Interface Effects on Tree Growth of Cross-linked Polyethylene

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Abstract

It is well known that treeing is one of the main causes of breakdown of CV cables. It has been also considered that the interface exists between two solid insulation materials become a weak point on the electrical strength of CV cables. Therefore, it is important to research on the tree growing properties when there exists an interface. For evaluating the interface effect on the AC tree growth, an experimental investigation has been carried out by preparing an interface between two cross-linked polyethylene(XLPE) blocks. This paper describes the experimental results under various interface conditions. It was found that the interface had a great influence on the tree growth. The time to breakdown was reduced by the interface in the present test conditions. Painting the silicone oil on the interface, not only reduced the time to breakdown but also prevented the breakdown through the surface of specimen(B). And the pressure applied on the interface had a slight effect on the time to breakdown but on the tree growth pattern. With the increasing of applied voltage, phenomena above mentioned were more significant. It is proposed that the discharge column activities and the gas pressure reduction in the tree channels play important roles in the present situation.

Key words: Electrical tree, Interface, Interface pressure, Gas discharge, Discharge column

1. Introduction

In spite of the fact that cross-linked polyethylene (XLPE) insulated cable(CV cable) has established an excellent service record, it had been once reported that some of CV cables failed in service over several years. This might be because the insulation of the CV cables was deteriorated by trees initiated and grown from voids in XLPE and interfaces between XLPE and other insulating materials under a high electric field. In fact, careful microscopic analysis of the CV cables broken down in service has found various types of trees.

Recently, it has been known that the interface prepared between two materials plays an important role in electrical insulation resistance. Therefore, it is important to investigate the electrical strength of the interface because it seems that the interface prepared between two materials becomes a weak point on the electrical strength of CV cables.

A trial was performed on evaluating the electrical strength of an interface prepared between two XLPEs. In this paper, we describe the experimental results for the interface's effect on electrical tree-growth in XLPE when an ac voltage with 50Hz was applied. It was found that the interface prepared

between two XLPEs had a great influence on tree growth.

2.Experiments

A XLPE block($12 \times 13 \times 4$ mm) was used as a specimen. After the specimen was heated for 15 minutes at 140°C , a needle (ground by Ogura Jewel Industry Co.) with tip angle of 30° and curvature radius of $5 \mu\text{m}$ was then inserted into it. The distance between the needle tip and the plane electrode(painted conductive silver) was 2mm without the interface, as shown in Fig.1(a). On the other hand, for the specimen with the interface the distance between the needle tip and the bottom of the specimen A was 1mm and the thickness of specimen B was 1mm as shown in Fig.1(b).

(a) Without interface (b) With interface
Fig.1 Configuration of specimen(mm)

The specimen set on the apparatus shown in Fig.2 was

immersed in silicone oil to prevent the surface flashover. The 50Hz, ac voltage was increased at a constant rate of about

Fig.2 Experiment apparatus

Fig.3 Diagram of experimental set-up

1kV/sec to a certain voltage, and then the growth and the shape of tree were observed on a display through an optical microscope ($\times 40$), a CCD camera and a video tape recorder. The magnitude and phase-PC of PD was measured

simultaneously. The experimental set-up diagram is shown in Fig. 3.

At present study, the following conditions were chosen:

(1) Three kinds of applied voltage, those were 10, 11 and 12kV. The applied time of voltage was till 120 minutes.

(2) Four kinds of interface pressure(the pressure applied on the interface), it was varied in the range from 1kg/cm^2 to 20kg/cm^2 . The interface pressure was controlled by a spring length of experimental apparatus shown in Fig.2. The interface pressure was measured by pre-scale(Fuji-Film Co.).

(3) With or without the silicone oil at the interface. Silicone oil was painted on the interface just before the test starting.

It has been reported that the difference of time to breakdown among various surface's roughnesses wasn't observed[2]. Therefore, in this study we kept the surface's roughness ground by sandpaper of #1000 as constant.

3.Experimental Results

3.1 The general aspect of tree-growth pattern

A typical aspect of tree growth and its shape when the interface is prepared between two XLPEs are shown in Fig.4. When a voltage is applied, tree initiates and grows toward the interface. About 10 minutes later, tree reaches the interface and temporarily stops the growth there, and then the tree channels are eroded. Consequently, the tree channels become thick in a few minutes. These phenomena are found for all conditions of the interface prepared. The tree-shape at the first stage when applied 10kV is shown in Fig.5. After that, however, the growth pattern of tree is divided into three groups depending upon the interface conditions prepared, as

Fig.4 A typical aspect of the growth and the shape of tree

Tree channels are eroded

12kV case(c)

Fig.6 Photographs of second stage

Fig.7. A typical tree growth curve

shown in the second stage of Fig.4. First is the case(a) where tree grows along the interface at specimen A side without growing in specimen B. In this case, no breakdown occurs even in the application time of 120 minutes. The second is the case(b) where the tree grows into specimen B and puncture breakdown occurs. On the other hand, (c) is the third case. In the case(c), tree grows along the interface, and finally breakdown occurs through the surface of specimen B. Fig.6 shows the photographs of the case(a), (b) and (c) under various applied voltages, respectively. A typical tree-growth curve is shown in Fig.7.

Table 1 Probabilities of tree pattern at second stage
(a) under various applied voltage s (%)

pattern voltage	(a)	(b)	(c)
10KV	5	95	0
11kV	4	67	29
12kV	0	39	61

(b) under various interface pressures (%)

pattern Pressure voltage	(a)			(b)			(c)		
	1	4	8	1	4	8	1	4	8
10kV	5	0	0	32	32	32	0	0	0
11kV	4	0	0	24	14	29	14	14	0
12kV	0	0	0	4	9	26	26	26	9

(c) with or without si-oil painted (%)

pattern	(a)		(b)		(c)	
oil	no oil	oil	no oil	oil	no oil	oil
voltage						
10kV	5	0	47	47	0	0
11kV	4	0	24	43	29	0
12kV	0	0	17	22	35	26

Fig.8 Breakdown time under various conditions

3.2 Probabilities of case(a), (b) and (c) at the second stage

The probabilities of treeing pattern of case(a), (b) and (c) at the second stage under various test conditions are shown in tables 1. The results can be characterized as follows:

(1) With the increasing of the applied voltage, the probabilities of case(a) and case(b) are reduced, meanwhile the case(c) is increased obviously;

(2) Painting the silicone oil on the interface, the probabilities of case(a) and (c), especially case(c), are reduced;

(3) With the increasing of the interface pressure, the probabilities of case(a) and the case(c) are reduced.

3.3 Characteristics of time to breakdown

Figure 8 shows the time to breakdown under various test conditions. From the comparison of the results under various applied voltages and the interface pressures the following facts are summarized:

- (1) The time to breakdown for the sample with the interface becomes shorter than those without the interface;
- (2) The difference of the time to breakdown among the interface pressures is not found;
- (3) The interface pressure can prevent final breakdown through the surface like case(C), and the prevention increases with the increasing of the applied voltage;
- (4) Painting the silicone oil on the interface, reduces not only the breakdown time, but also the probabilities of case(a) and case(c).

4. Discussion

For the specimen with the interface, it is observed that after the tree reaches the interface, many bubbles come out from there as shown in Fig.9. At the same time, the pulse number and the magnitude of PD are increased suddenly as shown in Figs.11 and 12. This phenomenon is observed in all the experiments. As the gas leaks through the interface, the gas pressure in the tree channels is reduced. So the gas discharge is more active. The electric field increased by the discharge column at the tip of old tree branches may be stronger [3,4,6]. Consequently, the tree growth may be faster. On the other hand, when the tree arrives at the interface, where exists a thin air or silicone oil layer, the discharge column is diffused as shown in figure 10. This may mean that at the tip of the old tree, the electric field is reduced[1,2]. As a result, the growth of tree is slower.

The growth of tree is controlled by these two factors, one is that at the interface the electric field is increased by gas leakage, another is that the electric field is decreased by the diffusion, depending on which one is more significant.

Fig.9 Photograph of bubbles

4.1 The effects of the interface pressure

From the experimental results, the difference of the time to breakdown among the interface pressures varied from 1kg/cm^2 to 20kg/cm^2 is not found. But with the increasing of the interface pressure, the tree growth pattern is changed from case(c) to case(b).

Fig.10 Gas discharge model

When the tree reaches the interface, the high voltage is partially transferred by discharge column to there. This divergent field may cause the partially breakdown(tree grow) along the surface. With the increasing of the interface pressure, withstand stress of gas or silicone oil may be increased by the pressure. Therefore, along the interface the growth of tree is slowed. It changes the tree pattern from case(c) to case(b) as shown in Fig.8.

In all of the situations, the bubbles come out from the interface even the interface pressure is 20kg/cm^2 . Therefore, it does not affect the gas discharge. Since the interface pressure does not affect the gas discharge, the time to breakdown is almost the same under present conditions.

4.2 The effects of the silicone oil painting

Painting the silicone oil on the interface, because silicone

oil has good adhesion for polyethylene, it penetrated into microvoids and defects on the interface's surface. The withstand stress on the surface of the interface is increased and the tree growth along the interface is limited. Consequently, the tree growth pattern changes from case(c) to case(b). On the other hand, because the mean free path or the flowability of the oil must be less than those of air, the diffusion of discharge column may be prevented, and then the maximum electric field at the interface is greater than that without silicone oil. Therefore, the time to breakdown may be shorter than the case of without silicone oil painted.

The typical PD characteristics for the specimens with and without silicone oil painted on the interface are shown in Figs. 11 and 12, respectively. It has been noticed that after large amount of bubbles leaked through the interface, for the specimen without silicone oil painted, the increase of PD magnitude and pulse numbers are more significant. The reason may be that the silicone oil also prevents the gas in the tree channels from being leakage. It is assumed that the increase of the electric field at the the interface by painting the silicone oil on it is more significant, so that the time to breakdown is shorter.

4.3 The effects of the applied voltage

When the applied voltage is lower like 10kV , since the gas pressure in the tree channels is relatively lower, the ignition of the gas discharge is easier[3,4]. In this situation, when the tree reaches the interface, the increase of the field increased by gas leakage is not very high. Consequently, together with the diffusion, the time to breakdown may be a little shorter even be longer as shown in Fig.8.

Fig.11 PD Characteristics(10kV,8kg/cm²,no oil)

Fig.12 PD Characteristics(10kV,8kg/cm²,oil painted)

On the other hand, with the increasing of the applied voltage, the gas pressure in the tree channels is higher. When the tree reaches the interface, bubbles come out from there are more, and as a result the discharge column field is higher. By comparison with the diffusion of the discharge column at the interface, the field increased by the gas leakage is more significant. Furthermore, with the increasing of applied voltage, the charge energy of discharge column is higher. The diffusion may be limited. For those reasons, the time to breakdown is extremely shorter than that without the interface as shown in Fig.8.

5. Conclusion

(1) The time to breakdown for the samples with the interface becomes shorter compared with those without it.

(2) There was not found the change of the breakdown time in spite of the increase of the interface pressure.

(3) The increase of the applied voltage increased the probability of breakdown pattern (case c) through the surface of specimen B.

(4) Painting silicone oil on the interface is possible to prevent surface breakdown pattern (case c) and the time to breakdown may be reduced.

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