Behavior of Residual Charges in Water-tree Degraded XLPE Sheets and Cable

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Many studies have been done on the application of residual charge measurement in cable degradation diagnosis. In this paper, the behavior of residual charges measured with water-tree degraded XLPE sheets and cable are discussed. At charge injection process, the charge is injected by applying dc voltage as a conventional method, suddenly cut-off ac voltage or impulse voltage. Therefore the residual charge is influenced by the applying process. At charge release process, transient dc current flows when applying ac high voltage and also ac high voltage superimposed to dc low voltage. From the results, new diagnosis method is suggested.

Keywords : Water-tree, Residual charge, Deterioration diagnosis, XLPE insulated cable

1. INTRODUCTION

A lot of XLPE insulated cables are being used now. However, water-tree deterioration occurs, while it has used for a long term, and it is finally worried to do dielectric breakdown[1]. This becomes an important subject. To prevent the dielectric breakdown beforehand, deterioration diagnosis is researched. Residual charge method[2] is paid to attention as the diagnosis. Authors have measured the residual charges of water-tree degraded sheets and cable, and studied the residual charge characteristic[3].

2. MEASUREMENT METHOD

2.1 Measurement circuit

Figure 1 shows the measurement circuit of the residual charge. When SW1 is shut, the high voltage is applied to the specimen. When SW1 is opened, and SW2 is shut, the charge in the specimen is discharged. However, some charge remains to be restrained near around water-trees. In addition, when SW2 is opened and SW3 is shut, the charges which restricted near around water-trees are released and the transient dc current is observed by the current detector. This current is integrated and the residual charge is calculated.

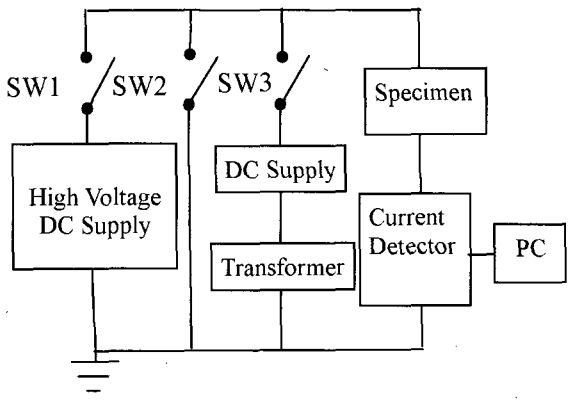

Fig. 1. Measurement circuit.

2.2 Measurement processes

There are four processes of charge removal, charge injection, ground and charge release in the measurement.

The process of charge removal was introduced to measure a little charge successfully, that is, ac voltage was applied to the specimen before charge injection process. This process is very important to measure a sheet specimen.

In the conventional process of charge injection, dc high voltage was applied and the residual charge characteristic was measured. For a sheet specimen, the residual charge was measured by two methods of applying dc voltage in step-up and step-down, as the influence of hysteresis was examined. For a cable specimen, impulse voltage instead of dc voltage was applied in the process of charge injection, and the residual charges were measured. Furthermore transient dc current was observed during the high speed cut- off of ac voltage and during the re- application of ac voltage.

In the process of charge release after ground, the dc transient current was observed during applying ac high voltage and the residual charge was measured. In addition, dc low voltage was superimposed to ac high voltage, and the residual charge characteristic was examined.

3. MEASUREMENT OF XLPE SHEETS

3.1 Sheet specimens

The specimens are XLPE sheets of thickness 1mm which is degraded with water-trees as shown in Fig. 2. There are two kinds of specimens, that is, the one with heavy deterioration and the slight one as shown in Table1. Moreover, the non-deterioration specimen is prepared for the reference.

3.2 Measurement condition

In the charge injection process of conventional method, dc voltage was applied. This dc voltage is shown

Fig. 2. Cross section of sheet specimen.

Table 1. Sheet of specimens.

	Degradation Degree
A	non-degradation
B1	Slight degradation
B2	Heavy degradation

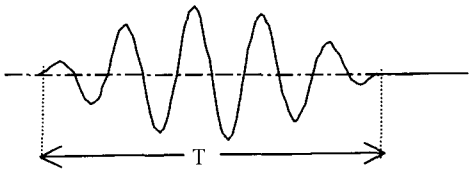

Fig. 3. AC voltage wave.

Vd in the table of the measurement condition. Moreover, in the charge release process ac voltage was applied and residual charge was measured. This ac voltage is shown Vac in the table of the measurement condition. The wave form of ac voltage was used to control accurately the time of the step-up and the step-down in the processes of charge release for the sheets experiment. This voltage is a sinusoidal wave with frequency f (Hz), and the envelope of the voltage is a half period (T) of the sinusoidal wave shown in Fig. 3.

3.3 Measurement results

(1) DC voltage characteristic

DC voltage characteristic of the residual charge by conventional method is shown in Fig. 4 and the measurement condition is shown in Table 2. The relation between the applied dc voltage and the residual charge was examined, and the higher dc voltage was, more the charge was. This is similar to the result of the cable that has already been reported. It was confirmed to be able to measure the residual charge of the sheet specimen by high sensitivity by introduction of the charge removal.

Table 2. Measurement condition of DC characteristics voltage.

Processes	Measurement Condition
Charge Injection	Vd : 0~max(-)5(kV), Charging period : 5(min)
Ground	Grounding period : 2(min)
Charge Release	Vac : 2(kV), f : 50(Hz) , T : 1(sec)

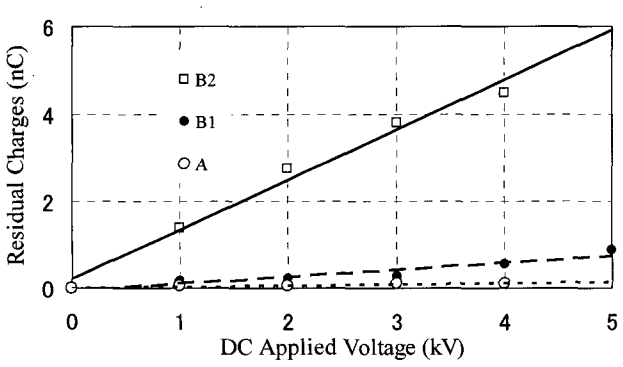

Fig. 4. DC voltage characteristics.

Table 3. Measurement condition of charge injection hysteresis.

Processes	Measurement Condition
Charge Injection	Vd : 0~max(-)2.5(kV), Charging period : 1(min)
Ground	Grounding period : 2(min)
Charge Release	Vac : 2(kV), f : 50(Hz) ,T : 1(sec)

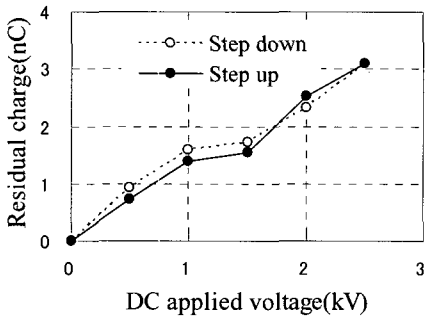

Fig. 5(a). Histeresis of charge injection (a).

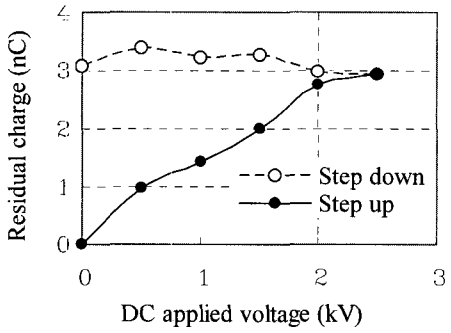

Fig. 5(b). Hysteresis of charge injection (b).

(2) Hysteresis of dc voltage application

It experimented in two kinds of charge injection processes to investigate hysteresis. The one always began to applied dc voltage from 0(V) in the descent process and applied until the voltage of the target. On the other hand, the voltage of the target was applied via each step of the rise though it was the descent process. Table 3 shows the experimental condition, and Fig. 5(a) and (b) show the results. It was confirmed that it has been shown that the applied process of dc voltage much influences the measured residual charge. The residual charge is decided depending on the maximum value of the dc voltage in the charge injection process.

Table 4. Measurement condition of bias superimposed characteristics.

Processes	Measurement Condition
Charge Injection	Vd : (-)2.5(kV), Charging period : 5(min)
Ground	Grounding period : 2(min)
Charge Release	Application voltage : Vac+Vb Vac :1, 2(kV), f : 50(Hz) ,T : 1(sec) Vb : (-)285(V) ~(+)285(V)

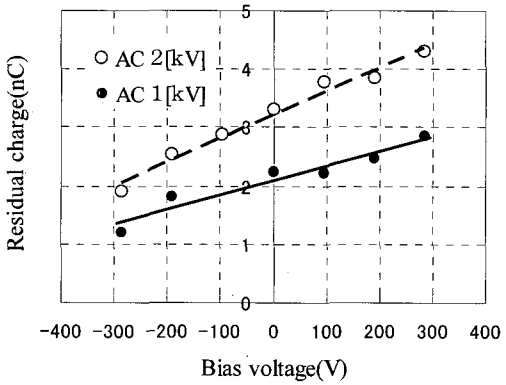

Fig. 6. Bias superimposed characteristics.

Table 5. Measurement condition of bias effect.

Processes	Measurement Condition
Charge Injection	(1) Non
Ground	(2) Non
Charge Release	Vac : 12.7(kV), f : 50(Hz) T : 2(min)

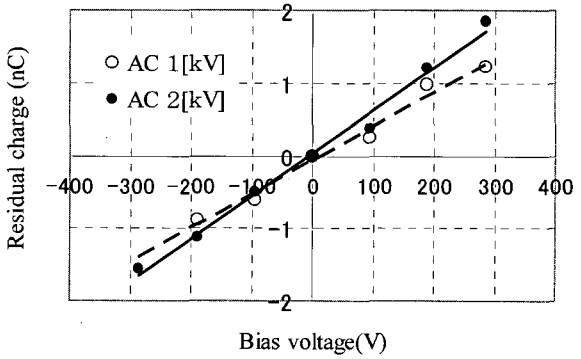

Fig. 7. Charge injection by bias voltage.

(3) DC superimposed characteristics

In the conventional process of charge release, the

residual charge is measured during ac voltage is applied. In this experiment, dc voltage was superimposed to ac voltage, and the residual charge was measured. The measurement condition shows in Table 4 and the results show in Fig. 6. It has been showed that the residual charge changes much even if the dc voltage is low. Then the charge injection process was omitted, and the sheet specimen was applied dc low voltage, bias, after that ac high voltage was superimposed to the specimen. According to the result, transient dc current was observed as well as a conventional residual charge measurement. This transient dc current was integrated, and got the charge. The result is shown in Fig. 7 and the measurement condition is shown in Table 5.

4. EMEASUREMENT OF XLPE INSULATED CABLE

4.1 Cable specimen

A cable specimen used here is 22 kV-class degraded XLPE insulated cable (5 m in length) wherein water trees are present in the insulation near the outer conductor.

4.2 Measurement condition

As shown in Table 6, three types of voltages were applied to the same cable specimen in order to investigate the effects in the process of charge injection[4].

At first, ac voltage was applied to the cable in the process of charge release after the application of dc voltage as the process of charge injection, and dc current transiently flowing to ground was measured. Then, this current was integrated to obtain the residual charges. This is conventional residual charge measurement, and in order to differentiate it with other methods, it is referred to as the dc residual charge. Secondly, residual charges were measured after application of standard lightning impulse voltage of 1.2/50 μsec at one shot as the process of charge injection. It is referred here as the impulse residual charge. Finally, ac voltage was cut-off suddenly at a certain phase angle using the high speed cut-off method with the thyristor, the residual charges were then measured after re-applying ac voltage as the process of charge release. This is referred to as the ac residual charge.

In either of the methods, the cable was grounded for two minutes after the process of charge injection. Furthermore, the current of the residual charge measurement was measured between the cable sheath and ground.

Table 6. Measurement condition of cable specimen.

processes	Measurement Condition
Charge Injection	DC(-)0~20(kV) Imp.(±)5~20(kV) Cut-off at 12.7(kV)
Ground	Grounding period : 2(min)
Charge Release	Vac : 12.7(kV), f : 50(Hz) T : 2(min)

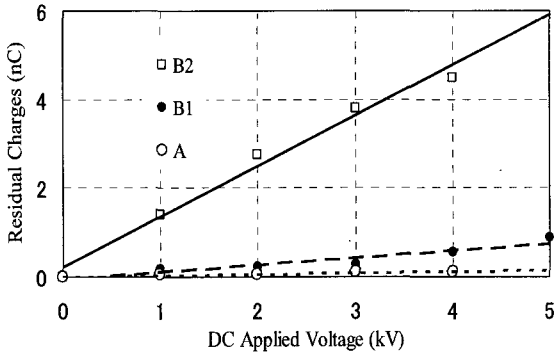

Fig. 8. DC characteristics.

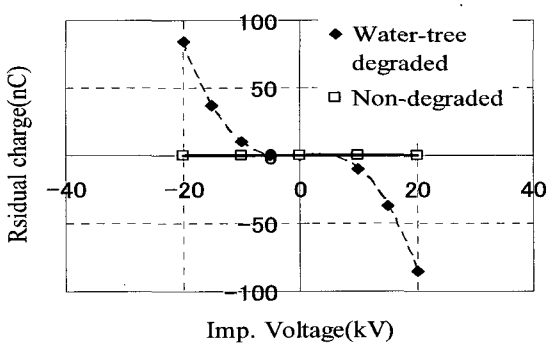

Fig. 9. Impulse residual charge.

4.3 Measurement results

(1) DC residual charge

Figure 8 shows the result of dc residual charge. As the applied dc voltage increases, the residual charges increase nonlinearly. In this figure, the residual charge is positive since negative dc voltage is applied to the conductor. Although it is not shown here, the absolute value of residual charges upon application of positive dc voltage has the same value with the negative one but with opposite polarity.

(2) Impulse residual charge

Figure 9 shows the result of impulse residual charge, this result is the same with dc application wherein the residual charges increase nonlinearly as the applied

impulse voltage increases. Also, there is no difference in polarity, Note that residual charges have been measured even with shorter application such as the impulse voltage in charge injection processes.

(3) AC residual charge

The transient dc current was observed during the high speed cut-off of ac voltage and during the re-application of ac voltage. Figure 10 shows the result of integration of this current. The magnitude of the charges is of equal value although their polarity is in opposite direction. It is considered that the injected charges during voltage cut-off are released with the re-application of ac voltage. Fig. 11 shows the relationship between the phase angles and their charge during cut-off. According to this result, hysteresis phenomenon is observed in these various charges.

5. DISCUSSION

In the report of a current residual charge, most is measured with cable specimens[3]. The residual charge was able to be measured also with the sheet specimen as we had shown in Fig. 4. The charge is smaller than the cable of Fig. 8 with about 1/100. There are two reasons for the results. It is because the noise decreased as the charge that had been electrified was removed before the charge is injected. It is moreover because the current grew as ac voltage was applied for a short time shown in Fig. 3 though the charge is a little.

The charge was injected by dc voltage, ac voltage was applied afterwards, and the residual charge was measured usually. But the residual charge was measured by applying suddenly cut-off ac voltage or applying impulse voltage in the cable as shown in Fig. 10 and Fig. 11. It is important for the cable to apply ac voltage first of all, and to remove the charge that has already been electrified.

The residual charge is much influenced by the application processes of dc voltage as shown in Fig. 5. Moreover, it also is much influenced by the phase of the ac voltage suddenly cut-off shown in Fig. 11. This feature looks like the polarization characteristic of the dielectric material well.

The charge is usually injected by dc voltage as mentioned above, ac voltage is applied next, and the residual charge is measured. However, dc low voltage is applied beforehand, and it charges the specimen enough. Afterwards, transient dc current flows when ac high voltage is superimposed to dc low voltage. When this current is integrated, the charge that relates to deterioration can be measured as well as the residual charge as shown in Fig. 7. As a result, it is suggested to be able to measure the deterioration of the cable.

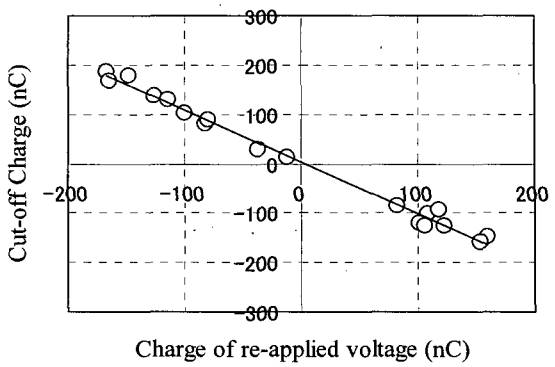

Fig. 10. Charge during and after cut-off.

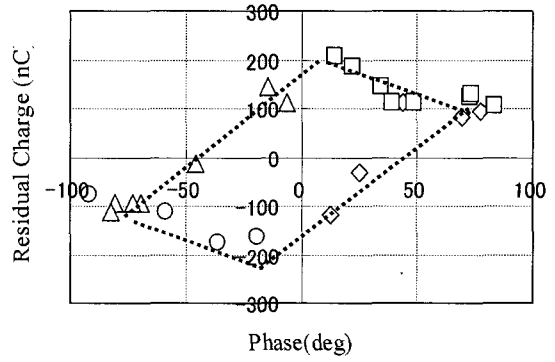

Fig. 11. Charge during cut-off vs phase angle.

6. CONCLUSION

Authors have measured the residual charges of the water-tree degraded sheets and cable. The result is summarized as follows.

The residual charge was able to be measured also with the sheet specimen. It is because the noise decreased as introduction of charge removal processes and ac voltage application for a short time.

The charge is injected by applying suddenly cut-off ac voltage or by applying impulse voltage. Therefore it is important for the cable to apply ac voltage first of all, and to remove the charge that has already been electrified.

Transient dc current flows when ac high voltage is superimposed to dc low voltage. It is suggested to be able to measure the degraded cable.

ACKNOWLEDGMENTS

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