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Realization of Direct Current System Insulation Monitoring Device Based on Fault Amplifying Method

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Abstract

This paper has analyzed the existing direct current (DC) system insulation monitoring methods. In view of poor anti-jamming and low sensitivity of existing methods, a new insulation monitoring device is designed based on Fault amplifying method. Under the condition of ensuring system security, the device detection resistors are put into the system by control switches, data is collected by the sensors and set to host computer by CAN bus. At last, the host determines insulation condition of the system by calculating the insulation resistances. This paper has introduced the main test circuit and program flow chart. It is verified by experiments and field operation that the device which is perfectly suitable for online DC insulation monitoring of power plants and transformers can monitor the insulation condition of system accurately and the sensitivity is high.

Keywords: *DC system, insulation, resistance switching, ground fault, DC bus*

1. Introduction

DC system is extremely important auxiliary power supply in power plants and substations, its reliability and stability directly has impact on the security of the entire power system. The DC grounding is a common malfunction. It can not cause serious consequences when single point grounding fault without a loop occurs. However, it may cause the malfunction of protection device and control circuit when double point grounding fault occurs at the same time, even cause short circuit [1-5]. Therefore, real-time online monitoring is necessary for DC system .When ground fault occurs, the device should sent warning signal to the staff and then the fault can be discovered and removed.

Commonly used methods conclude AC variable frequency and balance resistance method. AC variable frequency is to inject low-frequency AC voltage signal between DC buses and ground, the grounding fault branch can be determined according to the AC variable frequency [10-12]. Disadvantage of this approach is that it needs signal circuits and test results are influenced by the distributed capacitance. The system may be affected because AC signal is applied to the system. Balance resistance method is to form a balance resistance bridge with which the insulation state can be determined by connecting a pair of resistances (the same as each other) in positive ground and negative ground. This method can only define the insulation condition of the entire system, but can not accurately find out the grounding branch and when two grounding faults and the resistances reduced with the same value, the method cannot accurately send alarm [13-16]. The approach of this device has no impact on the system because it does not need any signal injected into the system, its accuracy is high and it won't be affected by environment.

2. Work Principle of the Device

In the case that ensuring system security, suitable detection resistors are put into the system by controlling switches the function of which is increasing fault signal and improving measurement accuracy. The voltage and the leakage current should be measured and insulation resistance can be obtained according to of the circuit theorem cutting resistance. Detection principle is shown in Figure 1. In the case that guarantee there is no effect on DC system. Detection resistors are put into positive bus and negative bus respectively by relay

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switches. Current sensors are installed in each branch by which the unbalanced current of branches can be collected. Under normal circumstances, no signal output when the switches are connected [17].

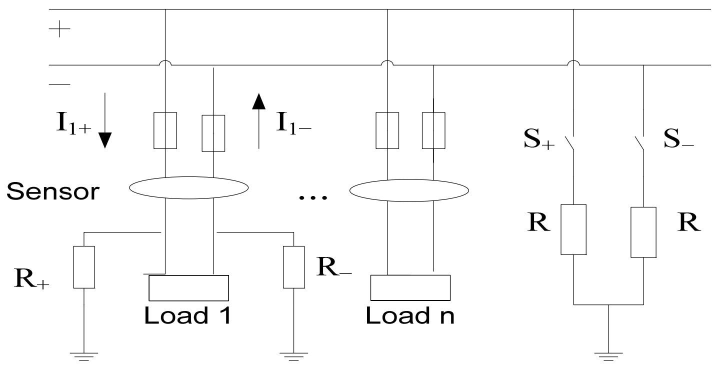
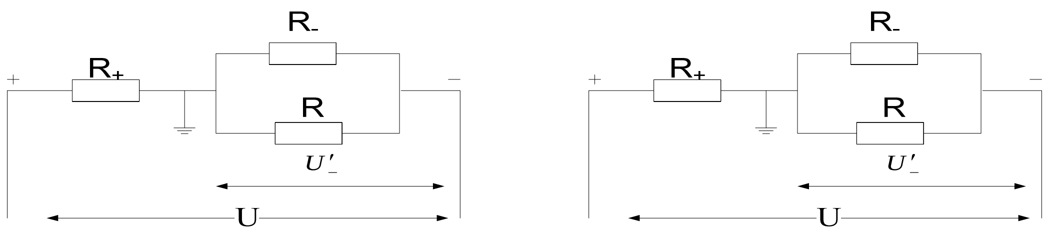


Figure 1. Principle of Detection

a) When S-is on , S + is off and the resistors R are inputted into negative bus, then the voltage of negative bus to ground is U'-, the equivalent circuit is shown in Figure 2 (a), the equation is given by (1-1).

b) When S + is on , S- is off and the resistors R are inputted into positive bus, then the voltage of positive bus to ground is U'+, the equivalent circuit is shown in Figure 2 (b), the equation is given by (1-2).



(a) Negative bus input R

(b) positive bus input R

Figure 2. Equivalent Circuit of Detection for Bus

$$\frac{U}{R_+ + R_- // R} = \frac{U - U'_-}{R_+} \tag{1}$$

$$\frac{U}{R_- + R_+ // R} = \frac{U - U'_+}{R_-} \tag{2}$$

Equation (1), (2) are synthesized to solve R+、R-:

$$R_+ = \left(\frac{U - U'_+}{U'_-} - 1 \right) \times R \tag{3}$$

$$R_- = \left(\frac{U - U'_-}{U'_+} - 1 \right) \times R \tag{4}$$

Where $U = |U_+| + |U_-|$ is total voltage, R is detection resistor.

$$\frac{\Delta U}{\Delta I} = R_+ // R_- = R_d \quad (5)$$

Equation (5) is the equation of insulation resistance for branch (the derivation is omitted). ΔU is voltage variation that is equal to the difference of anode voltage to ground when the detection resistances are put into negative bus and positive bus respectively. ΔI is the variation of leakage current that is equal to the difference of leakage current when detection resistors are inputted negative bus and positive bus respectively. The variation is a slight and the influence of environmental factors can be ignored. R_d is insulation resistance of the branch and it is an equivalent value that is equal to the value of positive insulation resistance in parallel with negative insulation resistance.

3. The Hardware Design of DC System Insulation Monitoring Device

3.1. Structure of System

Structure of system as show in Figure 3, the device mainly includes two parts: main control module and sensor acquisition module. PC communicates with the main control module that includes C8051F040 MCU and peripheral circuits、voltage detection module of bus、memory modules etc by PCI bus. The main control module transmits command of detection by CAN bus. The sensors detection module collect the data of monitor bus and branches of the entire DC system in real-time and the data is send back to the host of system by CAN bus. The host judges the insulation state of bus and branch through the difference between the insulation resistance and the normal.

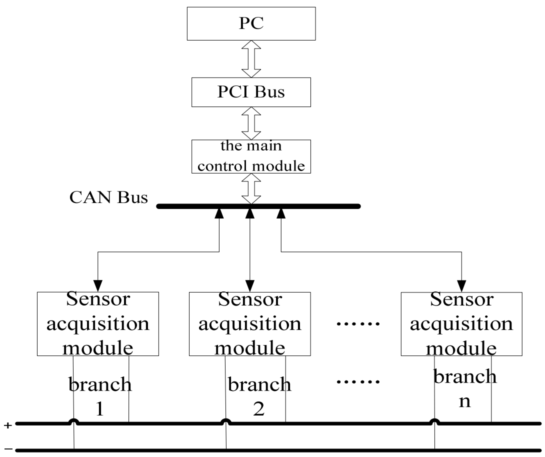


Figure 3. Structure of System

3.2. Hardware Design

PC communicates with MCU by PCI bus. The sensor communicates with MCU by CAN bus. CAN bus have the properties of strong error detecting ability and long communication distance (over 10kV). C8051F040 integrates CAN controller and an external CAN transceiver is needed so that the hardware structure is simple and performance is stable. Thus, using C8051F040 not only can complete the control of system but also can simplify hardware design of the system greatly and reduce the cost of system [18, 19].

3.2.1. Detection Module of Bus Voltage

Detection module of bus voltage transmits the collected voltage date which is collected by isolating amplifier circuit that consists of Linear Optical Coupler HCNR200 and operational amplifier LM358 to host. As shown in Figure 4, the isolating circuit concludes optical coupler, two operational amplifiers and two resistances. The two operational amplifiers use different power supply to achieve electrical isolation [20]. The gain of the isolating amplifiers can be regulated by changing R26 and R24 according to the characteristics of HCNR200.Capacitance C18 is used to eliminat oscillation. R26 = R24 = 300k in this design.

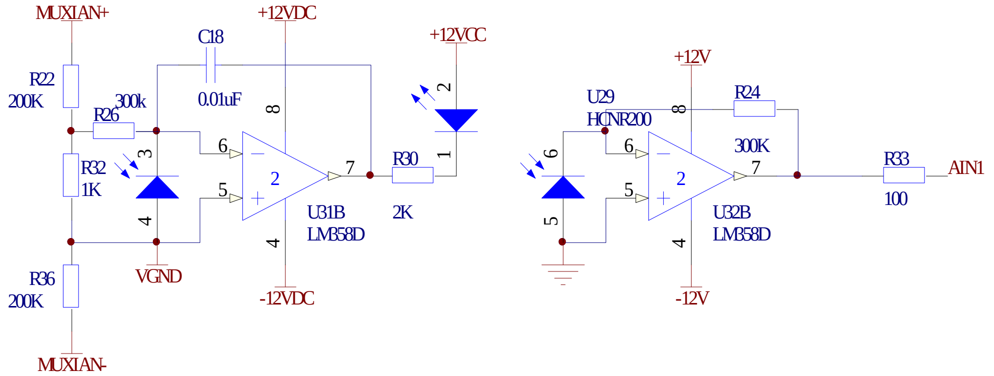


Figure 4. Detection Circuit of Voltage Bus

3.2.2. Switching Resistance Circuit

This module puts suitable current-limiting resistances (1k, 2k, 4k, 8k, 16k, 32k, 64k and 128k can be selected) into circuit by the relay switches. The range of the resistance is 1~255K and any value can be chosen in this range. Normally, the smaller the testing resistance is, the greater the leakage current is and the higher the detection sensitivity is. It may cause protection misoperation if testing resistance is too small, so the system puts all resistors into system in initial state and changes the current-limiting resistance by controlling relay switches s1~s8 to short-circuit current-limiting resistances in turn according to the current value in the circuit so that the current value can be regulated. Accuracy requirement is thus met. Meanwhile, isolation amplifier circuit that is the same as the one of bus voltage detection is connected to the output end of current-limiting resistance so that the interference signal that caused by common ground in analog circuit and other reasons can be eliminated. The principle diagram of switching resistance is shown in Figure 5. When the switches are off S = 0 and on S = 1, the value of switching resistor R is given by:

$$R = S_1 \times R_1 + S_2 \times R_2 + S_3 \times R_3 + S_4 \times R_4 + S_5 \times R_5 + S_6 \times R_6 + S_7 \times R_7 + S_8 \times R_8$$

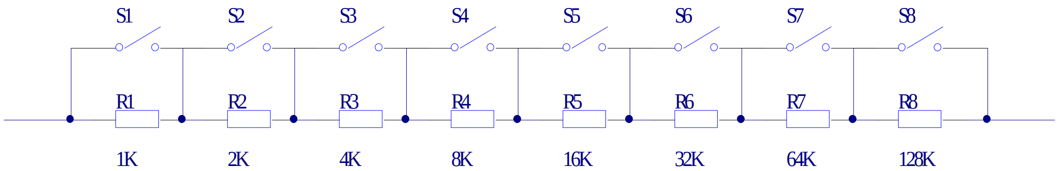


Figure 5. The Principle Diagram of Testing Resistance

3.2.3. Sensor Acquisition Circuit

The device monitors all branches by current sensors in real-time. The collected date is delivered to C8051F040 by the amplifying circuit that is structured by operational amplifier LF347 and voltage comparator LM311DR and then C8051F040 sent the date to the host by CAN bus. As show in Figure 6, LF347 is the core component of amplifying circuit. Sine wave can be changed into square wave with the same frequency by using LM311DR as the analog and digital circuit interface.

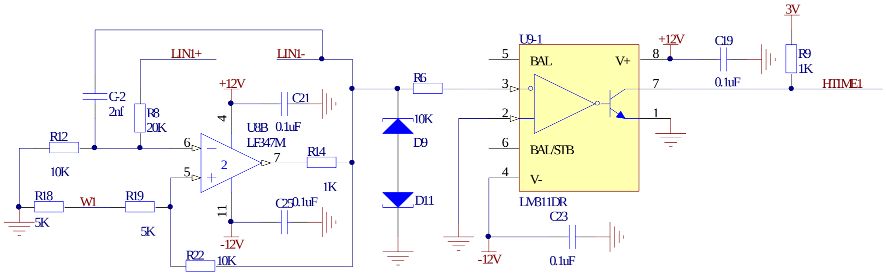


Figure 6. Signal Amplifying Circuit

4. Software Design

The software of the system is mixed programming of assembly language and C language programming based on hardware requirement [21, 22]. The device starts program self-checking when it begins to run by checking each interface and circuit to ensure the normal operation of the device. The same testing resistance is input into positive and negative bus after monitoring host has send testing commands by CAN bus regularly. The insulation resistances of bus and branches can be calculated after measuring voltage and leakage current twice and then it can be obtained that whether there is a grounding fault and which branch has occurred fault. The fault one will appear fault flag. The system's monitoring interface can show the history curve of each branch even if the system is well insulated. The staff can also see the insulation resistance value of each branch [23]. The flow chart of main program is shown in Figure 7.

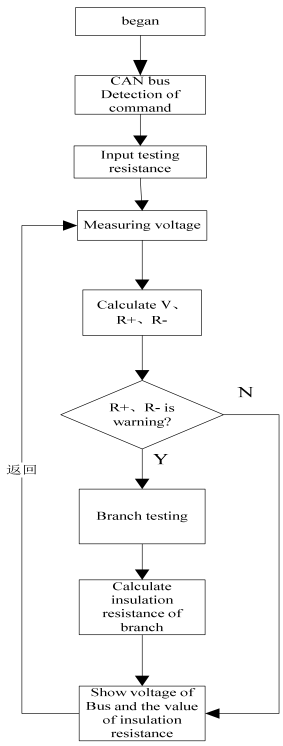


Figure 7. Flow Chart of Main Program

5. Conclusion

The paper has introduced a new insulation monitoring device used in DC system based on fault amplifying method after traditional insulation testing methods are analyzed. The device that has cooperated main control module with sensor acquisition module can monitor the insulation condition of bus and branches in real-time. A series of test experiments have been conducted in laboratory in the initial stage in order to verify the accuracy of the device. The experiments simulated the condition of branch. The device has the properties of high precision and high interference. The device can distinguish the fault branch and its fault degree correctly in the case that insulation resistance is less than 100 kΩ. The insulation monitoring scheme introduced in this paper has been installed in a number of substations and it can operate safely and reliably. It has provided reliable basis for grounding fault detecting in DC system, saved a lot of time and improved the security of power system.

References

[1] Bao Yan, Jiang Jiuchun, Zhang Weige. *Novel on-line insulation supervising method for DC system*. High Voltage Engineering. 2011; 37(2): 333-337.
[2] Jiang Jishun, Ji Hua. Study of Insulation Monitoring Device for DC System Based on Multi-switch Combination. *IEEE Transactions on Power Delivery*. 2009; 23(3): 429-433.
[3] Li Runping, Wen Quan. *Earth fault analysis of direct current system.* Huadian Technology. 2008; 30(2): 58-61.
[4] Zhao Bing, Hu Yulan. *Problems of Microcomputer-based Insulation Monitor for DC System.* Guangdong Electric Power. 2009; 22(14): 43-45.
[5] James Lenz, Alan S Edelstein. Magnetic sensors and their applications. *IEEE Sensors Journal.* 2006; 6(3): 631-649.
[6] Zhao Mengxin, Chen Guofeng, Yu Weicheng. *Modification of the leakage method for DC system insulation monitoring.* Automation of Electric Power Systems. 2009; 33(14): 83-88.
[7] Feng Xinghai, Sun Hongyu. Introduction for some Insulation Detection Methods in DC power supply system. *Power Supply Technologies and Applications.* 2007; 6(10): 63-69.
[8] Wang Ruixiang, Liu Feng, Xiong Xiaofu et al. *On-line Insulation Monitoring of Substation DC Power Supply.* Electric Power Automation Equipment. 2009; 29(12): 65-67.
[9] R Malewshi. *Micro Ohm Shunts for Precise Recording of Short Circuit Current.* IEEE PA S-96. 2007; 45(34): 579-583.
[10] Cavallini A, Conti M, Montanari GC, et al. PD inference for the early detection of electrical treeing in insulation systems. *IEEE Transactions on Dielectrics and Electrical Insulation*. 2004; 11(4): 724-735.
[11] Han Yang. A Pedagogical Approach for Modeling and Simulation of Switching Mode DC-DC Converters for Power Electronics Course. *TELKOMNIKA Indonesian Journal of Electrical Engineering*. 2012; 10(6): 1319-1326.
[12] FRANK, B Morgn, R Obsolescense. *Mitigation and Management of Electronics Test Equipment. Autotestc on IEEE.* 2007; 65(21): 527-536.
[13] Wang Youren, Cui Jiang, Liu Xinfeng. DC System Insulation Automatic Monitoring Instrument. *Chinese Journal of Scientific Instrument*. 2005: 26(8): 849-852.
[14] G Chen, Y Chen, Andh, etc. Identifying Chaotic System via a wiener-type cascade model. *IEEE Control System Magazine*. 1991; 8(1): 29-36.
[15] Su Yixin, Liu Linwei. Monitoring and detecting of DC system insulation by balance resistance method. *Automation of Electric Power Systems.* 2003; 27(14): 65-68.
[16] K Satyanarayana, Saheb Hussain MD, B Ramesh. Identification of Faults in HVDC System using Wavelet Analysis. *International Journal of Electrical and Computer Engineering (IJECE)*. 2012; 2(2): 175-182.
[17] Yin Xingguang, He Mingning, Xu Yufeng. *Analysis on the Wrongly or Missed Line Selection with DC Ground Fault Patrol Device.* RELAY. 2008; 36(10): 83-85.
[18] Li Liwei, Liu Xianfeng, Liu Bin. *Distributed on-line Grounding Monitoring System for DC System Based on Field Bus.* Electric Power Automation Equipment. 2006; 26(12): 55-58.
[19] Tian Yi, Liu Xiuhong. *Design of CAN Bus Communication System Based on C8051F040.* Modern Electronics Technique. 2006; 15(23): 29-31.
[20] Zhang Baosheng, Wang Nianchun. *Analog Isolation Board Based on H igh2linearity Analog Optocoupler HCNR200.* Instrumentation Technology. 2005; 5(13): 59-60.
[21] Shi Bin. *Programming of ARM with both Assembly and C/C++ Language.* Electronic Measurement Technology. 2006; 6(29): 89-91.
[22] Wang Jiajun, Hong Bin, Wang Hongmei. Electric Insulation Detection Method for High-voltage Insulators. *TELKOMNIKA Indonesian Journal of Electrical Engineering.* 2013; 11(7): 4086-4090.
[23] Hao Xiwei, Yang Dawei, Liu Guangyan. *Development of On-line Monitoring System for the Insulation Condition of Capacitive-type Substation Equipment.* High Voltage Engineering. 2009; 4(35): 828-832.