

Study on HIL system of electric vehicle controller based on NI

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Abstract. The test platform is built based on LabVIEW to test Vehicle Control Unit (VCU) and Battery Management System (BMS), and their control strategies are tested by the experiments. Using a series of NI hardware products, data acquisition, CAN communication, fault injection unit and signal conditioning, the hardware in loop simulation test system are realized. In the RT system, real-time vehicle model and the battery model are generated by Simulink, and with real load, a vehicle simulation environment is established. Finally, not only is the test for VCU and BMS completed, but also joint debugging is implemented.

1. Introduction

With the worsening of atmospheric pollution and the increasingly serious energy crisis, electric cars have become the focus of the world because of their zero-pollution and efficient advantages [1].

The electric vehicle EIC control system includes the Vehicle Control Unit (VCU), Battery Management System (BMS) and Motor Control Unit (MCU). They can detect the state of electric vehicles and conduct state processing, which has important influence on the power, safety and economy of electric vehicles. The development of the control units are based on V development mode including modeling and off-line simulation, rapid prototyping, the target code generation, hardware in the loop (HIL) simulation test and real vehicle test and calibration[2].

HIL test accounts for a large proportion of the development process of VCU and BMS. Before loading them on the vehicle, HIL test conducts virtual testing of VCU and BMS through the simulated environment, and verifies the respective control strategies. The advantages of HIL testing are mainly reflected in the following aspects: 1) To improve the quality of VCU and BMS and reduce the development risk. 2) To reduce the number of real car road test, shorten development time, and reduce cost.. 3) To realize the test which a vehicle or platform is difficult or almost impossible to complete and inject all kinds of faults and some dangerous conditions.

Therefore, the HIL test system plays an indispensable role in the development of control system of new energy vehicle.

In this paper, the HIL system is introduced in detail according to the requirements of VCU and BMS. The control strategy of VCU and BMS is tested and verified by the HIL test system, and the joint debugging is realized.



2. Hardware Design of Test System

The hardware part of VCU test system mainly includes power supply unit, upper computer, lower computer, signal transfer unit, signal conditioning unit and load unit. The hardware part of the BMS test system is added by the single battery simulator and the insulation resistance simulator. Figure 1 shows the structure diagram of VCU HIL, and figure 2 shows the structure diagram of BMS HIL.

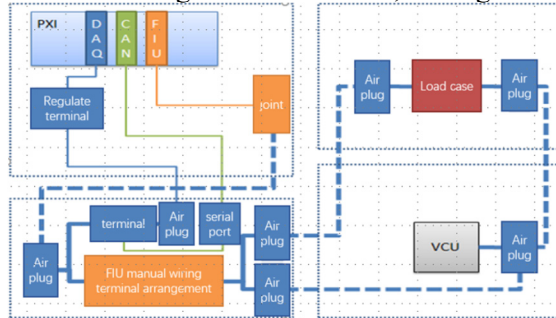


Figure 1. VCU HIL structure diagram.

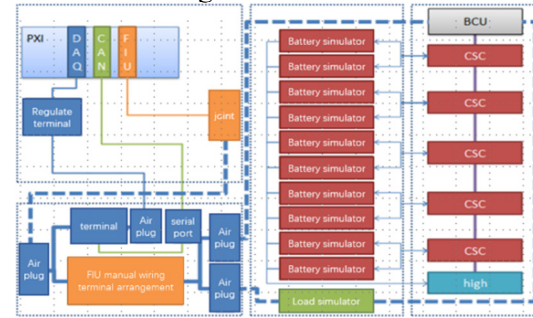


Figure 2. BMS HIL structure diagram.

The power supply unit is used to simulate the vehicle power supply to meet the load demand. The upper computer realizes the functions of system monitoring, information display, control input and CAN communication resolution. The slave computer realizes control of I/O port, model operation and failure injection. The signal transfer unit realizes the signal transfer of PXI signal external interface. Signal conditioning unit can realize signal conversion of 12V to 5V, 5V to 12V. The single battery simulator [3] is connected with PXI system to simulate the power battery system of new energy vehicle. According to the current feedback, it can be used as the balance current input of the battery model to calculate the target voltage and temperature of the battery in real time, and realize the output in the single battery simulator. Figure 3 shows the test site.



Figure 3. Test site.

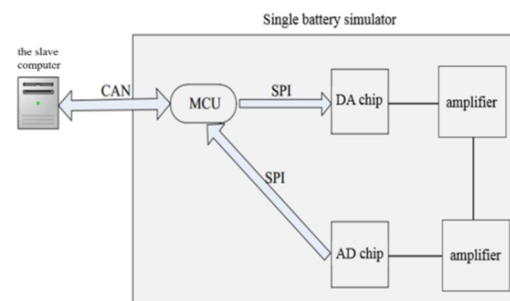


Figure 4. Schematic diagram of voltage signal simulation.

2.1. Battery temperature signal simulation

Temperature signals are most commonly used for BMS, and the temperature of the single power cell is detected by temperature sensor. In BMS, the most commonly used temperature sensor is Negative Temperature Coefficient (NTC) temperature sensor [4]. The characteristic of NTC temperature sensor is that, with the increase of ambient temperature, its output resistance is decreased exponentially. Therefore, the temperature signal can be showed by simulating the output resistance of the temperature sensor.

The resistance value of the resistance signal simulation device is increased by binary system, with 16 digits in total. For example: if the main circuit is composed of 16 slave circuits, the resistance of 16 of slave circuits is $2^0 \dots 2^{15}$. So when you need to simulate and output anyone in the resistance value of 0 to $2^{16}-1$, the resistance value can be transformed to binary number, then according to the binary number, opening or closing of each auxiliary circuit relay can be chosen. The resolution in the example is 1 ohm. When you need to keep the precision in the premise of 1 ohm, increasing the scope of the simulation is

also need that simulation resistance tolerance is more than $2^{16}-1$. Then you can increase the number of the slave circuit, and even different devices can be in series. If the number of the auxiliary circuit is increased from 16 to 32, so the simulation range becomes 0 to $2^{32}-1$.

2.2. Battery voltage signal simulation

Voltage signal simulation of the single battery simulator is controlled by voltage closed-loop. As shown in figure 4, the slave computer with the single battery simulator through CAN bus. The voltage value is sent to the simulator MCU, which is passed to the DA chip via the SPI communication bus, but it is not equipped with carrying capacity at this time. The amplifier will enhance the drive capability, and the relay simulate open circuit, short circuit and reverse fault, the AD chip is connected with the end of relay, and the sampling voltage value is sent to MCU via the SPI communication bus, and is compared with the target value sent by the slave computer to form a voltage closed-loop.

2.3. Battery current signal simulation

The adopted road CAN communication is defined as internal CAN. According to the communication protocol of the current sensor as shown in figure 5, the analogue current sensor model is CAB 300-c/sp3-002, the frame message ID is 0x3C2, and can determine the slope and intercept to send the current information to BMS via CAN bus.

Information description	CAN ID	Name	Length of the data	Frame type	Type of information sent	Signal description	Signal name	Start bit	Stop bit
Value of the returned current Ip (mA)	0x3C2	CAB300_Ip	8	The standard frame	The transceiver is circular, with a period of 10ms.	Current value 80000000H=0mA 70000000H=-1mA 80000001H=1mA	IP_VALUE	0	31
						b0:the error message (0:normal,1:failure)	ERROR_INDICATION	32	32
						b7 to b1:RxQuality (0 to 100%)	ERROR_INFORMATION	33	39
						Reserved position (Fixed 0)	VACANT_DATA_3BYTES	40	63

Figure 5. Protocol for current sensors.

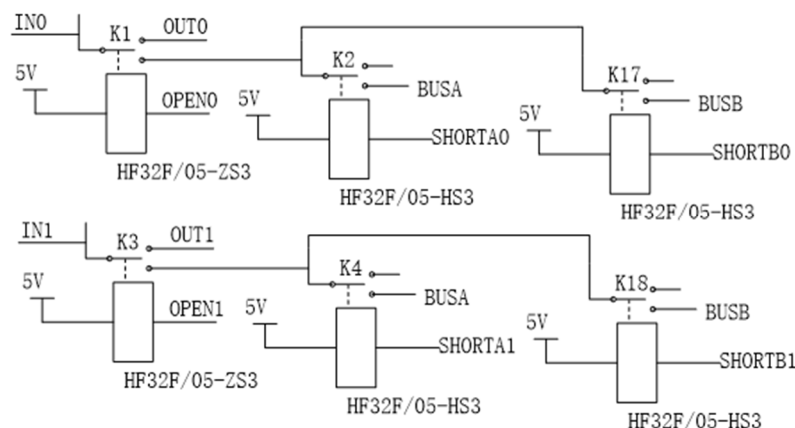


Figure 6. Diagram of internal circuit of fault injection.

2.4. Failure injection simulation

The fault injection is composed of a motherboard, six slave boards and a bus circuit board, and the motherboard communicates through CAN between the slave board and the bus circuit board. The faults are set by manual operation or upper computer, including open circuit, short circuit to GND, short circuit of power supply, etc.

The manual switch defaults in the closed state and toggling switch can realize the breaking of IN and OUT. When IN and OUT is in a broken state, connecting IN or OUT to the power positive terminal or GND can realize the short circuit to the power supply or to the ground.

The upper computer controls the switching of relay switches through the communication protocol of the fault injection unit. The fault injection simulation adopts the circuit diagram shown in figure 6.

2.5. Signal conditioning unit

It can realize high and low level conversion. As shown in figure 7, the structure of the signal conditioning circuit includes signal input, power supply unit, and electrical isolation, relay and signal output. It has some features, including the threshold adjustment of high level input, input and output electrical isolation and high level output can choose 12V or 24V.

In the signal conditioning circuit of low level switch 12V signal input port inputs to electrical isolation and relay at the same time, the low level signal is converted into high level signal, then outputs through the signal output port. In the signal conditioning circuit of high level switch 5V, the signal input port is connected to the linear comparator, then converts the high level into a low level by the electrical isolation part, and outputs by the signal output port.

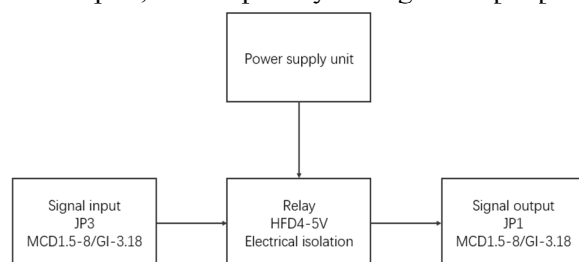


Figure 7. Diagram of signal conditioning unit.

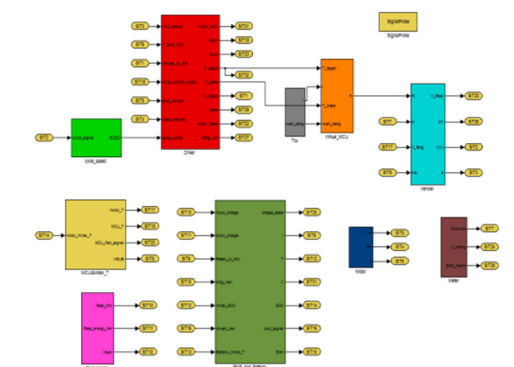


Figure 8. The vehicle model.

3. Test System Software Design

The software part of this test system is LabVIEW. Though LabVIEW adopts the data flow programming method, the data flow between the nodes in the block diagram determines the order of VI and functions.

The software of the test system is a common platform based on LabVIEW software and architecture development, including special software for testing solution based on development platform, model library for VCU testing and BMS testing, comprehensive test cases and fault injection. Special software for testing program based on development platform

Special software has the function of user-defined interface design. It can realize real-time resolution of CAN communication, provide the interface of Simulink model, realize the Excel configuration of I/O, and internal fault diagnosis. The basic functions of HIL system and VCU (or BMS) information interaction are realized through the special software based on the development platform.

3.1. Model library

Based on the Simulink environment, the vehicle control strategy is modelled in a hierarchical model, which makes the logic of the vehicle control strategy clearer and easier to debug [5].

Model library for VCU testing includes vehicle longitudinal dynamics model, motor model, main reducer model, driver model, battery model, etc. Figure 8 provides an overview of the vehicle model.

The driver model [6] can simulate the real driver of automobile driving. And it can be expressed as an adaptive system with multiple inputs and multiple outputs which is used to return some driving behaviour. In motor speed test, although the target speed is not entirely clearly reflected in the driver's driving behaviour, the driver will be based on the current speed and its gap with expectation speed and send out acceleration/deceleration instructions constantly. In terms of dynamics, the output of the driver model can be reduced to the control of the accelerator pedal and brake pedal.

Virtual controller model and battery model are added in model library for BMS testing. The modelling of battery cell is the core of the power battery system model. The battery in the power battery system used in this paper is lithium battery. It is the most commonly used power battery simulation method in recent years. Based on the characteristics of intuitive, convenient and convenient modelling, the equivalent circuit model is used to build the power battery model. As shown in figure 9, the second-order RC equivalent circuit model is used in the real-time system of this test system.

The main parameters of the model are the values of various resistors and capacitors in the resistance capacitance network. According to the relevant data obtained from the battery intermittent charging and discharging experiment, the characteristic curve of the battery is obtained. The battery model established in this paper is a good simulation of the characteristics of the real battery. The human computer interaction interface established by LabVIEW is used to monitor the status information of the battery [7]. Figure 10 shows the comparison diagram of the second-order RC battery model and the voltage collection data of BMS.

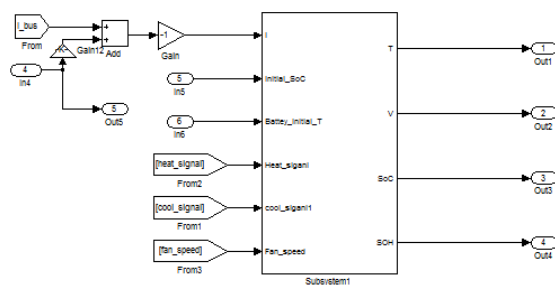


Figure 9. The second order RC battery model.

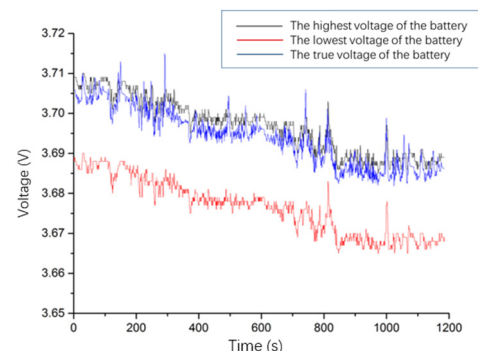


Figure 10. The charge and discharge curve of the second order RC battery model.

In the real vehicle, the VCU controls BMS and MCU, so this part of VCU is indispensable. For this purpose, a virtual VCU model can be set up to satisfy the control motor speed mode and send the power instruction function to BMS [8]. The function of this model is to give the key signal, and BMS receives the power signal and high voltage power instruction. For motor control, according to the difference of input gear and the size of speed, the motor control modes are judged, including forward, reverse or stop.

3.2. Automated test cases

The automatic test case [9] module can realize the functions of system monitoring, information collection, information display, control input and CAN communication resolution. It interacts with the operator through the upper computer software, which contains the control input interface, instrument display interface, fault centralized processing interface, controller output state interface and CAN message resolution interface. The upper computer can display the current state of the system in real time, control it, and realize CAN communication with each device.

3.3. Fault injection

The fault injection module is implemented in two ways: fault injection unit and NI PXI-2510 board card. It realizes the short circuit and disconnection between any two signals and a short circuit to the power or ground. It also can realize the fault diagnosis test of vehicle controller and battery management system[10].

4. Joint Debugging of BMS HIL and VCU HIL System

The HIL platform is connected with the vehicle power bus VCAN of each controller, and the power supply line is connected with the energy line so as to ensure the upper and lower power sequence. Figure 11 shows the operational sequence of the intermodulation.

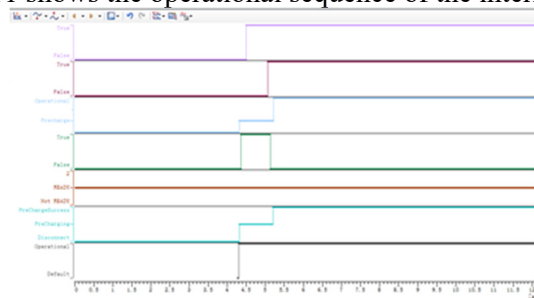


Figure 11. The operational sequence of the intermodulation.

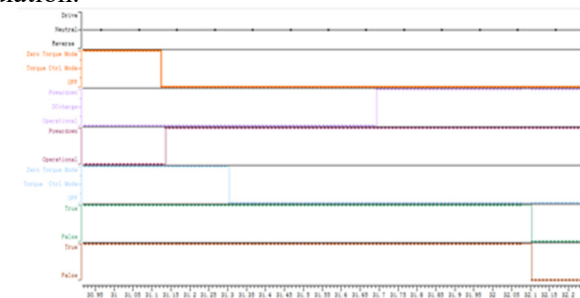


Figure 12. The power down sequence of the intermodulation.

When the upper computer key position is switched from OFF to ON, VCU's request mode VCU_HVBatMdReq for the battery is the default mode. After the BMS self-check is passed, it is in the Ready state. After receiving the mode request of VCU, it will be initialized, and after the initialization is completed, it will enter the Standby mode. After receiving the Standby status of BMS, VCU switches to operational mode from the battery's request mode VCU_HVBatMdReq. After the BMS receives the operational mode request, it will enter pre-charge mode, first close the pre-charge relay, and then close the main negative relay. After the BMS pre-charge is completed, the main positive relay is closed first, then the pre-charge relay is disconnected, and the working mode of BMS is switched from pre-charge mode to operational mode. The whole car is electrified.

The gear is in N gear, and the upper computer key is turned OFF from the ON. The whole vehicle drive Mode signal VCU_VehDrvMdReq sent by VCU is switched from Zero Torque Mode to Off Mode. The battery work mode request signal sent by VCU is switched from operational mode to power down mode. The MCU enters the OFF Mode from Zero Torque Mode. BMS operation mode signal BMS_HVBatWokngMd is switched from operational mode to power down mode, and the main positive and main negative relay is disconnected and the power down is completed.

5. Conclusion

This article introduces the principle and hardware and software implementation in detail of hardware in the loop test system of VCU and BMS. The test personnel can complete the test of the control strategy of VCU and BMS through the upper computer interface operation. It proves that VCU and BMS run well on the HIL test platform., meets the test requirements of VCU and BMS, realizes the validation of control strategy, and the joint debugging function towards VCU and BMS is verified.

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