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Research on the control strategy of distributed electric vehicle based on xpc test platform

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Abstract. In this paper, the distributed hybrid electric vehicle is taken as the research object. A drive control strategy is proposed based on the optimal working curve control strategy of the engine, and taking full consideration of the battery SOC working range and boundary speed threshold. The strategy model was generated xPC Target executable program by MATLAB/RTW toolbox and it was downloaded to the target machine to be run in real-time. The vehicle controller access the xPC real-time simulation testing system, which have simulation analysis on the condition of 0-32km/h acceleration. The test results demonstrate that the hardware in the loop simulation of xPC structure is feasible, and the real-time simulation testing system is reliable, meanwhile the rationality of the driving control strategy on this platform is verified.

1. Preface

With the improvement of environmental protection requirements, more pollutants are emitted from traditional vehicles, and there are shortcomings in pure electric vehicles, such as short mileage and high battery cost. Therefore, The hybrid electric vehicles can be used as intermediate products for transition to electric vehicles\cite{1}. Because the hybrid power system has multiple power sources, this will improve the power assembly control technology, and the establishment of a reasonable and effective vehicle control strategy plays a vital role in improving the power and economy of the vehicle\cite{2}. At present, most of them are based on the rule logic threshold control, but the parameters are too single, so we need to further optimize the control strategy and improve the overall performance of the vehicle\cite{3, 4}.

The development of the vehicle controller is based on the modern V mode process. After the hardware and software design is completed, the test of Hardware in the loop is required. The HIL based on LabCar and dSPACE real-time system platform is widely used, high real-time but expensive.

This paper regards distributed hybrid electric vehicle as the research object. A control strategy based on multi parameter logic threshold to find the optimal working interval is proposed. The
Hardware in the Loop simulation test platform based on MATLAB/RTW/xPC structure is built, which verifies the reliability and feasibility of xPC real-time system and the rationality of drive control strategy. It introduces a convenient and low cost method for vehicle controller rapid prototyping development.

2. Design of vehicle driving control strategy

The vehicle driving control strategy mainly includes three key problems: vehicle demand torque analysis, working mode judgement and torque distribution. The driving control strategy based on the rule based logical threshold optimal working interval is proposed. The aim is to reasonably control the smooth switching of the hybrid power system under different working modes and make the total energy conversion efficiency reach the best.

2.1 Optimal operation interval control strategy for engine

The curve obtained by the optimal working point of the engine is determined as the optimal working curve $T_{e, best}$ of the engine economy by using the least square method. The maximum torque working curve $T_{e, max}$ of the engine and the engine closes the working curve $T_{e, off}$ can be obtained by fitting the test data external characteristics of engine.

The best economic working area of the engine are defined as $T_{e, low}$ and $T_{e, high}$ respectively. The schematic diagram of the logic threshold control strategy based on the optimal operating range of the engine is shown in Figure1.

![Figure1](image_url)  

**Figure1.** The schematic diagram of the logic threshold control strategy

When the power battery $SOC<SOC_{min}$, the vehicle demand torque is higher than $T_{e, best}$, because the SOC is low, it will be driven separately by the engine, and make it work on the $T_{e, best}$. If the vehicle's demand torque is lower than $T_{e, best}$, it will be limited to $T_{e, best}$, and the remaining power will be charged to the power battery by the generator.

When the power battery $SOC<SOC_{min}$, the vehicle works at low speed or low torque range, it will be driven separately by the wheel motor. If the vehicle demand torque is higher than $T_{e, best}$, both of the engine and the wheel motor drive together, the engine works on the optimal curve, and the remaining demand power is provided by the wheel motor. If the vehicle demand torque is between $T_{e, best}$ and $T_{e, off}$, the engine is limited to work in $T_{e, best}$, and the remaining power is charged to the battery by the generator.

2.2 Vehicle driving control strategy

The vehicle driving control strategy is mainly composed of three parts, namely vehicle demand torque analysis, working mode judgement and torque distribution.
2.2.1 Identification of the vehicle demand torque

Vehicle demand torque includes driver's demand torque, braking torque and charging torque of power battery pack. It is related to the acceleration / brake pedal opening size, SOC, the actual speed of each power unit and the transmission ratio. The calculation formula is as follows:

\[
T_{req} = \alpha (T_{eng_{ne}} + \beta) + \beta T_{brk_{max}} + \frac{P_{ch_{req}}}{\omega g} (1)
\]

In the formula: \( T_{req} \) is vehicle demand torque(N•m); \( T_{eng_{ne}} \) is maximum torque output at current engine speed(N•m); \( T_{mot_{nm}} \) is maximum torque output at current motor speed(N•m); \( P_{ch_{req}} \) is demand charging power for power battery(kW); \( \alpha \) is acceleration pedal opening(%); \( \beta \) is brake pedal opening(%); \( ne \) is engine current speed(r/min); \( nm \) is motor current speed(r/min); \( \omega g \) is angular velocity of the generator(rad/s); \( i_m \) and \( i_e \) is the current total transmission ratio of the mechanical power path and the electric power path.

2.2.2 Work mode judgment

Reasonable mode switching has an important influence on the economy and smoothness of the hybrid electric vehicle, which is related to the demand torque of the vehicle, SOC, velocity and the state of the power components. The specific mode of work switch conditions are shown in Table 1.

| Working mode   | Engine | Generator | Motor | Judgement condition                                                                 |
|----------------|--------|-----------|-------|-------------------------------------------------------------------------------------|
| Electric vehicle | Close  | Close     | Open  | \( 0 < T_{req} < T_{e_{off}} \) \& \( V_{act} < V_{m_{max}} \) \& \( T_{req} < T_{m_{max}} \) \& SOC > SOC_{l} |
| Engine drive   | Open   | Close     | Close | \( T_{e_{low}} < T_{req} < T_{e_{high}} \) \& \( V_{act} > 55 \) \& SOC > SOC_{low}          |
| Hybrid drive   | Open   | Close     | Open  | \( T_{req} > T_{e_{high}} \) \& \( V_{act} <= 55 \) \& SOC > SOC_{low}                     |
| Drive charging | Open   | Open      | Close | \( 0 < T_{req} < T_{e_{low}} \) \& \( V_{act} <= 55 \) \& SOC < SOC_{low}                 |

2.2.3 Torque distribution

According to the above analysis, the basic distribution torque of the engine, generator and wheel motor is first established. After the base torque is determined, which is corrected by the change rate of the pedal signal. At the same time, taking full account of the load carrying capacity and discharge capacity of the engine, motor and battery, the target torque of each power unit is finally determined.

3. Real-time simulation based on xPC Target

In this paper, a simulation platform was build based on real-time simulation of MATLAB/RTW/xPC Target and the hardware in the loop simulation test of the vehicle controller was carried out.

3.1 Construction of xPC Target real time system

3.1.1 Working principle of real time system

In the xPC Target real-time system, two PC machines are selected, one is the host and the other is the target machine. First, the simulation model of the vehicle and configure the interface model on the host computer was built. The target real-time code was generated by the MATLAB/RTW toolbox when the requirement function design was finished. The target executable program was compiled by VC and download it to the target machine that is running a real-time kernel provided by MATLAB. Last, the input and output device is equipped on the target machine to interact with the hardware of
external controller to realize the loop simulation [5,6,7]. During the whole real time simulation, modify parameters, monitor signals, and store data were carried on the host, and also be displayed on the target machine. The structure of the xPC Target real-time simulation system is shown in Figure 2.

Figure2. xPC Target real-time simulation system structure

3.1.2 Target machine configuration

The target machine is started by a special startup disk created by xPC Target, with a real-time kernel downloaded from xPC in the boot disk. The target boot disk plays the role of calling and running the real time kernel of xPC Target. In this paper, a U disk with memory of 128M is used to make the target boot disk. First, the U disk is made into a DOS boot disk by using USBoot to select ZIP work mode. And, in the xPC target environment setup dialog box, set the attribute configuration Targetboot to DOS Loader, click the BootDisk option, xPC will copy the real-time kernel file into the startup disk, and four files will appear in the disk. Finally, the target machine is loaded into BIOS, set to U disk startup, that is, the target machine starts to run the real-time kernel in the DOS environment, and the xpctest statement is entered in the host MATLAB command window, and the test script is run to check whether the connection successful between the two computers.

3.1.3 Hardware in loop communication test

Combining the characteristics of the controller and the xPC platform, the real-time serial communication between the host computer and the lower computer based on the xPC Target environment is adopted.

(1) Software design of controller serial communication interface

The interface software handshake protocol is preset before analysis data of the serial communication. It is intended to avoid the error or invalid of the data in the process of transmission. When the controller receives the handshake signal which is defined by the prior communication protocol, the data is received and received, and the time interval of each transmission is 10ms. If the handshake signal is not identified, keep waiting. The flow chart of the controller serial communication is shown in Figure 3.

(2) Design of serial communication interface software for xPC system

The Simulink/xPC Target/RS232 module library is called to provide six modules for serial communication, include Setup, Enable TX, Filter Int Reason, Read HW FIFO, Read and Filter. Baud rate, data bit, handshake protocol, and serial port address are set in Baseboard Serial Setup. It is required to meet the configuration requirements of the serial port on the main board. In order to verify the normal communication between xPC system and controller serial port. A set of accelerant pedal opening and motor speed given by the host computer are sent through the serial port. The test results
show that the controller can receive the data sent from the host computer and feedback the information.

![Controller serial communication flow chart](image)

**Figure3.** Controller serial communication flow chart

### 3.2 Real-time simulation analysis of acceleration performance

The controller is connected to the real-time simulation system, configuring the interface program, automatically generating the C code on the host machine's controlled object model, and compiling it into executable target program to download to the target machine. After the controller receives the excitation signal, the controller is executed according to the control strategy, and the result is transferred to the object model in the target machine. After the controlled object model runs in the real-time system, the state information is transferred to the controller. The state and control variables are monitored in real time on the control interface of the target machine.

Under the condition of normal communication, the real time simulation test of vehicle in 0-32km/h acceleration is carried out. The relationship between velocity and gear with time is compared with off-line simulation results, as shown in Figure 4. In real time system, the response time of vehicle running velocity is faster and the gear switch is more sensitive, but the trend of simulation data curve is basically the same with off-line simulation. The results also verify that the xPC Target real-time simulation system is not only reasonable and feasible, safe and reliable.

![0-32km/h Real-time simulation of acceleration performance](image)

**Figure4.** 0-32km/h Real-time simulation of acceleration performance
3.3 Real time test of xPC system

The real time simulation means that the running time scale of the simulation model is infinitely close to the system running under the real environment. The guarantee of simulation real time is not only dependent on the real-time performance of the simulation algorithm, but also a challenge to the running speed of the computer. For the xPC real-time simulation system, a group of verification tests that continuous cutting sample time were done to test the system's real-time operating limit at what level of sampling time. The comparison of the simulation results for the change of the shift at the three sets of sampling time in the 0-32km/h acceleration condition is shown in Figure5. The real line indicates that the sampling time is 0.1s under off-line simulation. The dashed line indicates that the sampling time is 0.1×10^{-2}s under real-time simulation. The dotted line indicates that the sampling time is 0.1×10^{-3}s under real-time simulation. The smaller the setting value of the sampling time, the higher the degree of real time. However, when the sampling time is less than 0.1×10^{-4}, the system invalid data cannot be displayed, and the target machine displays CPU overload error.

![Figure5. Different sampling times comparison of simulation results](image)

4 Conclusion

(1) With distributed hybrid electric vehicle as the research object, based on the optimal engine working curve, the design of the demand torque analysis, mode judgement and torque distribution control strategy were completed.

(2) The hardware in the loop test platform is built based on the real-time environment of Matlab/RTW/xPC Target. The results show that the real-time simulation is basically consistent with the off-line simulation results, which verify the correctness of the software configuration of the controller, the feasibility of the HIL technology of the xPC structure and the reliability of the real-time simulation test system.

(3) The real-time simulation system is affected by the real-time performance of the simulation algorithm and the running speed of the system environment. Under the same algorithm condition, the faster the system runs, the better the real-time performance. The faster the response time of the state and control amount in the model, but also limited.

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