

Application of Dynamic Programming Algorithm Based on Model Predictive Control in Hybrid Electric Vehicle Control Strategy

Xiaokan Wang* and Qiong Wang

Henan Mechanical and Electrical Vocational College, Zhengzhou, 451191, China

*Corresponding Author: Xiaokan Wang. Email: wxkbbg@163.com

Received: 01 January 2020; Accepted: 05 May 2020

Abstract: A good hybrid vehicle control strategy cannot only meet the power requirements of the vehicle, but also effectively save fuel and reduce emissions. In this paper, the construction of model predictive control in hybrid electric vehicle is proposed. The solving process and the use of reference trajectory are discussed for the application of MPC based on dynamic programming algorithm. The simulation of hybrid electric vehicle is carried out under a specific working condition. The simulation results show that the control strategy can effectively reduce fuel consumption when the torque of engine and motor is reasonably distributed, and the effectiveness of the control strategy is verified.

Keywords: State of charge; model predictive control; dynamic programming algorithm; optimization

1 Introduction

Safety, energy saving and environmental protection are important development directions and hot research fields of automobile industry. With the rapid increase of automobile production and ownership, great pressure has been exerted on traffic, resources and environment. In recent years, under the pressure of resources and environment, electric vehicles have become the hotspot of global automobile industry development. The control strategy of hybrid electric vehicle is to match engine power output with motor power output in a most reasonable way. On the basis of ensuring vehicle power demand, it is required to minimize vehicle exhaust emissions and reduce fuel consumption.

In paper [1], in order to ensure that the vehicle can maintain a constant speed downhill when the slope changes, according to the mathematical model of the proposed braking system, the adaptive model predictive control method is used to design the control system. Pan et al. [2] aimed at the nonlinear and strong coupling characteristics of automotive systems presented an improved nonlinear model predictive control method for regenerative braking that could effectively guarantee vehicle stability and improve control accuracy and regenerative braking energy recovery rate is explored. Wang et al. [3] and Ripaccioli et al. [4] described the application of stochastic model predictive control in vehicle dynamic management of advanced hybrid systems, Tang et al. [5] introduced a model predictive control method for low-complexity electric vehicle charging scheduling with optimality and scalability. Li et al. [6] and Pan et al. [7] presented the regenerative braking energy recovery control strategy of the hybrid bus based on the model predictive control which could ensure the braking stability while maximizing the braking energy recovery [8–10]. This study will propose a dynamic programming algorithm model predictive control in hybrid vehicle control strategy, through the model predictive control in the hybrid vehicle control strategy construction, the dynamic programming algorithm is applied to the model predictive control, based on the dynamic programming algorithm Model prediction control and the state of charge (SOC) reference trajectories are analyzed and studied. In this study, the power battery SOC reference trajectory is used as the state parameter constraint condition based on the dynamic programming model predictive control,

real-time control is carried out, and the torque of the engine and the motor is optimized, which can greatly reduce the consumption of the hybrid vehicle. To achieve energy conservation and energy saving [11–13].

2 Design of Hybrid Vehicle Optimal Control Function Based on Model Predictive Control

In order to ensure the proper distribution of the torque of the engine and the motor during the driving condition of the hybrid vehicle to ensure the normal operation of the power output of the vehicle, the model predictive control strategy is proposed to control the power system, thereby reducing the energy consumption of the vehicle [14–15]. And save energy and increase the mileage of the vehicle. In this study, the hybrid vehicle control strategy based on model predictive control is proposed to optimize vehicle control. By obtaining the information such as the running speed and acceleration at the previous moment of the vehicle's travel, combined with the running speed and acceleration at the current time, the predictive model of the vehicle's operating state is constructed, and the vehicle's operating state is predicted, thereby providing optimal information for predicting the time domain control. According to the calculated predicted vehicle state in the future time domain of the vehicle, and then calculating the demand torque of the vehicle, a specific algorithm is used to obtain the optimal motor torque sequence of the system in the predicted time domain under certain constraints. The first value of the optimal motor torque sequence calculated by the predictive control model is added to the vehicle, and then proceeds to the next moment, and continues to acquire information such as historical speed and acceleration of the vehicle, and predicts the running state of the vehicle in the next period to correct The predicted value of a moment. Finally, repeat the steps of prediction, optimization, and correction.

When the control strategy of hybrid electric vehicle is constructed with dynamic programming, its optimization index function is as follows:

$$J_k = \sum_k^{k+p} L(x(t), u(t)) = \sum_k^{k+p} f(t) \quad (1)$$

In the Eq. (1), $x(t)$ represents the state variable of the SOC value of the battery at time t ; $u(t)$ represents the motor torque variable at time t ; L represents the index function at a certain moment; J_k represents the total indicator function; $p \sim p+k$ represents the predicted time domain. $f(t)$ represents the instantaneous fuel consumption of the vehicle at time t .

3 Application of Dynamic Programming in Hybrid Electric Vehicle Model Predictive Control

By using the model predictive control method to predict the future running state of the vehicle, and combining with the dynamic programming algorithm, the optimal sequence of motor torque based on the working condition can be obtained, and then the multi-stage decision-making problem in the driving process of hybrid vehicles can be solved [16–19]. When a certain time domain prediction is carried out, the transition state variable needs to be optimally controlled under certain constraints, and then the SOC variation law designed in the dynamic programming algorithm is utilized, so that the reference trajectory of the SOC can be obtained as the SOC constraint condition in the optimization process.

3.1 Dynamic Programming in The Solution of Model Predictive Control

Suppose that at the time k of the model predictive control system, the predicted time domain of the system is: $k \sim k+p$. If the optimal motor torque sequence and the discrete state variables are solved by the model prediction control system based on the dynamic programming algorithm in this interval, the motor torque optimal value and the optimal index value at each moment can be solved in reverse order [20-23].

In the designed predictive time domain, the optimal index function can be obtained as follows:

$$J_k^*(SOC(k)) = \min_{u(k)} [L(SOC(k), u(k)) + J_{k+1}^*(SOC(k+1))] \quad (2)$$

In the formula, $J_k^*(SOC(k))$ represents the optimal index value from k time to $k + p$ time; $u(k)$ is the optimal torque value corresponding to the k time in the prediction time domain.

Only take the first value of the optimal motor torque sequence in the predicted time domain, and do not take the motor torque sequence at the remaining time to reduce the calculation amount and increase the running speed.

3.2 SOC Reference Trajectory and Its Application

When the cycle condition is determined (as shown in Fig. 1), the SOC curve obtained by global optimization has certain regularity. With the increase of vehicle mileage, the SOC changes from initial SOC value to the lowest threshold value of SOC. As shown in Fig. 1, the SOC decreases steadily and fluctuates smoothly around a straight line.

Assuming that the travel time of the car to the destination is determined, according to the law of SOC change in dynamic programming, the change of SOC is basically linear attenuation, The theoretical change trajectory of SOC is defined as the linear reduction from the highest value of SOC at the starting point of vehicle operation to the lowest value of SOC. The theoretical SOC change trajectory is taken as the SOC reference trajectory, and the model predictive control is constrained. The SOC theoretical reference trajectory is shown in Fig. 1.

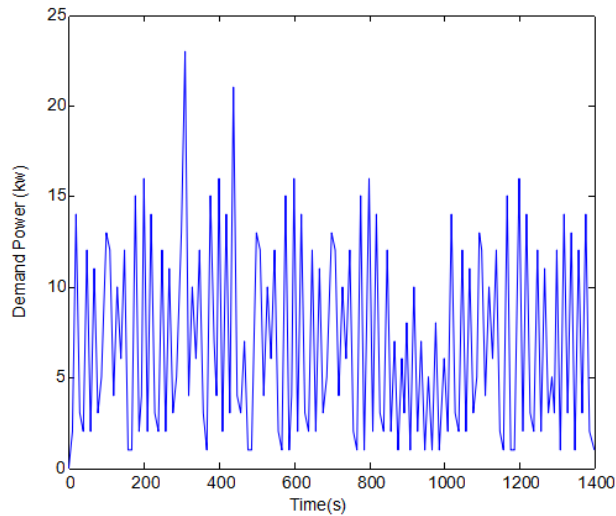


Figure 1: Demand power diagram under cyclic conditions

The reference SOC value for any time k can be calculated by the following formula:

$$SOC_r(k) = SOC_0 - \frac{k}{S}(SOC_0 - SOC_f) \tag{3}$$

In Eq. (3), $SOC_r(k)$ represents the SOC value at time k at the reference trajectory, SOC_0 represents the SOC value of the initial running state of the vehicle, which can be set by itself according to the actual situation. SOC_f represents the lowest threshold value of SOC; S represents the length of the total mileage.

The main function of acquiring the SOC reference trajectory is to limit the fluctuation of the SOC under the reference SOC trajectory under actual operation [24–26]. The reference value of the SOC at each time is calculated by the formula (3). The initial SOC value and the termination SOC value can be defined according to the actual situation. Usually, the initial SOC value should reserve a part of the

electricity to provide energy for vehicle start-up, so the initial SOC value should be moved down by a small amount:

$$SOC_0 = SOC_i - 0.01 \quad (4)$$

In the above formula, SOC_i represents the SOC value at the departure time.

At each moment k of the vehicle's operation, the predicted time domain is $k \sim k + p$, in general, the SOC value at each time is constrained to improve the accuracy of the model control. Usually, the quadratic cost function is used to constrain the formula. The formula is as follows:

$$J_k = \sum_k^{k+p} (f(t) + h(SOC(t+1))) \quad (5)$$

In Eq. (5), h is the cost function of SOC. The formula is as follows:

$$h(SOC(t)) = \begin{cases} 0, & SOC(t) \geq SOC_r(t) \\ \alpha(SOC(t) - SOC_r(t))^2, & SOC(t) < SOC_r(t) \end{cases} \quad (6)$$

In Eq. (6), $SOC_r(t)$ represents the SOC reference value at t time; α represents the weight coefficient, takes 1×10^{10} . $SOC(t)$ represents the actual SOC value. When the actual SOC value is greater than or equal to the reference SOC value, the cost function is 0, which has no effect on the index function. When the actual SOC value is less than the reference SOC value, the cost function value is larger, and the larger the difference between the actual SOC value and the reference SOC value, the larger the cost function value is. In this way, the actual running trajectory of the SOC can always be kept above the reference trajectory, which plays a role in the SOC constraint [27–29].

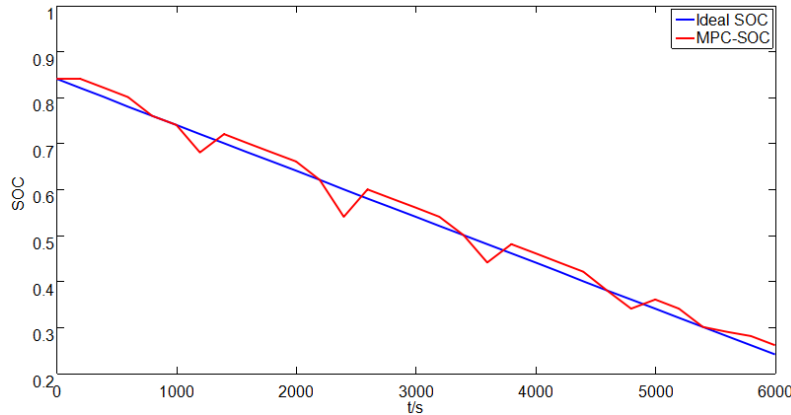


Figure 2: SOC curve of storage battery

This paper takes a hybrid vehicle as the prototype and carries out simulation experiments based on MATLAB simulation software. The vehicle has a mass of 1070 kg, a rated voltage of the power battery of 72 V, a battery capacity of 150 AH, a motor power rating of 5.5 kW, and a rated speed of 3000rpm [30–32]. The UDDS operating conditions were developed by the US Environmental Protection Agency (EPA) to test the cyclic performance of various performances under the urban roads of vehicles. In the case of demand power under cyclic conditions, the system is simulated, and the results are shown in Fig. 2.

It can be seen from Fig. 2 that the dynamic prediction-based model predictive control designed by this paper can optimize the system well, and the SOC value is close to the ideal result, and the expected effect is achieved.

4 Conclusion

In this paper, the application of hybrid vehicle control strategy in model predictive control is discussed. The application of dynamic programming algorithm in model predictive control is proposed. It is mainly used to predict the optimal control motor torque sequence in time domain. The planned reference SOC trajectory is used, and the solution steps of the model predictive control and the SOC reference trajectory constraints on the actual SOC value at each moment are introduced. It is proved that the model predictive control is based on different predictive models, adopting the principle of rolling optimization, and has the advantages of strong robustness, good effect and high stability in linear and nonlinear control systems.

Acknowledgement: This work was supported by the youth backbone teachers training program of Henan colleges and universities under Grant No. 2016ggjs-287, and the project of science and technology of Henan province under Grant Nos. 172102210124, 202102210269, and the Key Scientific Research projects in Colleges and Universities in Henan (Grant No. 18B460003).

Funding Statement: The authors received no specific funding for this study.

Conflicts of Interest: The authors declare that they have no conflicts of interest to report regarding the present study.

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