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Study on the high voltage electric safety of electric vehicle

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Abstract

Dongfeng Motor Corporation has a wealth of experience in developing the high voltage electric safety of electric vehicle battery and the matching system of high voltage electric safety. By analysis of electric vehicle needs and decomposition of target, we make detailed design of high voltage electric system, and then the design of relay assembly. The control interface of high voltage electric safety system module of the battery management system is confirmed. And the hardware and software of high voltage electric safety system are designed.

Through the studying on the high voltage electric safety system of electric vehicle, Dongfeng Motor Corporation masters the technique of it. The high voltage electric safety system with independent intellectual property right, high performance, safety and reliability, low cost, which can meet the need of different types of vehicles are developed. The technology research platform of software and hardware of battery management system with high voltage security is established. The research capability about the high voltage electric safety control of new energy automobile is developed. We also master the key technologies of high voltage electric safety system, such as external insulation test of battery pack, internal insulation and leakage detection of battery pack, the design of high voltage circuit control strategy. The fault mode, failure mode, automatic diagnosis and safety control strategy of high voltage electric system are evaluated. The test standard and evaluation certification system of high voltage electric safety system of the electric vehicle are formed.

Keywords: High voltage, Electric safety, Electric vehicle

1. Introduction

Electric vehicle is the 21st century green car, its market becomes bigger and bigger. Compared with the traditional diesel locomotive electric system, the voltage of electric vehicle has increased from tens of volts to several hundred volts[1-3]. The features such as high electric power and complexity of the electric system make the electric safety of electric vehicle different from that of conventional diesel locomotive[4-7]. So it should pay much attention to high voltage electric safety system. With the in-depth study of electric vehicle and the accelerated process of industrialization, the research of high voltage electric safety of electric vehicle becomes particularly important[8-10].

2. Research and Discussion

2.1 Research Methods

The research of the high-voltage electrical system composition of electric vehicle can be studied from power source, power distribution system and using electricity system aspects. In the respect of power source safety, dustproof, waterproof, fireproof, ventilation, cooling and insulation of the battery box is very important. In order to ensure the life of the battery pack, the safety of crash and wading of the power source should be assured. In the respect of electric shock protection of power distribution system, the circuit should be shut down by Maintenance switch and linkage locking switch before repairing of the high-voltage battery system. The electric shock of the repairman is simulated in this research. In the respect of influence of high-voltage on personal, the inspection system of leakage protection should be developed and integrated in the battery management system. Then the corresponding test is done to verify its accuracy.

By analysis of electric vehicle needs and decomposition of target, the performance target of battery pack and the design target of each high voltage electrical safety subsystem are obtained. We make detailed design of high voltage electrical system, and then the design of relay assembly. Then the types of sensor, insulation resistance, relay, fuse and other components are confirmed according to the design requirement, accuracy requirement and safety standard. The control interface of high voltage electric safety system module of the battery management system is confirmed. The hardware and software of high voltage electric safety system are designed. The control logic of power up and down, the control strategy of charging, the protection of insulation test, the control strategy of software, the design of hardware circuit are achieved.

The three-tier model is established by using the architecture of Autosar. This model formed the framework from underlying driver module to the upper control strategy. The control model is set up by using Matlab/Simulink and the offline simulation is carried out. Then multiple offline and online simulation of the entire control system is carried out to optimize the design. The rapid control prototype is developed by using dSpace to improve the efficiency of development.

In laboratory condition, the trial produce of relay assembly and BMS are accomplished and the fault simulation test is carried out. The high voltage safety control module of control system is tested to verify whether it achieved the expected result. The relay assembly is tested to verify whether it achieved the expected function. And then the electrical performance, leakage protection function, reliability, electromagnetic compatibility are tested under electric vehicle condition to ensure the safety of high voltage electrical system. The safety control and protection of high voltage electrical system of electric vehicle can be achieved in this way.

2.2 Technology route

The framework of the technology route is shown in Fig.1.

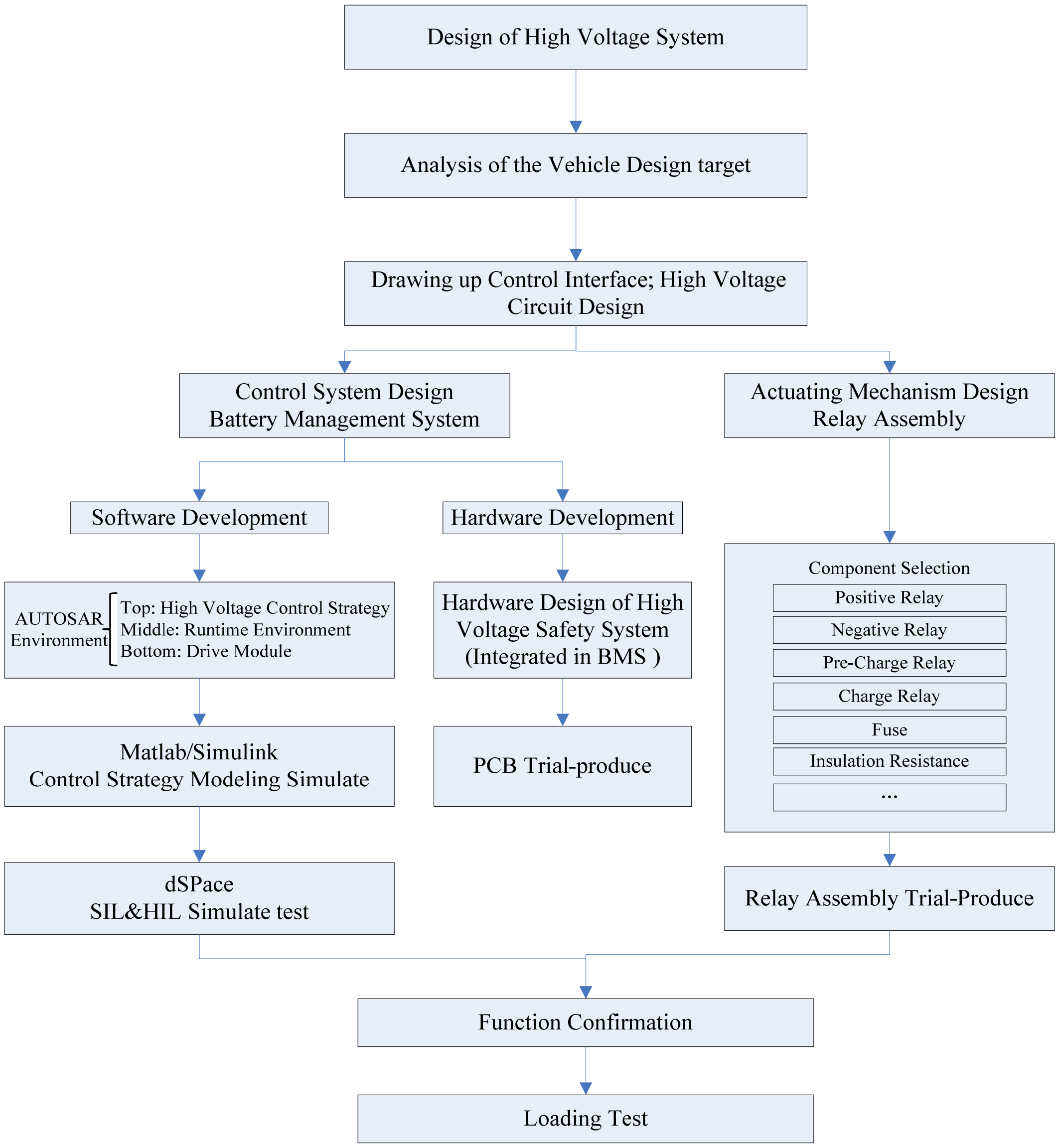

Fig.1 Technology route

2.2.1 The function of high voltage system

The main function of high voltage system is the logical distribution of electricity according to the requirement of electric vehicle. In addition, the leakage protection can be carried out by the high voltage system to ensure the safety of electric appliance and personal. The function of high voltage system is shown in Fig.2.

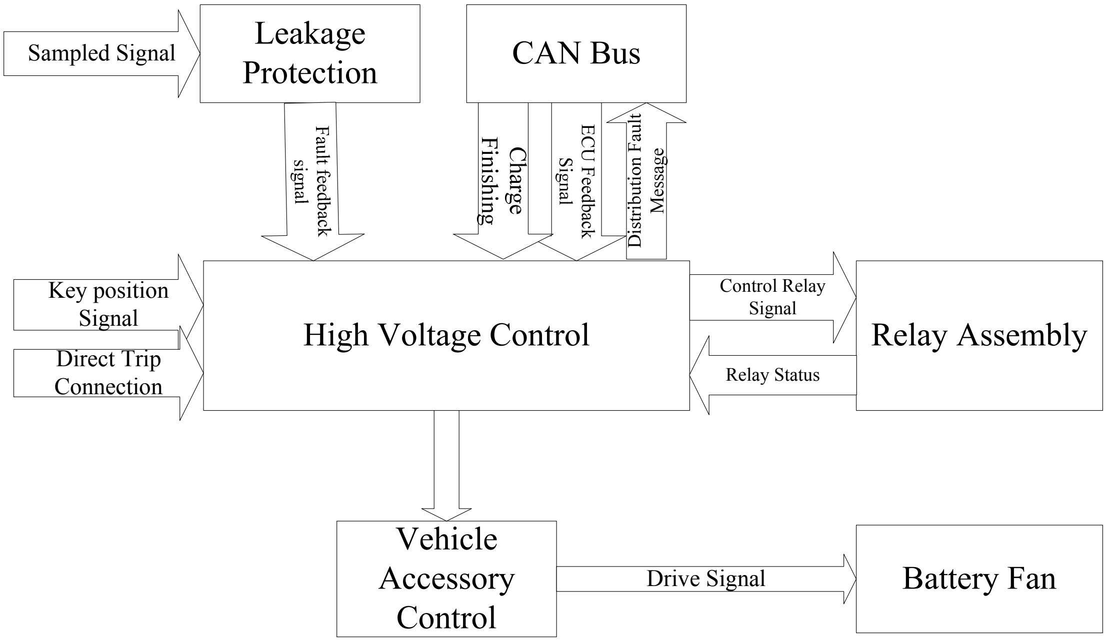

Fig.2 Structural drawing of function module of high voltage

2.2.2 Power-on logic

Turn on the high voltage system, then turn on the high voltage switch and driving/charging switch. At this time, high voltage electrical leakage inspection system starts to work. If it has leakage electricity, the high voltage auxiliary relay does not work and it will give the instruction to the multi-energy controller to alert. If there is no leakage electricity, the high voltage auxiliary relay will work, high voltage indicator light and high voltage value is showed on the dashboard. After that, the motor controller is pre-charged. Because the charge mode is direct current charging, large transient current is flowed in the circuit at the beginning of the charge. So the circuit requires larger power remaining. In the case of a certain charging voltage, there is only one way to only to increase the current limiting resistor to reduce the impact of the large transient current. The only one way is increasing the value of the resistance, but it will increase the charging time in this way. Another problem is the probably fault of the input of high voltage equipment. The fault will bring about high voltage impulse. It is dangerous in this situation.

To solve this problem, we can use the method of pre-charge (charging the external load circuit by battery) process. Its primary purpose is to determine the equivalent capacitance of high voltage system, select the pre-charge resistance and determine the pre-charge time. When the pre-charge of motor controller is completed, an instruction is sent to the high voltage controller. After receiving the instruction, the charging circuit is cut off, the high voltage controller is waiting for the order which sent from multi-energy controller. The main relay is controlled by the high voltage controller according to the order which sent from multi-energy controller. The direct high voltage is added to the motor controllers. Power-on process is completed.

2.2.3 Leakage protection

The insulation of electric vehicles is measured by the insulation resistance between high voltage circuit and car body. International standard stipulation of electric vehicle (China Automotive Standard GB/T18384.3-2001): The electric vehicle nominal voltage value of DC system is divided by the insulation resistance value, the result should be bigger than 100Ω / V. This is consistent with safety requirement.

2.2.4 High voltage safety module of control system

High voltage safety management system is characterized by multi-level, comprehensive protection mechanism. The characteristics are mainly expressed in the following aspects:

(1) The safety elements are considered at every level. At the system level，battery voltage, temperature, insulation resistance are analyzed. Furthermore, the change rate of battery temperature and voltage is analyzed.

(2) The self-diagnosis function is designed in the battery management system. The self-diagnosis of the sampling function and relay control function is designed. The situation of the sampling circuit and the relay whether they work or not is determined by the self-diagnosis result.

(3) A temperature sensor is installed in each battery electrode. The temperature sensor is a positive temperature coefficient thermistor. All of the thermistors are used in series. When one battery temperature is increased, the resistance of the thermistor is increased until the circuit is cut off. By detecting the resistance of the thermistor, the battery can be protected.

The fault diagnosis of electric vehicle high voltage system can be achieved by the working of battery management system. Recover condition is also designed in the fault diagnosis. When the fault level drops from high level to low level, the recovery condition should be matched the situation, otherwise it can easily causes the fault cannot be recovered or causes relay beating. This will affect the user operation.

2.2.5 Development of high voltage safety control system

(1) Rapid prototype development of high voltage safety control system

Rapid control prototype for high voltage safety control system, which means that the model of battery and battery management system is built rapidly by using rich function library of Matlab/Simulink and the whole control system is tested offline and online many times in the early development stage of high voltage safety control system. The actual operating result of predictive model can be directly obtained by this design and the model can be modified at any time until getting satisfactory result. If the problem is in the design not in the software, the model can be modified immediately and a new round of design starts. If control strategy need to be modified, it often need only a few minutes from modifying to the next testing. It avoids spending a few weeks to modify the software locally. It saves a lot of developing time and improves developing efficiency. The correctness of high voltage safety control strategy is confirmed after the online semi-physical simulation. Rapid control prototype development must be supported by specialized hardware and software. dSPace is used as a development platform in this project.

The programming of main processing board DS1005 can be easily done by using Matlab/Simulink and real-time interface library (RTI-1005MP) of dSPACE. It can set all the I/O boards which connect with the main processing board without any line of codes in the environment of Matlab/Simulink. Generating, compiling and downloading of the code only need to press Ctrl + B key. The basic C function which are used to initialize and access I/O is provided by dSPACE for those C code which are compiled directly by manual. With the help of debugger、compiler and download software, the downloading of code to DS1005 board can be easily done.

RCP development process can be divided into systems analysis, modeling, off-line simulation and real-time control. We summarize the following four-step development process for battery management system specifically:

(i) Function determination of BMS;

(ii) With the help of control model built by Matlab/Simulink, the off-line simulation is carried out by using the data which is obtained from EV.

(iii) The data which are input by work space during off-line time is replaced by model (DS2210MUX_ ADC_B1) which are dragged from RTI toolbox. The signal input channel and A/D conversion coefficient is set to carry out compiling and downloading.

(iv) The ControlDesk experimental software package and real-time controller are operated interactively. The control parameter is adjusted online, the state of control system is displayed, and the experimental data is recorded.

(2) The hardware development of high voltage safety control system

According to the hardware function, high voltage safety control system can be divided into micro-controller minimum system, signal collection circuit, power circuit, photoelectricity isolation circuit, signal inspection circuit, CAN communication and serial communication, and EEPROM expansion circuit. The hardware framework of high voltage safety system is shown in Fig.3.

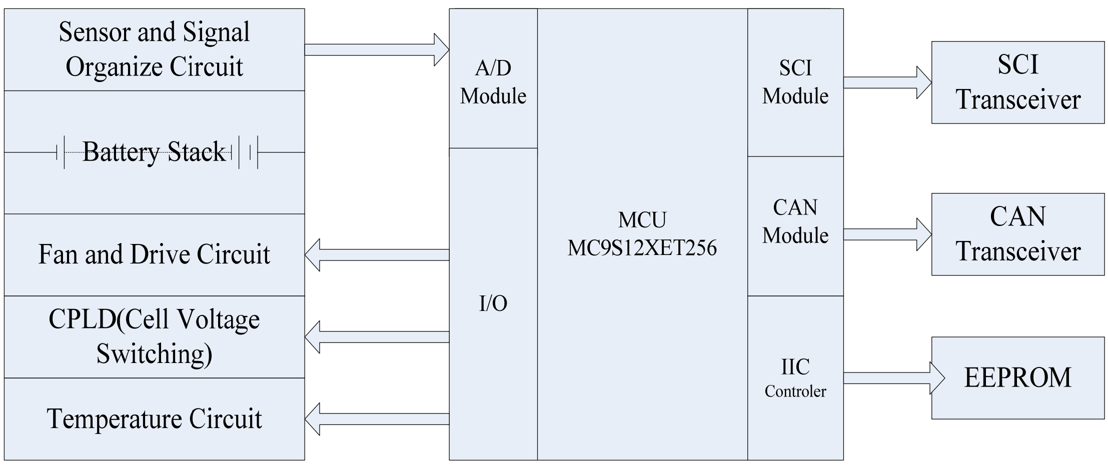

Fig.3 The hardware framework of high voltage safety system

(3) The software design of high voltage safety control system

The stable framework should be built firstly, and then different task is built in different "layer". The software can be reliable, easy maintenance and upgradation in this way.

The software "frame" is the operating system software which supports embedded system application. It has basic characteristics of general operating system. For example, it can manage more complex system resource effectively, it can provide function library, driver program, tool and application program. Compared with the general operating system, embedded operating system has many prominent features in the respect of real-time efficiency, hardware related dependency, software solidification, application specialization, and so on.

There are many models for software task development, such as waterfall model, prototype model, spiral model, basing on four generations technology model, fountain model, and so on. We use basic waterfall model as the foundation of software development. Its central idea is developing software according to the procedure. The implementation is separated from analysis and design of function to share out the work and help one another.

(4) Software test

Software test plays an increasing important role in the process of software development. It can be divided into static test and dynamic test. The static test for the source code includes the completeness, consistency, accuracy, easy modification, predictable, easy understanding of code. The dynamic test can be divided into white box testing and black box testing. White box testing is used to analyze the internal structure and test the unit, while black box testing is used to test the system.

(5) Hardware-in-loop test of high voltage safety control system

When the design of new control system is accomplished and its product is fabricated, the detailed test of control system should be carried out under the condition of closed loop. However, it is difficult to test for the reasons of the limit test, failure test, or more expensive test cost in real environment, and so on. Now, many control engineers regarded HIL simulation as a typical method replacing the real environment or equipment test. In the HIL simulation, the closed loop test system is made up of the actual controller and the simulation model. The component which is difficult to establish mathematical simulation model can be retained in the closed loop. This method can test ECU in laboratory condition. It can reduce development cost significantly and shorten the time of developing. This method is usually called "virtual test" technology.

Compared with off-line simulation, analog signal is tested in the HIL simulation. The control algorithm is written by C language in the micro-controller. Not only the control algorithm is verified, but also the actual fabrication of controller hardware and software is tested.

Thus, the simulation optimization test can be carried out effectively by using hardware-in-loop simulation system. The control strategy can be optimized continuously according to the result of simulation test. The result of actual control algorithm is verified by the result of experiment.

In addition, the test which originally need a few hours can be accomplished within one minute now. The test can be carried out repeatedly until the output result meets the requirement. The testing cost can be reduced significantly.

(6) The calibration of high voltage safety control system

The control accuracy of high voltage safety system largely depends on the accuracy of the calibration data. Calibration is the last step of development of high voltage safety systems, and it is a key step. If the previous researches on battery performance and control principle are general characteristic of high voltage safety control system, the calibration is the process of adjusting and optimizing the operation and control parameters according to the performance requirements(accuracy, safety and real-time) of high voltage safety system. The items of calibration consist of hardware collection system calibration and control parameter calibration of software.

3. Conclusion

All in all, Dongfeng Motor Corporation masters the technique of high voltage electric safety system of electric vehicle through studying on this project. Dongfeng Motor Corporation accumulates a lot of experiences in developing the high voltage electric safety of electric vehicle battery and the matching system of high voltage electric safety.

Acknowledgments

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Biography:

Yang Xia received his M.S degree and Ph.D degree at Wuhan University in China. Now he works in Dongfeng Motor Corporation. His main research topics are battery performance, battery management and high voltage electric safety.