optimal control solution for all stages has been completed. If so, the solution process ends, and then arrange all the values obtained in order to obtain the optimal strategy.

5 Simulation Experiment and Result Analysis

Firstly, the effectiveness of the dynamic planning strategy is analyzed, and the effectiveness of the proposed energy management control strategy and PHEV fuel economy are tested under typical Chinese operating conditions. Under actual vehicle conditions, it is necessary to improve the overall economy of the vehicle as much as possible while ensuring its power performance. In situations where power cannot be guaranteed, this may lead to safety issues. Set the initial *SOC* to 80%, and use the UDDC cycle and NEDC cycle conditions to test the vehicle's speed following situation to verify the proposed control strategy. The results are shown in Fig. 4, and the current speed is well following the target speed.

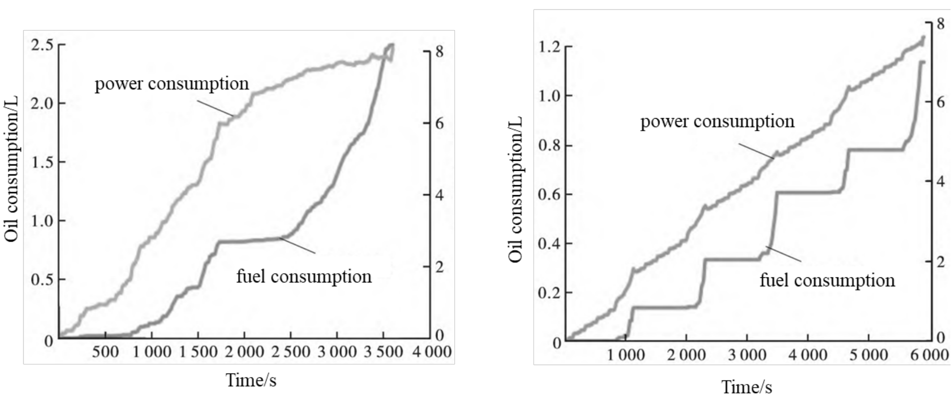


(a) UDDC operating conditions (b) NEDC operating conditions

(c) UDDC working condition following results (d) NEDC working condition following results

Fig. 4. Simulation results of working conditions

The most important way to improve the fuel economy of PHEVs is to make the engine work within the economic fuel consumption range as much as possible, and the main way is to adjust the power distribution between the engine and the motor in a timely manner. From Fig. 4, it can be seen that the proposed strategy is implemented under various operating conditions, and the engine and two motors jointly provide power for the entire vehicle's driving. Under the UDDC and NEDC operating conditions, there was no significant difference in *SOC* between the two control strategies during the initial period of time. However, compared to the original control strategy, the current energy management strategy gradually slowed down the trend of *SOC* decline, and over time, the difference in *SOC* values between the two continued to widen. The original vehicle control strategy *SOC* first decreased and then maintained a certain value, The battery was not used properly throughout the entire driving process. Compared to the rule-based control strategy of the original model, the current strategy can enable the motor to adjust the engine operating point over a longer time and mileage span, resulting in a slow decrease in *SOC* and better economic performance of the entire vehicle under operating conditions. The experimental results are shown in Fig. 5.



(a) UDDC energy consumption (b) NEDC energy consumption

Fig. 5. Energy consumption under different working conditions

6 Conclusion

This article has implemented strategies for controlling the power supply system and energy management of fuel lithium battery hybrid vehicles. After improvement, the fuel consumption and electricity consumption per unit time have been significantly reduced, and the energy utilization rate has been significantly improved. However, there are also shortcomings in this article. The modeling process did not fully consider the working conditions of summer air conditioning cooling and winter heating. Therefore, in further research, based on the content of Chapter 3, a mathematical model for night cooling and heating will be developed to achieve energy control under the most realistic operating conditions.

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