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Study on grasping partial discharge development using an acoustic emission technique

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To investigate the stage development of Partial Discharge (PD) for Ethylene Propylene (EP) rubber used for insulation material of joint and terminal sections of cross-linked polyethylene (XLPE) cable, we focused on the magnitude of PD and the cumulative number of PDs per unit time. It was difficult to grasp the stage development of PD by temporal variations in Acoustic Emission (AE) signal intensity and the number of counted AE signals because they contained periods during which PD activity was not high even before breakdown occurred. In contrast, the cumulative number of AE signals could clearly show a point of time when a PD might form a pit or a tree in EP.

Keyword: *Condition monitoring and diagnostics, partial discharge, solid dielectrics*

1.0 INTRODUCTION

A stable power supply with high quality is strongly demanded for advanced information society, and any electric failures in electric power apparatus are not allowed. For transmission and distribution lines, cross-linked polyethylene (XLPE) cable plays an important role in distributing the stable power to customers. Electric failure for the XLPE cable decreases year by year because of progress of manufacturing technique. However, at joint and terminal sections of the XLPE cable, Partial Discharges (PDs) occur in defects of insulating materials. The PD generation can occur at any points in the insulation system where electric field strength exceeds a PD inception electric field and can develop until breakdown occurs. That is, PDs which are owing to local electrical stress in the insulation or on the surface of the insulation reflect a kind of sign of insulation deterioration. Therefore, PD measurement is a useful technique of assessing the insulation deterioration of XLPE cables.

Incidentally, it is well known that the occurrence of PD is accompanied by charge transfer, heat, electromagnetic wave, and Acoustic Emission (AE). Until now, various monitoring techniques [1, 2] have been developed and examined based on detecting secondarily emitted phenomena mentioned above. However, it seems that the correct evaluation about the amount of electrical charge due to PDs and the degree of insulation deterioration are difficult. The AE consists of sound and ultrasonic waves as elastic waves and can be observed when stress or energy is released in material. The piezoelectric device changes change of the wall pressure by mechanical vibration into charge migration. An AE technique [3-7] is to analyze the AE signals detected by the piezoelectric AE sensor set on the surface of electric power apparatus. The detection sensitivity may be lower than those using electromagnetic sensors [2]. However, the noise level of the AE sensor is relatively low in comparison with other sensors and the noise reduction processes after detecting the AE signal are not difficult by using

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a digital filter through a fast Fourier transform (FFT). Because AE sensors are directly attached to power apparatus, a complicated removal technique is not required. In the case of measurement on a XLPE cable, most of noise components owing to vibration of the XLPE cable are excluded, easily. Otherwise, obvious difference in detection times of a PD when 2 or more AE sensors are arranged appears due to the position relation between the PD and AE sensors. Additionally, it is possible to locate a PD by setting several AE sensors. Thus, an AE technique is useful for grasping occurrence of PDs even under operating condition. From the above reasons, we have engaged in study on advanced diagnostic technique using AE sensors [8]. Until now, we investigated characteristics of attenuation of elastic waves in ethylene propylene (EP) used for insulation material of T-branch joint section for a 22 kV distribution system [8]. Based on the results, we can estimate the intensity of AE at a PD source position by using a damping coefficient. However, a PD magnitude isn't enough to fully understand PD activity and to estimate the remaining lifetime of insulation.

In this study, to investigate the stage development of PD for EP rubber which is a basic material of a T-branch joint section for a 22 kV distribution system, we first formed an air gap between a tip of a needle electrode and the surface of EP rubber. Experiments should have been carried out using an actual XLPE cable joint; however, the control of minute gap is difficult. For an actual T-branch joint section, electric field becomes high at the corner of the contact surface area between the tip of the cable conductor and the surface of EP rubber. There is a possibility that the discharge occurs in a minute gap of the contact surface area; therefore, it is desirable to generate PDs between a needle electrode and EP rubber surface. Thus, we made experiments under a plate-like EP. AE signals owing to the PDs were detected using AE sensors set at the rear side of the EP rubber. We evaluated the magnitude of PD, the accumulated number of PDs per unit time, and the cumulative number.

2.0 EXPERIMENTAL SETUP AND METHODS

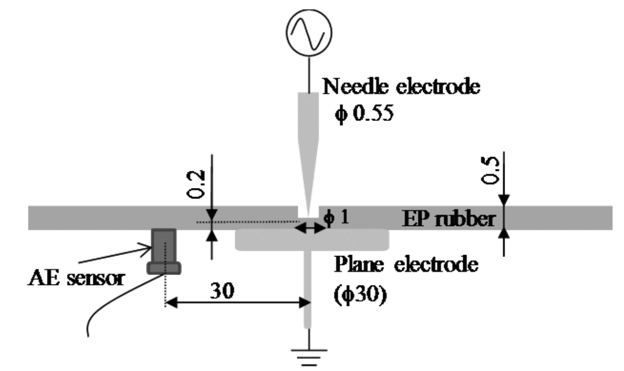

FIG. 1. STRUCTURE OF OUR USED ELECTRODE SYSTEM. THE GAP LENGTH BETWEEN A NEEDLE ELECTRODE AND THE EP RUBBER SURFACE IS 0.1MM. PDS ARE GENERATED BY APPLYING SEVERAL KV WITH FREQUENCY OF 60 HZ TO A NEEDLE ELECTRODE

Figure 1 shows the structure of our used electrode system. A grounding electrode with a diameter of 30 mm and a thickness of 5 mm was set at the rear side of the EP rubber surface facing a needle electrode. The dimension of the EP rubber with density of 1.19 g/cm^3, dielectric constant of 3.0 and volume resistivity of 5×10^{15} Ω·cm was as follows: Height 200 mm x Width 200 mm x Thickness 0.5 mm. The EP rubber had a hole with a diameter of 1 mm and a depth of 0.3 mm. The gap length was set at 0.1 mm by using a micrometer, and PDs were generated by applying several kV with frequency of 60 Hz to a needle electrode with a diameter of 0.55 mm. Figure 2 shows a spatial distribution of electric field around a gap. When the applied voltage is 2 kV, a maximum electric field near a tip of a needle electrode is 14 kV/mm. As one of normal approaches to investigate PD activity, a minute void is prepared by putting a sheet of EP rubber with a small hole between 2 sheets of EP rubber. In our study, to extend the non-uniform electric field and to steady the position of discharge formation, a gap was formed by setting a needle electrode facing the surface of EP rubber. Additionally, this electrode structure suppresses undesirable PDs among material surfaces. Before anything else, because electric field for a T-branch joint section becomes high at the corner of the contact surface area between the tip of the cable conductor and the surface of EP rubber, we generated PDs between a needle electrode and EP rubber surface. If there is a minute gap 0.1 mm in length between the cable conductor and the EP rubber surface of a T-branch joint cable for a 22 kV distribution system, the maximum electric field is calculated as 14 kV/mm. Our experimental condition simulates such electric field.

In our preliminary experiments, a large time difference in occurrence of breakdown in EPR was confirmed, which was mainly due to the void size. In this paper, results obtained in the case where a breakdown occurred at approximately t = 200 h are mainly referred. However, a tendency of the signal variation was the almost same without being concerned with the void size, which will be mentioned again later. An AE sensor with a diameter of about 10 mm and a length of 35 mm was set at the rear side of the EP rubber and 30 mm away from the center of a grounding electrode.

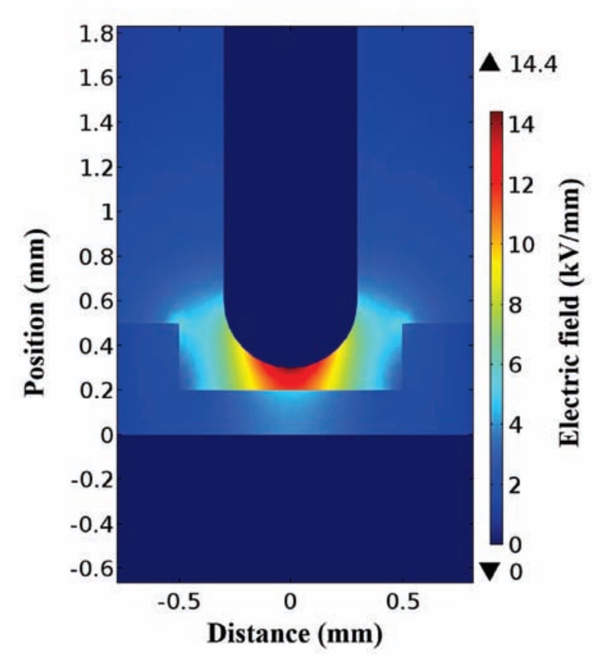

FIG. 2. SPATIAL DISTRIBUTION OF ELECTRIC FIELD NEAR A TIP OF A NEEDLE ELECTRODE. MAXIMUM ELECTRIC FIELD IS FORMED AT THE TIP OF A NEEDLE ELECTRODE

Figure 3 shows a schematic diagram of experimental setup for generating PDs and a detection system. The frequency sensitivity of an AE sensor is the almost same in the range of 20 kHz to 1000 kHz. The AE signal detected by the AE sensor was amplified by a preamplifier of 40 dB (Maximum gain: 40 dB) with a frequency band of 2 kHz to 1.2 MHz and a main amplifier of 60 dB (Maximum gain: 60 dB) with a high pass filter of 50 kHz and a low pass filter of 500 kHz, i.e., a total amplification was 100 dB in a range of 20 kHz – 500 kHz. The signal from an amplifier system was sent to a digital oscilloscope with a sampling frequency of 100 MHz and then recorded with a computer for further analyses including FFT. The effective use of the FFT allows us to evaluate correctly frequency characteristics and the intensity.

PD current with a pulse width of several tens ns was detected with a CT sensor through a grounding electrode and was sent to a digital oscilloscope with a sampling frequency of 100 MHz, which triggered a digital oscilloscope used for recording AE signals. The measurements of the AE signal and the PD current against time (t) elapsed from the voltage application were continuously carried out.

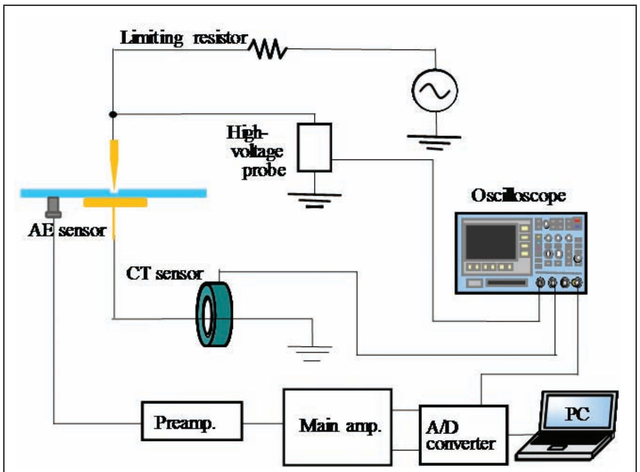

FIG. 3. SCHEMATIC DIAGRAM OF EXPERIMENTAL SETUP FOR GENERATING PD AND A DETECTION SYSTEM.

3.0 EXPERIMENTAL RESULTS

Figure 4 shows a typical waveform of a detected PD current. A full width of half maximum of the PD pulse and a peak value were 20 ns is 50 mA, respectively. The amount of electric charge, calculated by integrating the detected waveform, is 979 pC. A typical AE signal is shown in Figure 5, in which 0 ms in this figure means the ignition of PD. An AE signal with a maximum magnitude of about 1.6 V is seen, and a period which the AE signal was continuously detected is about more than 0.1 ms. Such AE signal was continuously detected every 8 ms. Additionally, the amount of electrical charge due to a discharge was mostly in a range of 20 pC – 1000 pC. Figure 6 shows FFT spectra of a detected AE signal. It can be seen from this figure that frequency components around 70 kHz – 120 kHz are remarkable. The elastic wave is caused by the compressional wave in a void. Because the pulse width of a PD was ~ 20 ns, the frequency range of the compressional wave in the void might be over 50 MHz or more. However, frequencies induced by the compressional wave and detected by an AE sensor depend on the frequency sensitivity of the AE sensor and the attenuation characteristics of elastic waves. That is, although some wave modes in EP might be coupled and generated [4], the intensively detected frequency is dependent on the kind of the material, the frequency sensitivity of the AE sensor, and the attenuation characteristics of elastic waves. The pulse width of a PD is independent on the amount of charge and never changes. Only the intensity of the compressional wave caused by the PD (the amount of charge) is varied. A frequency component around 70 kHz -120 kHz becomes large at the last stage close to breakdown. In this study, we recognized AE signal detected with SN > 2 and a remarkable frequency component at around 70 kHz – 120 kHz as that due to a PD. Figure 7 shows a variation in maximum AE signal intensity. The AE signal intensity increases gradually while repeating increase and decrease. Anyway, it was difficult to grasp the growth of a PD from a temporal variation of PD magnitude because the intensity of AE didn't monotonically increase. Figure 8 shows variation in the number of the counted AE signals per 10 min. In this study, a total number of detected AE signal from beginning to end of the experiment was 823. The number of PDs per unit time doesn't also show a monotonous increase tendency although that increases gradually. Thus, because temporal variations in the AE signal intensity and the number of the counted AE signal contain period during which the PD activity is not high, it is difficult to grasp the growth of a PD.

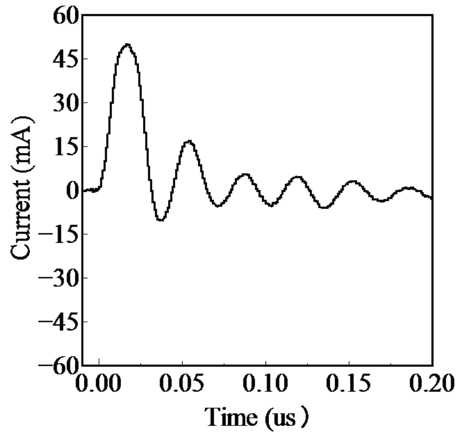

FIG. 4. TYPICAL DETECTED PD CURRENT.

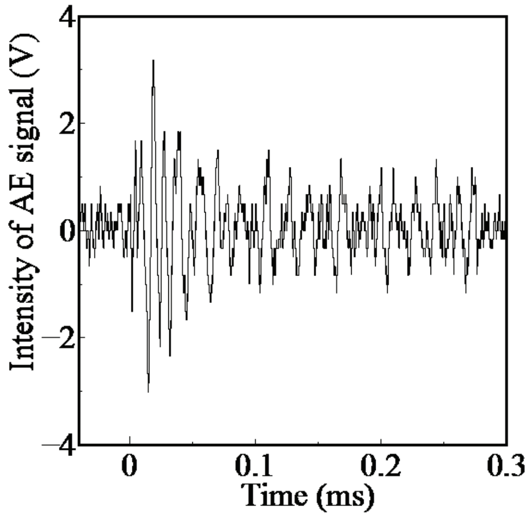

FIG. 5. TYPICAL AE SIGNAL DETECTED BY AN AE SENSOR.

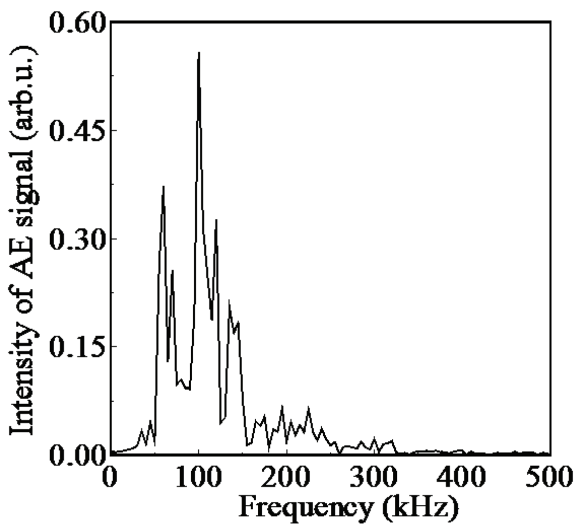

FIG. 6. FFT SPECTRA OF A DETECTED AE SIGNAL.

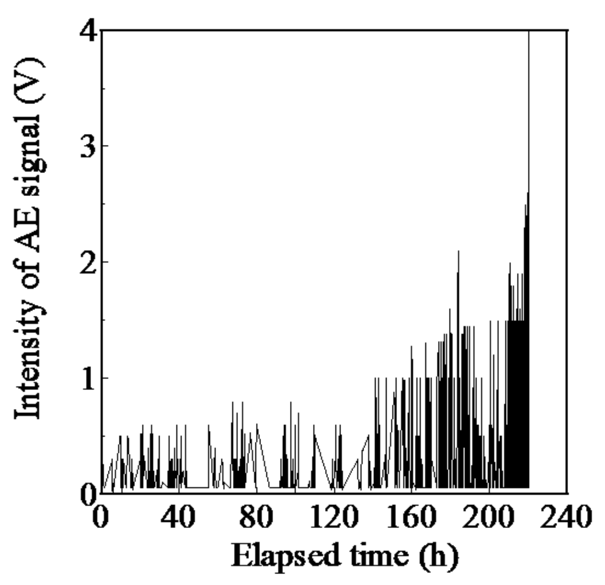

FIG. 7. TEMPORAL VARIATION IN AE SIGNAL UNTIL BREAKDOWN OCCURS.

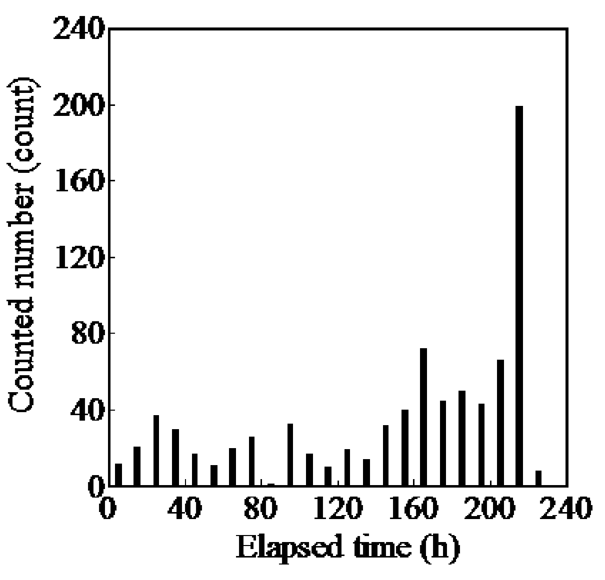

FIG. 8. THE NUMBER OF THE COUNTED AE SIGNALS PER 10 MIN.

4.0 DISCUSSIONS

We found that PD activity doesn't monotonically become high, i.e. simple temporal - variations in AE signal intensity and the number of the counted AE signal per unit time don't directly refer the growth of a PD. Therefore, we examined to evaluate the growth of a PD by integrating the number of PDs by time. Figure 9 shows the cumulative number of the counted AE signal. The cumulative number extremely increases from 160 h. The count rate of detected AE signals after 160 h is about 7.9 times per hour while that before 160 h is 2.13 times per hour; therefore, there is a kind of a turning point. PDs uniformly erode the surface of EP till around 160 h. The pit formation may be achieved after then, and PD activity may become high. It is also confirmed from Figure 7 that the AE signal intensity after 160 h becomes high. Thus, the cumulative number of the AE signals can clearly show a point of time when a PD forms a pit on the surface of EP and the activity becomes high. It is also noted that there seems to be another turning point at around 210 h. Such turning points at around 160 h and 210 h were confirmed even under other electric field conditions. The lower the electric field, the more obvious the turning points become. They refer the progress of an electrical tree owing to PDs. In contrast, such turning points appear early and become unclear under higher electric field conditions.

Incidentally, the number of detectable AE pulses are about 340 until a first turning point of 160 h, i.e. one pulse is detectable for 30 min. The PD activity extremely becomes high after 160 h. As for the practical application, it would be better to recognize as "careful" for the measuring object if the number of detectable AE signals per 30 min is more than 2.

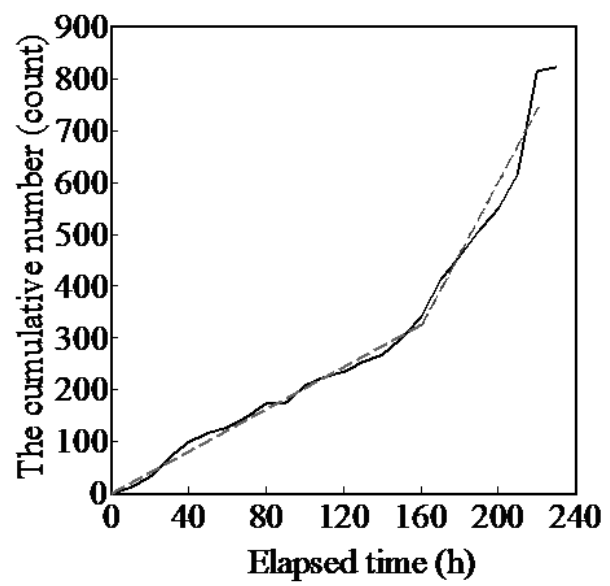

FIG. 9. THE CUMULATIVE NUMBER OF THE COUNTED AE SIGNALS.

5.0 CONCLUSION

We investigated temporal variations in AE signal intensity, the number of the counted AE signal per unit time, and the cumulative number of AE signal. The intensity of AE signal and the number of PDs per unit time don't show a monotonous increase tendency although those increase gradually. That is, PD activity doesn't monotonically become high. Therefore, it is difficult to grasp the growth of PD only by focusing the intensity of AE signal and the number of PDs per unit time. On the other hand, the cumulative number of the AE signals can show an obvious point of time when a PD may form a pit or a tree in EP. The PD activity becomes high since then.

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