Analysis and model development of hybrid power control strategy

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Abstract: Plug-in hybrid electric vehicle, as a part of new energy vehicle, plays an important role in energy saving and emission reduction. Taking one Plug-in Hybrid Power System as a sample, this paper first analyses the vehicle control strategy through experiments, including mode switching conditions, energy management strategy and other control strategies; and then builds the vehicle control strategy model to simulate the relevant economic indicators using Simulink according to vehicle benchmark strategy. Finally, the simulation results are compared with the experimental results, which further verifies the correctness of the vehicle control strategy and model, realize the model development of competitive car. The development of competitive vehicle model not only has the reference value of vehicle key control strategy, but also can study and analysis the influence of these parameters on vehicle dynamic and economy by modifying the component parameters or key control parameters in the simulation model, so as to provide the direction for the development of new vehicles.

1. Introduction
With the continuous inclination of the state's policy on hybrid vehicles, major domestic OEMs have invested in the research of hybrid vehicles. However, the whole vehicle strategy design of hybrid electric vehicles is complex for new company. Therefore, the role of model development of competitive cars is gradually highlighted.

In the model development of competitive vehicle, firstly, through a large number of tests, analysing the key control strategies of the whole vehicle, then building the control strategy model of the whole vehicle based on this. At last the accuracy of the whole vehicle simulation model is improved by constantly improving the control strategies of powertrain, component parameters and test data. It is convenient for the main vehicle factory to efficiently select the powertrain and vehicle matching design, and reduce the cost of test, save vehicle development cycle [1].

2. Analysis of key control strategies of powertrain
In this paper, one PHEV vehicle of P2 frame is taken as the research object. P2 powertrain architecture in this paper includes engine, clutch, motor, automatic transmission and output shaft, as shown in Figure 1 below:
Figure 1. P2 power system architecture.

The powertrain control strategy refers to the control process from the driver's input to the final output of the vehicle in the driving state, which is analysed according to the strategy framework shown in Figure 2. The paper mainly introduces the mode switching and energy management strategy.

2.1. Analysis of mode switching strategy
The vehicle has three energy management modes, namely Max E-drive, Auto E-drive and Save, and have three driving modes, namely Eco, Comfort and Sport. Through the experiment and analysis, the switching law of vehicle working mode under three kinds of energy management modes and three kinds of driving modes is analysed. This car has two working modes, electric mode and hybrid mode. In electric mode, the clutch is disconnected and the motor drives the vehicle separately; in hybrid mode, the clutch is closed and the engine or motor drives the vehicle together. Mode access conditions are related to energy management mode, driving mode, vehicle speed, SOC, driving force and other factors.

When the whole vehicle is in auto E-drive energy management mode and switched to sport mode, the engine is always in start state, and the vehicle is mainly in hybrid mode. When switching to eco / comfort mode, driving force and vehicle speed are the switching conditions, and the driving force and vehicle speed switching values are not equal in CD and CS stages, as shown in Figure 3 and figure 4 below.

From figure 3, it can be seen that in CD stage, when the vehicle speed is lower than 70km / h, the switching conditions of pure electric and hybrid mode is related to driving force and vehicle speed; when the vehicle speed is higher than 70km / h, the vehicle directly enters the hybrid mode.

From figure 4, it can be seen that in CS stage, the engine starting condition is related to the vehicle speed and driving force when the speed is below 18km / h. And above 18km / h the driving force condition will not change until the maximum switching speed is about 53km / h. The switching condition
from hybrid mode to electric mode is that the driving force is less than 700N·m and the vehicle speed is less than 50km/h.

When the vehicle is in the Max E-drive energy management mode, no matter which mode is switched to Eco / Comfort / Sport, the vehicle runs in pure electric mode, until the SOC is less than 35%, the vehicle enters the Save mode, the engine starts, and the battery is charged.

When the whole vehicle is in the Save energy management mode and switched to Eco / Sport mode, the vehicle can enter the hybrid mode when driving; when switched to Comfort mode, the mode switching is mainly based on the conditions of vehicle speed and driving force, which is consistent with the switching values of vehicle speed and driving force in Auto Comfort mode.

2.2. Energy management strategy

There are three kinds of energy management modes in the vehicle. Under the Max E-drive energy management mode, the vehicle is driven by pure electricity, and the motor provides energy source.

In the hybrid mode, there are two energy allocation strategies: power following and power generation.

There are two energy management strategies in Auto E-drive and Save. When SOC is higher, power following strategy is used, and when SOC is lower, power generation strategy is used [2].

2.2.1. Power following strategy. Under the power following strategy, the engine power and driving power are basically the same, the motor does not participate in the driving, basically does not consume electricity, and can maintain the SOC basically unchanged. As shown in Figure 5, it can be seen that the motor torque range is less than 20N·m after the engine starts, and the duration is very short, which is used for compensation in the process of engine working point change, and the torque size depends on the engine response state.

![Figure 5. The relationship of power source in power following strategy.](image)

2.2.2. Power generation strategy. Under this strategy, the driving power of the engine is higher than the driving power at most of the time, and the redundant power is used for power generation. Take one of the sections, as shown in Figure 6. When the engine is turned on, the motor basically keeps generating power. When the engine works in steady state, the generating power is about 15kw; when the engine works in unsteady state, the motor will coordinate with the engine to supplement or absorb the power of the engine.
3. Vehicle Simulink model and simulation

3.1. Vehicle simulation model design
According to the analysis of control strategy, use Simulink to build the longitudinal dynamics simulation model of the whole vehicle, and the top-level design is shown in Figure 7 below:

Clock is the time model. The Drive Cycle model generates the required vehicle speed for the cycle conditions. The Driver model is the driver model, and the pedal opening is calculated according to the current speed and the required speed. The Control Strategy model is a control strategy model, which controls the vehicle according to driver input and vehicle status. Vehicle model is a vehicle model. The following mainly introduces the Control Strategy model [3].

3.2. Control Strategy model
The purpose of simulation of control strategy model is to establish the longitudinal dynamic model of the real vehicle, and simulate the real vehicle as much as possible for further research.

The overall control idea of the vehicle is as follows: after the signal input by controller is processed, it is used to estimate the working target and working capacity of the vehicle under the current state, mainly including the maximum torque of each power source, driver’s demand driving force, charging power, etc. Then according to the analysis of the vehicle mode switching rules, we can judge which mode the vehicle should work in, and switch to this mode when conditions permit; the vehicle is divided into three modes: pure electric, hybrid and braking. Then, in the corresponding mode, the target gear of the system is determined according to the gear switching rules and the gear diagram. Then the working condition of each power source is calculated in the corresponding mode, mainly the demand torque of the engine and motor; the motor is used to meet the demand in pure electric mode; the engine demand...
torque is determined according to the total demand power of the system in hybrid mode, and the motor is used to supplement the difference between the driver demand torque and the engine torque; when main control mode is braking, the motor produces negative torque, and the motor simulates the braking force that can be generated by the brake disc under normal mechanical braking. The insufficient braking force is supplemented by the brake. Finally, the signal is sorted out and output.

3.3. Master control model
The whole vehicle control strategy is established in Simulink, including data input model, input signal processing model, main control model and signal output. The main control model is the core of the control strategy and the basis of its function. The structure of the control model in the strategy is shown in Figure 8, including data estimation model, mode selection model, gear selection model, energy management model and clutch control model. This paper mainly introduces mode selection model and energy management model [4].

![Figure 8. Master control model.](image_url)

![Figure 9. Mode switch model.](image_url)

3.4. Mode selection model
Mode Switch model let the vehicle enter the corresponding mode and perform the relevant actions of state switching, the model is shown in Figure 9, the input mode switching signal, the flag of the output mode and the the already switched mode. When receiving the driving / braking switching signal, it will switch to the corresponding driving / braking mode. In the driving mode, it will switch to the corresponding driving mode according to the switching flag bit of pure electric / hybrid drive.

3.5. Energy management model

The energy management model is shown in Figure 10. After the energy management model obtains the vehicle state, each power source is controlled according to the mode and demand.

Vehicle working mode is mainly divided into pure electric (EV) mode and hybrid drive (HV) mode. In EV mode, the motor responds to the driver's full demand, the engine does not start, and the braking torque is zero.

In the hybrid drive mode, if the power following strategy is used, the engine only needs to meet the driving power demand; if the charging strategy is used, the engine needs to meet the full power demand of driving and generating. The target torque of the engine is determined by the total demand power combined with the current engine speed, and then the motor fills in the difference between the actual torque of the engine and the target torque of the driver[5].

4. Comparison between the simulation results of the model and the actual results of the whole vehicle

The economic simulation selects the NEDC cycle condition of CS stage. The purpose of the simulation is to verify the correctness of the model and the whole vehicle control strategy by comparing the parameter of the simulation model under the same condition as the real vehicle, including the difference of the working point of each power source, SOC value, comprehensive fuel consumption value, etc.

Take Auto drive + Comfort mode as an example, select the initial SOC of the CS phase is 34.2% of the NEDC cycle condition, and the simulation is carried out under the same condition to obtain the speed, SOC and motor engine speed. The comparison between the simulation results and the experimental results is shown in the following Figure 11-14: the speed is basically the same, the simulation results of SOC value and the experimental results are not much different, the maximum difference of SOC real-time error is not more than 1%, the simulation values of motor speed, the values of engine speed and the experimental results are basically the same.

SOC is almost the same in NEDC cycle test, and the fuel consumption is 7.85L/100km. The actual comprehensive fuel consumption of the real vehicle is 3.9L/100km, and the driving mileage of pure electric vehicle is 27 km, According to the formula in national standard 19753-2013[6]:

\[ C = \frac{D_e c_1 + D_{av} c_2}{D_e + D_{av}} \]  

(1)
So getting the fuel consumption is 8.1L/100km in CS stage. The difference between simulation and test is 3.1%, which meets the accuracy requirements.

5. Conclusion
In this paper, the P2 structure of the hybrid is taken as a sample, through a large number of test, the whole vehicle powertrain control strategy is analysed, including working mode switching conditions, energy management strategy, etc. Firstly the P2 powertrain control strategy is preliminarily analysed. Then, based on the analysed control strategy, the whole vehicle power system model is built to simulate the whole vehicle economy in CS stage.

Compared to the simulation results and experimental results, the difference of SOC, motor speed and engine speed is little, the maximum difference is less 1%. And the comprehensive fuel consumption obtained by simulation are basically consistent with the actual values, the simulation result is 7.85L/100km, the actual result is 8.1L/100km, the difference between simulation and test is 3.1%, which meets the accuracy requirements. So further verifying the correctness of the vehicle powertrain benchmarking strategy and model.

Through strategy benchmarking and model building, the goal of model-based development of competitive vehicles is realized, which can provide research direction for P2 architecture about plug-in hybrid power development, and appropriate adjustment of model parameters can also be applied to the development of new power system control strategy, shorten the R & D cycle and save enterprise costs.

6. References
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