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Research on Energy Management Strategy of Hybrid Electric Vehicle

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ABSTRACT: To improve the fuel economy and reduce emissions of hybrid electric vehicles, energy management strategy has received high attention. In this paper, by analyzing the deficiency of existing energy management strategy for hybrid cars, it not only puts forward the minimal equivalent fuel consumption adaptive strategy, but also is the first time to consider the driving dynamics target simultaneously, and to explain the future development direction of China's hybrid energy management strategy.

Keywords: energy management strategy; hybrid electric vehicle; the driving dynamics target

1 INTRODUCTION

Energy and environment problems prompt hybrid cars' development towards more energy-efficient and environmentally friendly directions, whereas, the vehicle comfort also requires the automobiles have good driving performance. As the core technology of the hybrid electric vehicle, energy management strategy achieved a reasonable distribution of torque between engine and motor, in order to obtain maximum fuel economy performance, low emission and good driving performance. This paper puts forward the development direction of the energy management strategy in today's global hybrid vehicle, and aims to provide a fast learning and research direction for the researchers, through the comparison of various energy management strategies.

2 RESEARCH STATUS OF ENERGY MANAGEMENT STRATEGY OF HYBRID ELECTRIC VEHICLE

The hybrid control strategy can be divided into three types: main control strategy based on the technology of intuitive judgment, the global optimization control strategy and the instantaneous optimal control strategy.

2.1 *Control strategy based on the technology of intuitive judgment*

Control strategy based on the technology of intuitive judgment including control strategy based on rules, fuzzy logic control theory or the theory of neural network control strategy, can be used in hybrid real-time control. For the control strategy based on rules, Trummel and Burke[1,2] proposed to set the speed threshold value. When the vehicle speed is lower than the threshold value, the car is driven by a motor; when the demand for power exceeds the power of the motor which can be provided, driving engine and motor should be combined; when the speed is higher than the speed threshold value, the car is driven by the engine; only when the demand for power exceeds the power of the engine which can be provided, the motor starts and the engine joints the drive. Later, An[3] and Bulter[4] et al. designed the speed threshold value as a function of storage battery SOC, under different conditions or mileage, dynamic adjustment of the speed threshold value, thus greatly reducing vehicle emissions. The control strategy of fuzzy logic control theory is based on the neural network theory, aiming at achieving a reasonable distribution of hybrid power flow. For example, Kheir[5] proposed the fuzzy rules of controller that the fuzzy logic control rule sets up 44 fuzzy control rules to obtain the optimal torque distribution, exerting the advantage of intelligent control. Based on the rule, the fuzzy logic control strategy based on the control theory is relatively simple, which cannot guarantee that each member of a hybrid system to get the best matching, in obtaining emissions with relatively good performance, and cannot get the best fuel consumption simultaneously.

2.2 *Global optimization control strategy*

Global optimization control strategy of a vehicle in the designated general overall fuel consumption and emission is the minimum to optimize the objective function. In order to realize the global optimization, Rimaux[6], proposed to use DP algorithm to study the global optimal control problem, and set a battery with upper and lower SOC, to obtain optimal engine, power of motor and gear box. But the algorithm only considered the fuel economy, and the emissions did not reduce maximally. And because of its large amount, the calculation of the DP algorithm must know the running condition in advance, so it is difficult to control and apply in vehicle. Later, Delprat[7] et

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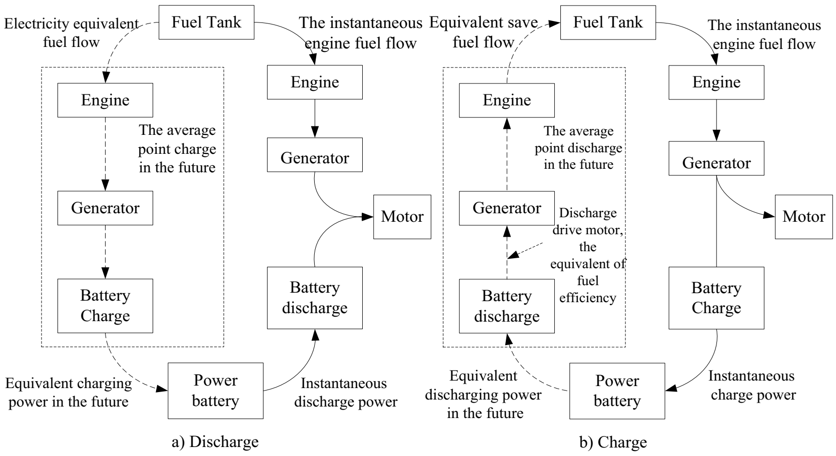

Figure 1. The equivalent fuel consumption map of series hybrid electric vehicle

al updated them, but they only simplified the control parameters and the vehicle application to achieve global optimization, which is still a key technology worth looking forward to.

2.3 *Instantaneous optimization control strategy*

Instantaneous optimization control strategy generally sees instantaneous equivalent fuel consumption and emissions of the hybrid power system minimum as the goal, or considers the system power loss minimum as the optimization objective, so the optimal torque of engine, motor/engine and transmission ratio can be used for real-time control. Paganelli [8] used this strategy to simplify the global optimization problem to a local optimization problem with minimum instantaneous equivalent fuel each time cycle as optimization objective, and the equivalent consumption is equal to the engine instantaneous fuel consumption and the electric motor that can convert to fuel consumption. The experimental results of this control strategy, without significantly lower fuel economy under the premise of NO_X emission can be reduced by more than 10%, and can be applied to the real vehicle. Later, Kleimaier[9] has done some improvement to this policy, but ultimately only considered the fuel economy and emission performance. As the core parameters of the equivalent fuel consumption equivalent factor, it is mentioned very little.

3 EQUIVALENT FUEL CONSUMPTION MINIMIZATION STRATEGY

3.1 *The principle of ECMS*

Equivalent fuel consumption minimization strategy sees the battery as an energy buffer, and all energy consumption will be equivalent to the engine's fuel consumption. The battery can be regarded as a reversible spare energy conversion tank, and the power battery discharge process of the electric energy of consumption needs is in the later stage of the process by the engine fuel consumption supplement. For a particular car condition point, there may be two kinds of circumstances which are as follows:

a) If the power of the battery is positive (discharge), it needs to be charged by the extra fuel of engine.

b) If the power of the battery is negative (charge), the stored energy will be used to reduce the load of the engine, thereby saving part of the fuel.

In the two cases mentioned above, the electricity equals to the fuel consumption, plus the equivalent fuel consumption of the future and the actual fuel consumption. Now instantaneous equivalent fuel consumption can be got, which is shown as follows:

$$\dot{m}_{eqv} = \dot{m}_f + \dot{m}_{ress} = \dot{m}_f + \frac{s}{Q_{lhv}} P_{elec} \qquad (1)$$

Among which, $\dot{m}_f$ is the instantaneous fuel consumption of motors, s is the equivalent factor, P_{elec} is the motor power flow, Q_{lhv} is the fuel heating value, and $\dot{m}_{ress}$ is the power battery power changes in the corresponding equivalent fuel consumption.

According to the positive and negative power battery power, battery power consumption changes of the equivalent fuel correspondingly also can be positive or negative, and thus the equivalent fuel consumption may finally get higher or lower than the actual fuel consumption. The fuel consumption of hybrid vehicles of equivalent series is shown in Figure 1.

3.2 *Equivalent factor*

The equivalent factor is very important for equivalent fuel consumption minimization strategy, which represents the efficiency of the engine and the motor of the future, and its value directly influences the maintainable of a car's power and the effectiveness of the control strategy. If it is too high, the value of the electricity consumed in energy conversion will be overestimated, and the whole hybrid system cannot achieve optimum; if it is too low, consumption value is underestimated, and battery power consumes too fast, and then the maintenance of electricity will be bad. But under the existing research background, the process of the equivalent factor is generally based on the range of SOC. When the SOC value is low, less electricity is used; whereas more electricity is used. The calculation of equivalent factor is mostly based on experience formula, and the instantaneous optimization does not reach it.

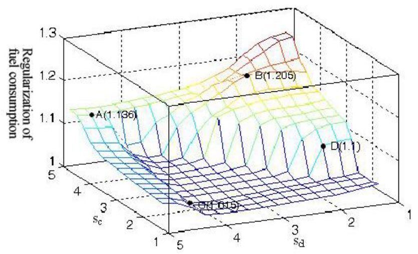

Figure 2. Equivalent factor's influence on fuel consumption figure.

4 ADAPTIVE CONTROL THEORY

To avoid predetermined factor values influence the minimum of equivalent fuel consumption at real-time optimal control, the dynamic adaptive theory is applied to the energy management strategy. Dynamic adaptive control is a kind of modern control algorithms that can adapt to the change of the controlled object's characteristics, and make the system always run in the optimal state. The change of the dynamic adaptive control for object properties, and drifting and environmental interference effect of the system, gradually reduce and eliminate the impact through online identification.

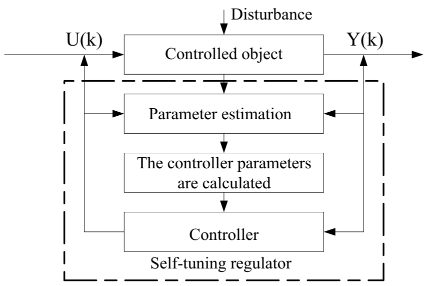

Figure 3. Self-tuning control flow chart.

5 DYNAMIC ADAPTIVE A-ECMS BASED ON EQUIVALENT FUEL CONSUMPTION MINIMIZATION STRATEGY

Dynamic adaptive theory can be used in the equivalent fuel consumption minimization strategy. According to the road conditions, use the battery parameters such as SOC, and real-time adjustment equivalent factor value, to achieve the instantaneous optimal, so as to reduce fuel consumption and emissions, and can get the driving performance parameters based on instantaneous optimal model, to get a multi-objective optimization model.

5.1 *The condition of adaptive prediction*

Use any future information feedback to the ECMS control model to ensure more suitable equivalent factors, which is the first kind of method for A-ECMS. In a series of papers, A-ECMS is created into real-time energy management control by adding a rough algorithm according to the driving conditions to predict the equivalent factor to ECMS framework, to gain A-ECMS algorithm. The main idea is based on the current road load, the driving condition prediction, and the period of updating control parameters. Integrating the past and predicting the data of driving condition to determine the optimal equivalent factor in a certain optimization area and the SOC is also constant.

5.2 *A-ECMS algorithm based on pattern recognition of driving*

Driving pattern recognition method is used to get better predictive equivalent factor in different driving conditions. When the vehicle is running, the periodic analysis of the past running conditions of the time window is recognized as one of the most representative driving patterns; the limited driving mode is recognized as far as possible, and each code corresponds to a preset good equivalent factor (pre calculated on off-line). Battery SOC management uses PI controller to maintain it in a ratings (using SOC feedback); this method does not need to acquire information of future driving conditions without using too much computational calculation, but it needs more storage capacity.

5.3 *Adaptive algorithm based on SOC feedback*

By using SOC feedback controller, updating the equivalent factor values at each instant, and compensating the SOC deviating value from the reference value, the most ideal results are that the equivalent instantaneous correction factor can counteract the SOC deviation corrector, and the proportion of P part has the same effect on penalty function weights, and the relationship between the equivalent factor and penalty function is a line. Equivalent factor update based on the current SOC value feedback, significantly changes the equivalent factor value to make reference value of SOC maintenance. SOC feedback based algorithm has three kinds, respectively, a simple proportional controller, the PI controller, A-ECMS based on the discrete time. The characteristic formula of A-ECMS[10] is based on discrete time series as follows:

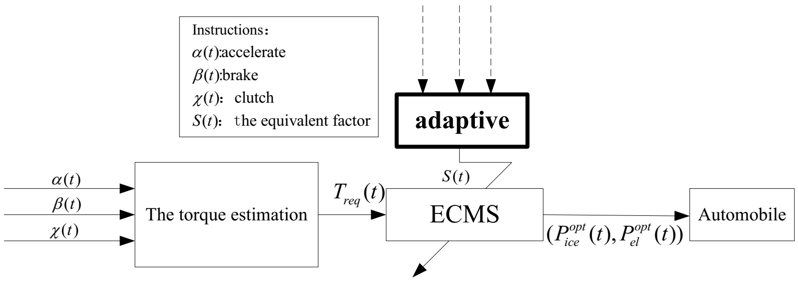

Figure 4. The basic principle diagram of A-ECMS.

$$S_k(x,T) = \frac{s_{k-1}+s_{k-2}}{2} + k_P^d(x_{ref} - x(T)) \qquad (2)$$

A-ECMS is based on discrete time series, using autoregressive moving average (ARMA) model, with two autoregressive and a moving average model. The main characteristics are the continuous time discrete to a period of time, and avoid the time instant, which make SOC can be maintained constantly over a period of time, and can get the optimal equivalent factor value, but also can simplify the control strategy.

5.4 *Adaptive equivalent principle diagram of the minimum fuel consumption*

As shown in Figure 4, where $T_{req}(t)$ is the demand torque, and $(P_{ice}^{opt}(t), P_{el}^{opt}(t))$ is the engine and motor power demand. According to the condition of driving pattern recognition, the SOC feedback, adaptively adjusts the equivalent factor value and achieves the real-time optimal control.

5.5 *The vehicle control model considering the driving performance*

The vehicle control model allows for the driving performance, and establishes the evaluation of driving performance to extract the feature parameters from the fuel economy and exhaust emissions performance. The model of adaptive equivalent factor is based on the feedback of SOC, and as the change of the battery SOC, the response function of equivalent factor is established.

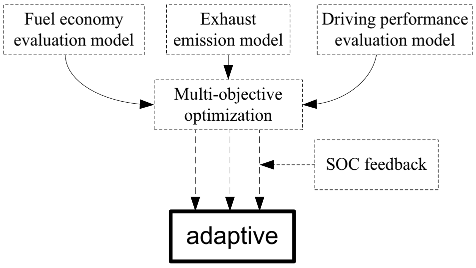

Figure 5. Multi-objective optimization of A-ECMS.

6 CONCLUSIONS

a) With the method of artificial intelligence, combining the learning ability with the adaptive neural network control and adjusting the equivalent factor are the development trend in the future.

b) Energy management strategy should satisfy the real-time control on the basis of the optimization algorithm, and reduce the load of computer, so that it can be more suitable for real vehicle control.

c) Energy management strategy, which can be combined with the control of the whole vehicle, takes the fuel economy, emission, driving comfort, safety performance as well as other indicators into consideration.

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