Research on DC XLPE Cable Leakage Current Detection Technology Based on GMR Sensor

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Abstract: The state detection of DC cable need the support of advanced sensing technology. Leakage current is an important means to characterize the insulation state of cables. Aiming at the demands of current measurement of XLPE insulated cable, a leakage current sensor based on giant magnetoresistance effect was developed, and an experimental platform for leakage current detection of XLPE cable was built. Taking the defect of XLPE insulated scratch as the research object, the characteristics of leakage current of XLPE cable and the influencing factors of detection were analyzed. The experimental results shown that the leakage current of XLPE cable can be detected effectively. The designed sensor can measure leakage current of DC cables accurately with a measurement range of ±30 mA, error less than ±2% and sensitivity up to 1 μA. In terms of factors affecting on-site measurement, the leakage current of XLPE insulated cables was affected by voltage polarity and detection time, and the leakage current under negative polarity voltage was proportional to positive polarity. High, leakage current reading tends to be stable after 200s. This paper studied and realized the detection of DC cable status by leakage current under operating conditions, which laid a foundation for the on-site condition evaluation and maintenance of the cable.

1. Introduction

Due to the lack of phase information in DC cable system, AC cable state detection method can not be directly applied to DC cable. Leakage current is an important means to detect the insulation deterioration of DC cable. Leakage current is the current flowing through the main insulation under a certain voltage, which can reflect the overall deterioration or dampness of the insulating medium [1, 2].

At present, the leakage current detection of DC cables is based on off-line condition or different voltage applied in the laboratory. The leakage current detection value is affected by many factors, such as temperature, humidity, position of micro-ammeter, waveform and polarity of power supply voltage, pressure speed and cross-linking by-products, etc.. Leakage current was only used in the insulation detection of field cables in the voltage level below 10 kV. Usually, the leakage current through the test sample was measured by means of high voltage direct series micro-ammeter. At the same time, the infrared remote control switch was used for range control and data reading[3,4], while the development test and type test of DC cables were carried out. At present, there is no stipulation in the domestic and international standards for pre-qualification test. Leakage current is an important index to characterize the insulation performance of power equipment. In theory, it can be used to evaluate the state of DC cable by detecting leakage current. At present, there were few studies on leakage current of DC XLPE cable in operation, and it was impossible to measure leakage current of DC XLPE cable in operation[5].

Giant magnetoresistance effect refered to the phenomena that the resistivity of ferromagnetic materials such as iron, cobalt and nickel changes dramatically in the magnetic field. According to the magnetoresistance system, it can be divided into multilayer structure (ML), spin valve structure (SV), granular film structure (GA) and magnetic tunnel junction multilayer structure (MTJ)[6,7]. In 1991, J.S. Moodera discovered the MTJ effect in CoFe/Al2O3/Co structure. At 295 K and 4.2 K, the magnetic resistivity reached 11.8% and 20%[8]. Since then, GMR technology has made a lot of achievements in material system, structure design, sensitivity improvement, noise performance optimization and sensor development. MTJ has the highest sensitivity among many magnetoresistance systems. The magnetoresistance of MTJ with Al2O3 and MgO as insulation materials can reach 70.4%[9-11] and 108%~500%[12,13] at room temperature, which provided basic conditions for detecting the current of equipment in a wide range and high precision smart grid.

In this paper, designed the structure of the sensor, a high performance GMR current sensor for leakage current measurement of DC cable was developed. An experimental platform for leakage current detection of DC XLPE cables had been set up in the laboratory. Taking the defect of XLPE insulation scratches as the research object, the characteristics of leakage current of XLPE cables and the influencing factors of detection had been analyzed. The sensor developed had been applied in Zhoushan ±200 kV flexible cable project. The actual measurement shows that the GMR current sensor developed can detect leakage current effectively. It can meet the requirement of field measurement of leakage current of DC cable.

2. Experimental Preparation

2.1.Giant Magnetoresistance Lleakage Current Sensor

In order to realize the accurate measurement and convenient installation of the sensor when the cable was onsite, the GMR current sensor was designed as a clamp-like closed-loop structure. As shown in Figure 1, negative feedback was introduced through operational amplifier and feedback coil. The GMR sensor chip senses the magnetic field in the air gap of the magnetic ring and generates an output voltage, which was amplified by an operational amplifier and generates a feedback current I1 in the feedback coil. The magnetic field produced by the feedback current in the air gap of the magnetic annulus was offset by the magnetic field generated by the current to be measured, which makes the GMR sensor chip work in the state of near zero flux. At this time, the voltage on the sampling resistance was the output voltage of the sensor U_{out}. Compared with the open-loop structure, the closed-loop structure had better linearity and dynamic range. By optimizing and designing the magnetic ring, a giant magnetoresistance leakage current sensor was developed. See Figure 2. The sensor can detect the magnetic field produced by DC current effectively. The detection range was ±30 mA and the error was less than ±2%.

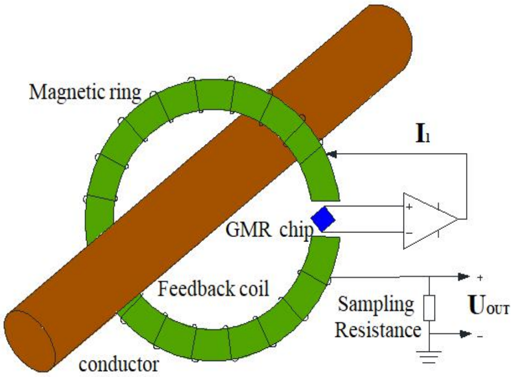


Figure 1: Closed-loop structure of GMR current sensor.

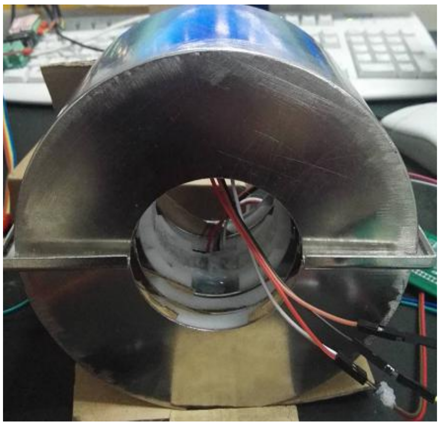


Figure 2: GMR Current Sensor.

2.2.Experimental Platform

The experimental system was shown in Figure 3. The test DC was a 5 kVA/200 kV test transformer; C1/C2 was a 200 kV/100 pF AC/DC voltage divider; C3 was a 200 kV/10 000 pF filter capacitor; and R1 was a 10 K protective water reswastance. The leakage current detection system consists of a leakage current sensor, a picoammeter and an oscilloscope. Among them, PIAM was KEITHLEY 6485, with 8 current ranges and fast automatic range functions, which can measure the current from 20fA to 20mA.

Pi-ampere meter was connected in series to ground lead of XLPE cable. The leakage current detection system was calibrated first. Pi-ampere meter was selected with appropriate range and continuous acquisition mode. The sampling interval was 1 s. The leakage current sensor was clamped on the cable grounding line and reads through the oscilloscope. During the experiment, the voltage level was maintained and each voltage level was maintained for 30 minutes. After the test was completed, the step-down discharges are stationary for 24 hours, and then the next test was carried out.

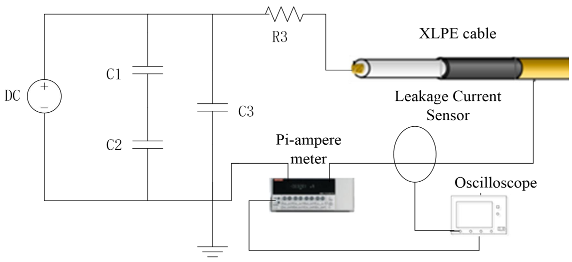


Figure 3: Test system.

2.3.Defect Model Design

In the experiment, 8.5/15kV YJV-120mm2 single core XLPE cable was used as defect model. The diameter of conductor was 13.2mm, the thickness of inner semi-conductive shield layer was 1mm, the thickness of XLPE insulating layer was 4.2mm, the thickness of outer semi-conductive shield layer was 1mm, and the thickness of copper shield and outer sheath was 1.5mm.

Taking the insulation scratch defect as an example, the process of making defect samples was as follows: in the process of making model cable terminal joints, scratches of 30 mm in length, 1 mm in width and 3 mm in depth were made along the axis of the XLPE surface of the model cable with blades. The scratches will form conductive channels, generated free discharge and gradually reduce d the insulation level. Then installed the cold shrinkable cable terminal connector. All the operation process was carried out according to the corresponding standards of cable terminal connector installation to ensure that there was no other discharge source except for the set defects. At the other end, a pressure equalizing ball was inserted and suspended. All insulating surfaces were polished smooth with sandpaper. The schematic diagram of cable insulation scratch defect model was shown in Figure 4, and the field installation of the test is shown in Figure 5.

Figure 4: Defect model of cable insulation scratch.

Figure 5: Cable test site.

3. Experimental Results and Discussions

3.1. Performance Test of Giant Magnetoresistance Sensor

In order to study the testing performance of giant magnetoresistance (GMR) sensor, the leakage current was stabilized by observing picoammeter, and the reading of GMR leakage current sensor was recorded. Because the scratch defect simulated in the laboratory was at the micro-ampere level, the range of measurement is chosen to be ±100μA. In fact, the range of sensor developed was ±30 mA. The test results were shown in Table 1. The leakage current sensor was basically the same as the picoammeter value, and the error was less than ±2%, which meets the application under laboratory conditions.

Table 1: Sensor parameter test result.

picoammeter value（μA）	Sensor value（μA）	error
100	98.9	-1.1%
80	80	0.0%
60	60.5	0.5%
40	41.1	1.1%
20	21.9	1.9%
-20	-18.8	1.5%
-40	-38.4	1.6%
-60	-58.2	1.8%
-80	-78.4	1.6%
-100	-98.6	1.4%

3.2.Effect of Voltage Polarity on Leakage Current

In order to study the influence of voltage polarity on leakage current of DC cables, six repetitive tests had been carried out for different test samples and experimental voltages. The experimental results were in good agreement. The experimental results of leakage current under positive and negative voltage tests were shown in Table 2.

Table 2: Leakage current detection results.

Applying voltage（kV）	Positive polarity leakage current（μA）	Negative polarity leakage current（μA）
7.5	1.20	1.79
10.0	2.18	3.28
12.5	2.77	3.59
15.2	5.63	6.30
20.0	6.88	8.00
22.5	7.82	8.90
25.3	8.87	9.79

The results shows that the voltage polarity had a significant influence on the leakage current measurement of DC cable. For the sample under the same environment, the leakage current under the negative polarity voltage was larger, which may be caused by the electroosmosis phenomenon. The XLPE insulation generally contains a small amount of water, and the water is positively charged. When the positive polarity was applied, the leakage current was larger than that under the negative polarity voltage. When the test voltage was applied, the water was far away from the high electric field area, i.e. the cable conductor, so the measured leakage current value becomes smaller. When the negative polarity test voltage was applied, the water moves towards the high electric field area under the action of the electric field, so the leakage current value measured increased.

3.3.Effect of Test Time on Leakage Current

The leakage current curve with time was shown in Figure 6. It can be seen from the figure that the leakage current reaches its maximum at the moment of applying voltage, then the current decreased gradually and tend to be stable after about 200 seconds of pressurization. At the same time, the leakage current fluctuated sharply when the applied voltage was high.

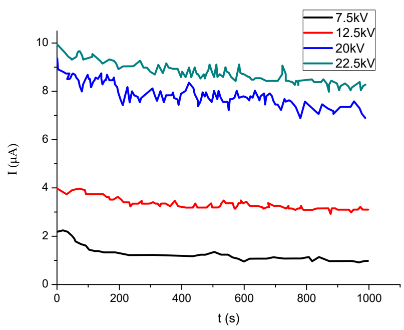
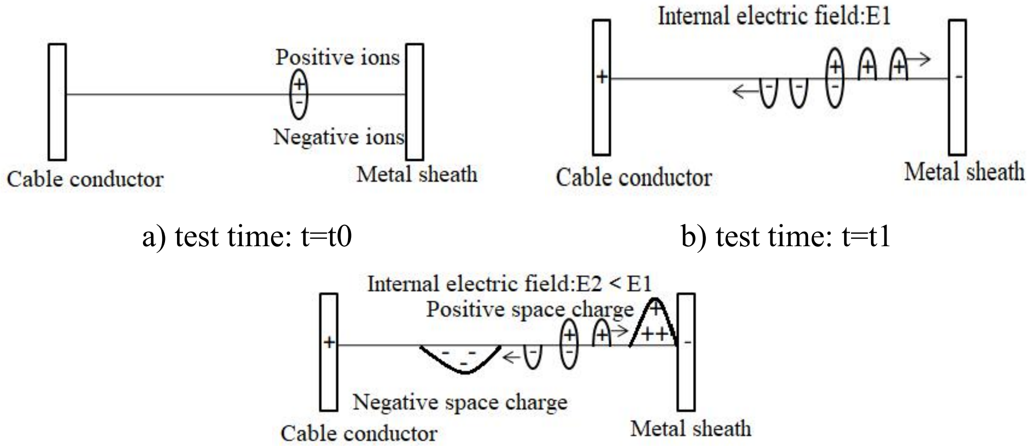


Figure 6: The curve of the leakage current of scratch defect with time.

The main reason was the injection, migration and dissipation of positive and negative space charges in XLPE cable insulation under high voltage electric field. According to the research results of scratch defect and leakage current of normal cables, a model of DC leakage current of scratch defect was proposed. As shown in Figure 7, carried in the air gap of scratch defect migrate to the two poles of cable conductor and metal cladding respectively by applying voltage (t=t1). With the increase of the number of migrating carriers, space charge (t = t2) was formed in the insulating layer of the cable. The formation and aggregation of space charges reduced the local electric field in insulation. When the electric field was lower than Schottky barrier, the space charge escaped and the carrier injection of electrodes decreased. At the same time, the local electric field strengthend. Thus, the leakage current oscillated in a short time. In the test period (1000s), the decrease of DC leakage current was due to the decrease of carrier migration velocity, which was due to the relaxation of electric field in insulation.



a) test time: t=t0 b) test time: t=t1

c) test time: t=t2

Figure 7: A curve model of the leakage current of scratch defect.

4. Field Test

In the study of leakage current characteristics of ±200 kV DC cable line in Zhoushan of China, the giant magnetoresistance sensor was used to measure the leakage current of positive and negative DC cable. The sensor was installed on 10 kV 1×240mm2 direct grounding line and read after 200s. The field test was shown in Figure 8. The results show that the leakage current of positive 200 kV XLPE cable was 10.7 mA, negative 200 kV XLPE cable leakage current was 15.1 mA. The negative leakage current was larger than the positive leakage current, which was consistent with the experimental results.

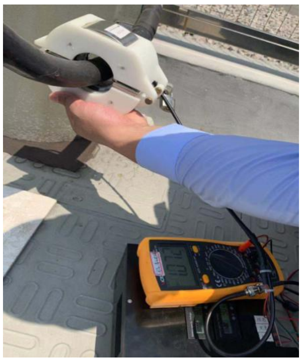


Figure 8: Leakage current sensor field test.

5. Conclusions

In this paper, a micro-ampere giant magnetoresistance leakage current sensor was designed and developed, and an experimental platform for leakage current detection of DC XLPE cable was built. Taking the XLPE insulation scratch defect as the test sample, the characteristics of leakage current of XLPE cable and the influencing factors of detection were analyzed. The main conclusions are as follows:

(1) The leakage current sensor based on giant magnetoresistance effect has a measuring range of ±30 mA, an error of ±2% and a sensitivity of 1μA. It has good performance in the measurement of leakage current of DC cable. Compared with other current measuring devices, it has the advantages of small volume, high sensitivity, large measuring range and high integration. Potential.

(2) Leakage current of XLPE insulated cable was affected by voltage polarity. Leakage current under negative polarity voltage was higher than that under positive polarity. Therefore, it is easier to detect defects by leakage current test under negative polarity voltage.

(3) Leakage current tends to decay when the insulation contains defects, and the reading tends to be stable after 200 s. Leakage current curve was relatively smooth when the voltage was small. With the increase of voltage, leakage current fluctuates obviously.

Acknowledgments

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