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Insulation and monitoring system for pure electric vehicle based on microcontroller unit

HAN PENG[1]

Abstract. The purpose of this paper is to study insulation and monitoring system of pure electric vehicle. By insulating the performance decline of insulated wires, it is proved that pure electric vehicle based on micro controller unit will lead to serious consequence. The insulation detecting methods is used in the market to put forward an improved detecting method. Its characteristic refers to utilizing the bias resistance to detect insulation, while the main control chip provides signals to control the bias resistance. In the end, the peripheral circuit was designed centered on Advanced RISC Machine (ARM) micro controller unit (MCU for short). Modular programming is adopted to simplify the programming process. The experimental results show the accuracy and reliability of the insulation detection system by constructing an experimental platform. In the verification experiment, the insulation resistance is measured and its value with theoretical value $100\,\mathrm{k}\Omega$ is compared. The relative error is only $0.173\,\%$, and the standard deviation is 3.70. The insulation detecting system of pure electric vehicle designed this time is of certain accuracy and feasibility. Based on the the above finding, it is concluded that the design of insulation detection system is suitable for pure electric vehicle based on micro controller unit.

Key words. Micro controller unit, pure electric vehicle, insulation detecting system, main control chip.

1. Introduction

Environmental pollution caused by the fuel vehicles exhaust is becoming more and more severe owing to the increasingly expanding of automobile market. Faced with the existing energy-environment problems, the research, development and promotion of high-efficient clean electric vehicle are becoming an irresistible trend in automotive field [1]. However, most cars are fuel-powered, so they are free from the disasters caused by insulation. On the contrast, electric vehicle is electric-driven. To ensure enough power, there is always a high-voltage power supply assembled in the vehicle [2]. In the high voltage circuit of electric car, high-voltage and low-resistance

[1]School of Mechanical Engineering, North China University of Water Resource and Electric Power, 450045, China

will form heavy current. Therefore, the battery voltage pf high voltage side of the electric vehicle should remain high-voltage (about 300 V). In addition, the positive and negative pole of the high-voltage battery are connected on the ends of the insulated wire, whose resistance is very low, so transient current of the high-voltage side loop will be very heavy [3].

As a result, the quality of the insulation system of the electric vehicle is of high importance. Insulation aging of the high-voltage side will pose a threat to drivers even the security of passengers.

2. Materials and methods

2.1. Design of insulation detecting system

Power system is very important to the electric car. Particular electric devices are schematically shown in Fig. 1. The requirements to voltage is different in different places, and meanwhile the high and low voltage side power system appeared [4]. High-voltage power system consists of four parts and drives the operation of high power devices like motor [5]. While the low-voltage power system supplies electric to electric devices, in order to avoid electric leakage and other issues. We emphasis on the high-voltage electric system in this research.

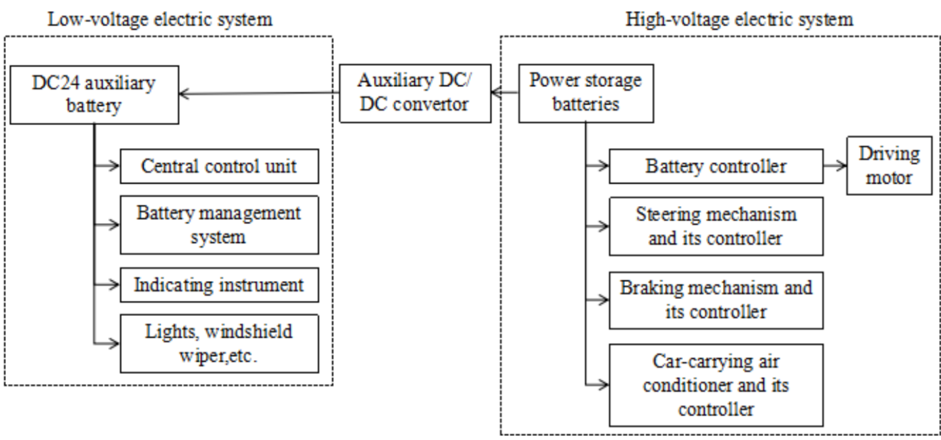

Fig. 1. Electric devices of electric vehicle

At present, the frequently used insulation detecting methods have bus end voltage method, AC signals injection method and DC voltage insulation measurement method [6]. The circuit used in bus end voltage method is simple but of unreliability, cannot influence fault like short circuit to ground. AC signals injection method refers to injecting AC signals in the DC system of the high-voltage side of electric vehicle, comparing, calculating and working out the insulation condition of the monitoring system. DC voltage insulation measurement method is realized by measuring the insulated resistance. Mosfet tube is used in the switch, so it is unavoidable for the high current signals to produce some disturbing signals during the measuring. This will influence on the calculating accuracy [7].

2.2. Insulation detecting method

The insulation condition of electric vehicle is measured by the insulated resistance of DC positive and negative bus to the earth, according to the regulations of BS ISO 6469-1-2009: divide nominal voltage U of electric vehicle DC system by insulation resistance value, the result greater than 100 Ω/V conforms with the security requirement, the result lower than this value shows the insulation fault of pure electric vehicle [8].

The principle of measurement is shown in Fig. 2, in which, V_{b} is the storage battery voltage, R_{p} and R_{n} are the insulation resistances of the positive bus and negative bus on the earth, respectively. The exterior of the short dash box is the monitoring circuit model of the insulated resistance of the pure electric vehicle, in which R_0 is the nominal bias resistance, R_0, S_1, S_2 construct a bias resistance network. R_1 and R_2, R_3 and R_4 construct the measurement voltage division circuit, V_{p} and V_{n} represent the voltages of positive pole and negative pole to the earth, respectively. During measuring, turn off S_1 and S_2, and draw V_{p} and V_{n}. And then according to the values of V_{p} and V_{n}, judge whether R_0 is in parallel with R_{p} or in series with R_{n}.

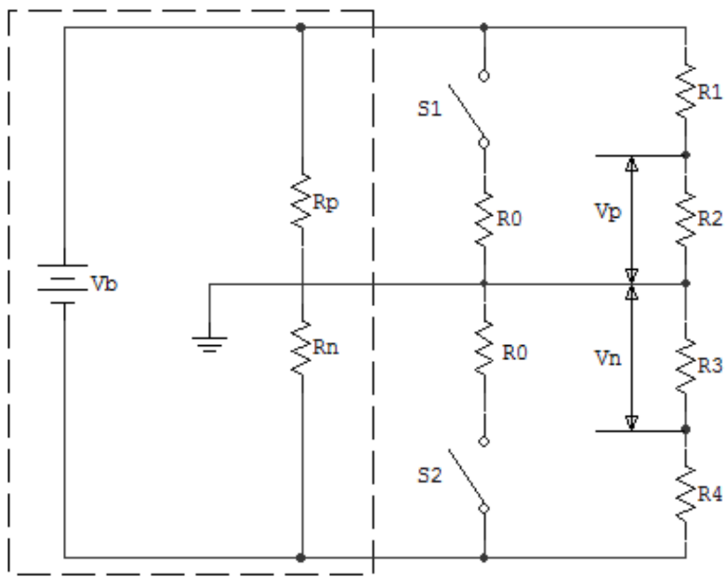

Fig. 2. Schematic circuit diagram of insulation detecting

If $V_{\mathrm{p}} > V_{\mathrm{n}}$, turn off S_1 and disconnect S_2, then we can measure the voltage value of the positive and negative buses to earth V_{p}' and V_{n}'. According to the circuitous principle, we can work out the calculating formula of insulation resistance R_{i} of the

DC high-voltage system:

$$\frac{V_\mathrm{p}}{R_\mathrm{p}} = \frac{V_\mathrm{n}}{R_\mathrm{n}},\ \frac{V'_\mathrm{p}}{R_\mathrm{p}//R_0} = \frac{V_\mathrm{n}}{R_\mathrm{n}}\,. \tag{1}$$

Now we can draw that

$$R_\mathrm{n} = R_0\left(\frac{V_\mathrm{p}V'_\mathrm{n}}{V'_\mathrm{p}V_\mathrm{n}} - 1\right)\,. \tag{2}$$

As $V_\mathrm{p} > V_\mathrm{n}$, then $R_\mathrm{p} \geq R_\mathrm{n}$. Therefore, choose the lower resistance R_n as R_i. For the same reason, when $V_\mathrm{p} < V_\mathrm{n}$, the relative insulation resistance can be worked out.

3. Hardware design

We use the intelligent system of the high-voltage fault diagnosis and safety monitoring as the monitoring device of the pure electric vehicle this time, to reach a better effect in monitoring. Fig. 3 refers to the systematic principle construction diagram. ARM chip is the core part of the whole controlling system. We apply with STM32F107 chip, whose detecting speed and accuracy are relatively higher. Under the control of the measuring main controller, this system can measure the accuracy of voltages to earth of the positive and negative bus, and is of good anti-interference quality and security [9]. As to the design of alarming system, based on the voltages to earth of positive and negative bus collected by the system, we can make comparative calculation with the standard value of the electric vehicle. When there is fault, it can give an alarm, or the system will turn off the circuit to protect the safety of the device [10].

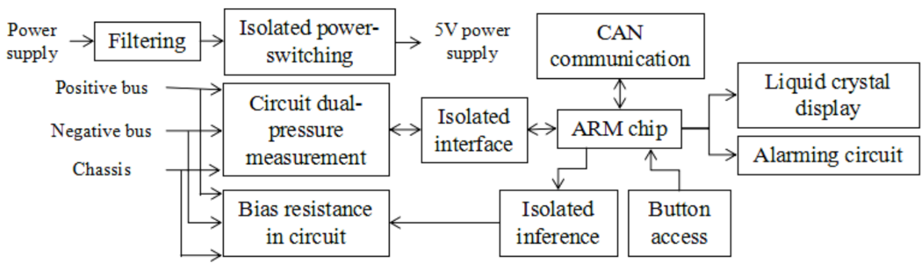

Fig. 3. Hardware principle construction diagram

Relative functions module circuits of the above hardware structure will be introduced in details as follows.

3.1. Power circuit

Seeing at the security and practicability of design, two kinds of working power supply 24 V and 5 V are applied this time. Those power inputted by them should be under relative protections like filtering and reversed connection-avoidance. Pure electric vehicle uses DC 24 V, so we designed the 5 V power circuit and switch it with the 24 V power circuit [11].

3.2. Measuring circuit

When the electric vehicle is moving, the insulation detecting environment will be worse, thus the voltage of insulated end is high and unstable [12]. Voltage measured by STM32 is only several VA, so we apply TE6664N chip to construct the measuring circuit, using two circuits in measuring, one for collecting the voltages between ground wire and positive bus, the other one for collecting voltages between negative bus and ground wire. Moreover, high-pressure optronic relay can be used to control high-voltage circuit and the bias resistance access circuit. The voltages decreased after the signals pass the multilevel voltage division resistor [13].

3.3. Bias resistance access circuit

Figure 4 represents the schematic diagram of the access circuit of bias resistance R0. C_Detect+ and C_Detect- is from the controlling signals of STM32, and is equal to switch S1 and S2 in the schematic diagram. SGIELD is the ground wire, and U2 and U3 is optronics, playing the role of insulating to raise the stability of circuits. The resistance connected with the right end of optronics is bias resistance R0. Controlling signals output by the STM32 control R0 by controlling the continuity of U2 and U3, it can decide whether connecting R0 with the circuit of positive bus to the ground or with the negative one [14].

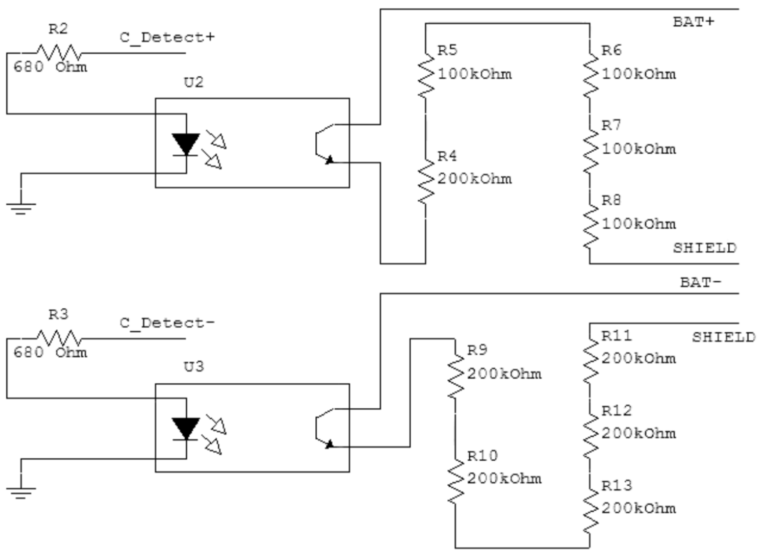

Fig. 4. Schematic diagram of bias resistance access circuit(BAT+ and BAT- refer to the positive bus end and negative bus end of the power storage battery respectively)

3.4. Protective circuit

The voltage of storage battery cannot be too high or too low [15], so we must adopt high-voltage and low-voltage protective circuit (see Fig. 5). Safe voltage value range of storage batteries is 150~300 V. The system should be designed including a specific function to detect the voltages of the two ends of the storage battery. When the signals have not been fed back to the system, the alarm will be given to reach real-time process.

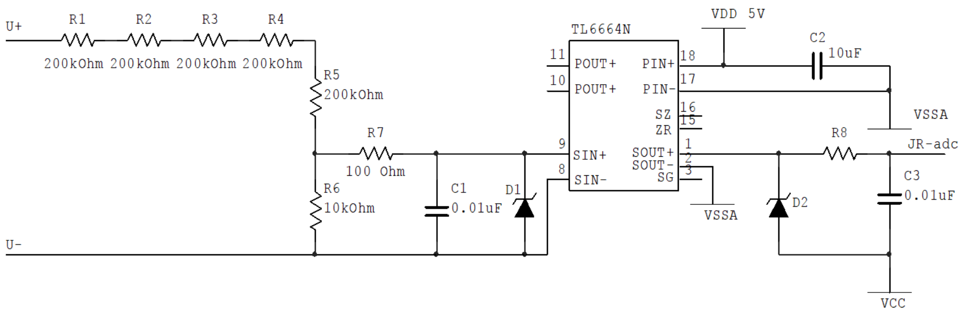

Fig. 5. Protective circuit

3.5. High-voltage loop inter-lock circuit

The reliability of high-voltage loop is of great significance. To better detect the integrity of the high-voltage power-supply loop, we show the high-voltage inter-lock detecting loop in Fig. 6. In the fig, the on-off condition of Q6 is controlled by the controlling signals given by the high-voltage loop inter-lock of the main controlling chip. It controls Mosfet tube to control the on-off of 5 V voltage signals. 5 V voltage in the circuit is supplied by the power circuit of the monitoring system, and is inputted in the high-voltage loop J1 to force the return voltage to be detected in time. If the voltage detecting system has not received the return signals, high-voltage loop inter-lock will recognize the fault, and then the circuit will give an alarm and at the same time, it will turn off itself automatically.

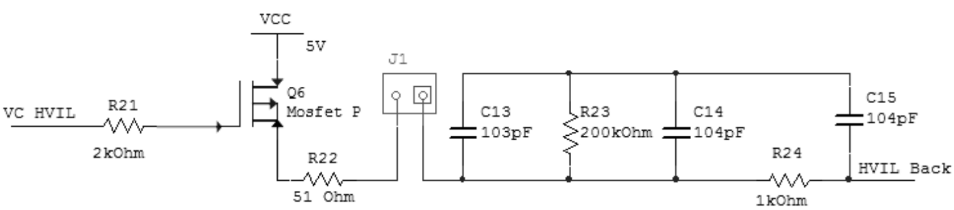

Fig. 6. Schematic diagram of high-voltage loop inter-lock circuit

In this system, there are also temperature measurement circuit of the power storage batteries(adopting DS18B20 sensor), circuit design of liquid crystal display

(2.8-cun, 16-bits TFT LCD, 320×240 resolution ratio), and CAN communication circuit (applying with module TD301DCAN) (not covered here).

Moreover, we also design the anti-interference quality and operating managing of the hardware. In the field of pure electric vehicle, high-voltage DC system was seen as strong electromagnetic interference. Therefore, its anti-interference quality will be set as a standard, whose value largely decides the reliability of the electric parameter, and also plays a vital role in the operating of the system. During the operating of high-voltage system, there are two levels of fault: minor fault and major fault, which is called class one failure and class two failure in software respectively. Fault in high-voltage loop belongs to class one, and fault in insulation resistance refers to class two. Faults resulted from the high temperature of power storage supply can be defined to class one failure and class two failure according to the extent of damages.

4. Software design

The core of control section of this research is STM32F107. Form a complete set of software by invoking firmware library to control each function module, thus to realize the monitoring to the insulation system, and at the same time, realize the functions of relay, PWM signals control, alarm display, CAN communication, sampling measurement controlling, insulated resistance calculating and so on. In this way, the principle of active insulation monitoring is realized. We can draw the resistance values of the positive and negative insulated resistance with relevant calculating method.

We adopts Keil uvision3 as the software development platform, and realize the programming of STM32F107 by invoking firmware library. The operating environment of the pure electric vehicle is complicated, so we add some protective circuits and anti-interference measurements to reinforce the reliability of the system, such as digital filtering technology and "watchdog" technique. The flow chart of main systematic program is shown in Fig. 7.

There are twice sampling of AD needed to be done, sampling two data signals every time, thus to draw the insulated resistance value. The first sampling is bias resistance and will not be involved in the whole system. Collect two data signals at the second time, work out the insulated resistance value of the bus insulated wire. The flow chart of AD sampling is in Fig. 8.

Fig. 9 refers to light alarm system. The positive and negative insulated resistance value calculated above is the condition to judge the light alarm condition. Figure 10 shows the flow chart of operating managing and disconnecting controlling, when in failure.

The pure electric vehicle may suffer from faults no matter in the starting, operating and parking process. When encountering fault, the monitoring system of high-voltage electricity will be access to the control strategy of disconnecting when in failure, thus to turn off the high-voltage loop.

During the reliability design and optimization of the systematic software, concerning with the functions needed to be realized as well as the whole process, the

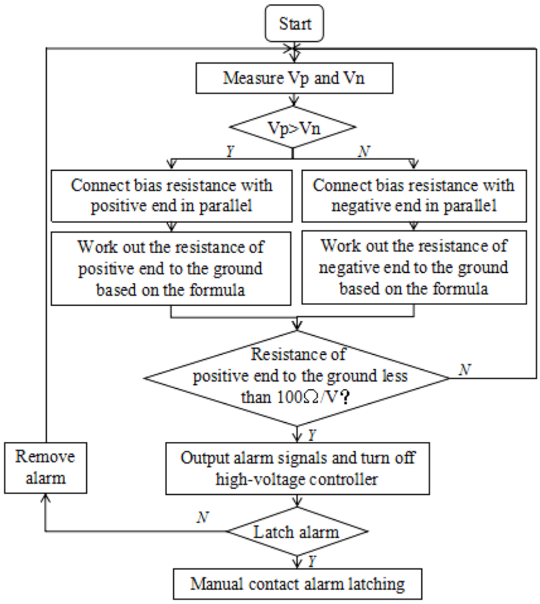

Fig. 7. Flow chart of main systematic program

linkage process of every motion must be fluent and natural during the whole insulation detecting. So we use optional structure "Switch" in the complete system. The connections between every action statement is accomplished by its multi-branch statements. All in all, frequently used modular programming method used in this time makes a higher systematic readability.

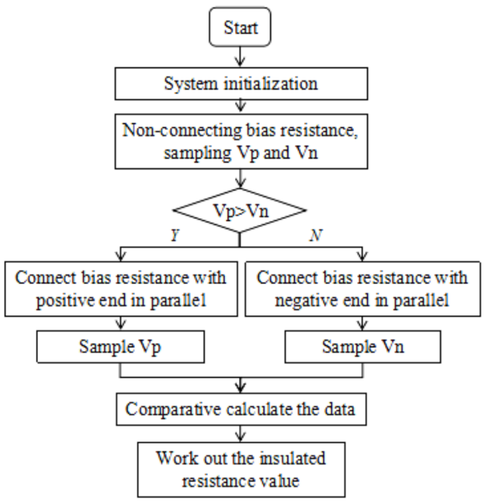

Fig. 8. Flow chart of AD sampling

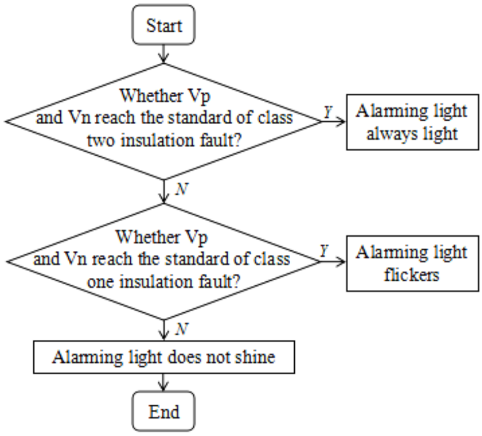

Fig. 9. Light alarm program

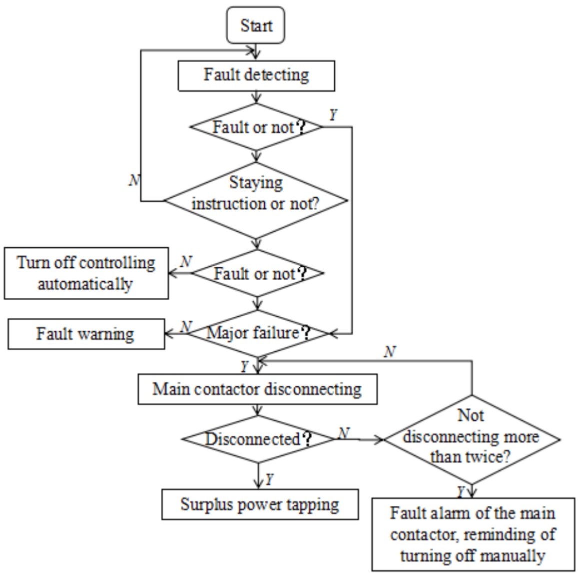

Fig. 10. Flow chart of operating managing and disconnecting controlling when in failure

5. Results

To judge the insulation condition of the insulated system, we construct the system test platform. The test platform constructed for the high-voltage safety test system of pure electric vehicle includes: 200 V high-voltage DC supply, 24 V DC supply, oscilloscope, multimeter, safety monitoring system, etc.

To ensure rationality and comprehensiveness of the test, our testing sequence is from partial to the whole, i.e. debugging software first and then the hardware, debugging the low-voltage environment first and then the high-voltage.these are all the sequences to conduct test. The test results of insulated resistance value are shown in Table 1.

Table 1. Test results of insulated resistance value (kΩ)

	No.1	No.3	No.4	No.5	No.6	No.7	No.8	No.9	No.10	Average value
Measured value	97	98	98	101	99	100	97	98	102	99.1
Standard value										
Error	–3	–2	–2	1	–1	0	–3	–2	2	

The standard value is:

$$S = \sqrt{\frac{\sum_{i=1}^{n}(s_i - \bar{s})^2}{n}} =$$

$$= \sqrt{\frac{3^2 + 1 + 2^2 + 2^2 + 1 + 1 + 0 + 3^2 + 2^2 + 2^2}{10}}\,\mathrm{k\Omega} = 3.70\,\mathrm{k\Omega}\,.$$

Seeing the results in Table 1 and comparing the measured value of insulated resistance with theoretical value 100 kΩ, we can draw that the relative error is only 0.173 %, and the standard deviation is 3.70. This is persuasive enough to prove the accuracy of the calculating module of the insulated resistance designed in this research.

6. Conclusion

We designed a detecting system based on ARM MCU directing at high voltage circuit safety monitoring on pure electric vehicle, and tested the feasibility of it. The main research process and result are as follows:

To put forward an improved insulation detection method concerning with the reasons why the high voltage side of electric vehicle need insulation detecting and also referring with the existing detecting methods in the market.

To design the schematics of many aspects like interposing the bias resistance, insulation detecting, high and low voltage protection, high voltage loop interlocking according to the principle of voltage detection. To show the whole hardware structure of the system. To compile a program that can realize the relative functions of hardware electric circuit based on Keil uVision 3 as the software developing platform, as well as the modular principles.

To construct the testing platform, and testify the feasibility and reliability of this theory and method.

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