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Breakdown on LDPE film due to partial discharge in air gap and its correlation with electrical properties and surface degradation

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Abstract

This paper describes the breakdown characteristic of the low density poly ethylene film caused by partial discharge in the air gap. The purpose of this paper is to clarify the effect number of discharge under repetition rectangular pulses with a needle-plane electrode system as a function of pulse frequency. The result performed, from 10 Hz up to 1000 Hz. From 10 Hz to 200 Hz, the pulse number up to breakdown did not change significantly with increasing the pulse frequency and the magnitude of partial discharge function of pulse number with varied frequency until breakdown were similar. By using both potential decay and surface degradation analysis function of number of pulse, the breakdown phenomena caused by partial discharge was shown to reveal a significant correlation between electrical properties and the transparency of its surface to change deposited on it by a partial discharge exposure.

***Keywords**: needle-plane electrode, partial discharge, potential decay, repetition rectangular pulses*

1. Introduction

The lifetime of insulation system is often determined by degradation of insulation material subjected to the partial discharge (PD). PD causes the degradation of insulating material and dominates the lifetime of high voltage power apparatus and cables. This can ultimately lead to a breakdown in the high voltage apparatus and cables. Therefore, it is important to understand the PD behaviors in the aging process of insulating materials.

Despite careful dimensioning technology imperfection may occur in cable, like strange inclusion as crack and gas filled void, which may give rise to initiation of PD. Gas-filled void and cracks can be simulated by a point-to-plane arrangement if an insulation barrier is put between the electrodes, referred to as Air-polymer Composite Insulation [1-9]. Actually there are many researches had been using this needle plane electrode [10-12], but some problems still exist. Using high voltage AC with variation of frequencies, found the relationship between those frequencies with the length of breakdown time. Increasing the frequency can decrease the breakdown time. However, in this case, magnitude of PD during process is not similar. This work was continued, that controlled the magnitude PD using the repetition rectangle wave pulses and then measured the surface temperature when discharging.The result found that there are good agreements between the breakdown characteristics and the frequency dependence of the temperature rise [13]. If the repetition period of applied voltage is shorter than the heat constant, the sample temperature increased and the insulation sytem lead to breakdown at a few numbers of the applied pulses. However, if the the repetition period of applied voltage is larger than the heat constant, the sample temperature did not increase significanly and the insulation sytem to breakdown at a large numbers of the applied pulses. In these cases the number of pulse to breakdown (N_{BD}) did not changce significanly with increasing of pulse frequency. In this paper, to classify evolution phenomena before damage, the relationship between decay potential and surface degradation in pulse frequency variations is investigated.

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2. Research Method

2.1. Electrode and Specimen

The partial discharge of various frequency of pulse was measured using needle-plane electrode shown in Figure 1. The high voltage electrode is a steel-needle electrode, 1 mm in diameter with a tip angle of 30° and a tip radius of 10 m. A grounding disc electrode of aluminum was placed opposite the high voltage electrode. The LDPE film with the thickness 20 µm was placed on the grounding electrode. The distance from the needle tip to the specimen surface was set to 0.5 mm (the distance gap length). The adhesion of the film to this grounding electrode is obtained by a set of 1 mm diameter holes in the plane electrode connected to a moderate vacuum pump. The position of hole is designed to avoid any deformation on the film area where PD is present. Moreover, the gold was evaporated on the film surface that faces the plane electrode to avoid an occurrence of PD at this side of the film.

2.2. Experiment set up and Partial discharge measurement system

The schematic diagram of experimental setup is presented in Figure 2 the square wave voltage with variable repetition frequency generated by function generator are amplified 2000-fold in the power amplifier (Model 20/20; Trek. Inst.) and passed through the specimen. This high voltage amplifier which derived by function generator is totally controlled by a PC via GPIB and is able to generate voltage 20 kV, duty cycle 5-95% and slew rate 0.6 kV/ms. The entire test considered here are relevant to square waveform having duty cycle 50% and the frequency was changed to 10-1000 Hz. The pulse number of discharges up to breakdown (N_{BD}) was measured under 8 kV repetitive square positive voltages on air-polymer composite insulation2. Here one discharge in the air occurs usually in one square-wave pulse application. Duration time to breakdown (DTB) can be determined through the interval between the time the source is turned on and when the response time the tool automatically turns off the source in the event of a breakdown. As a result that N_{BD} is DTB multiplied by the frequency of pulse.

Morever at the same time the maximum of PD magnitude is measured until breakdown occurred. Discharge current through the specimen was integrated by a RC circuit and was digitized by using a peak detecting function of the digitizing oscilloscope. The PD magnitudes Qmax were measured directly after the pulse voltage applied, after that with interval 1000 pulse voltage applied.

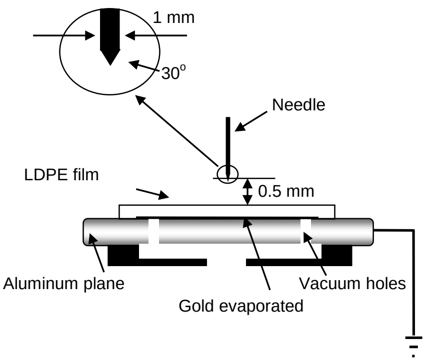

Figure 1. Electrode configuration

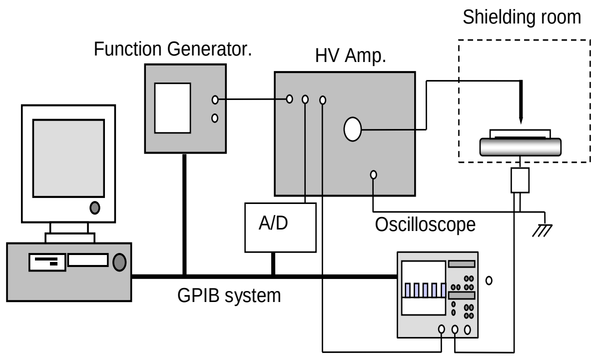

Figure 2. PD detection circuit and experimental set up

2.3. Electrical observation and correlated surface morphology.

The measured decay of potential LDPE film was subjected to PD with different pulse number, to evaluate the characteristics with electrification. As shown in Figure 3, for the measurement, the film was placed on a grounded aluminum plate. The film was exposure by PD with difference number of discharge for 400 and 8000 pulses with frequency of pulse 200 Hz. Subsequently, the decay curve of the surface potential was measured by High-voltage electrostatic voltmeter (Trek ink 341). After PD exposure, the sample on its substrate is quickly transferred under an electrostatic voltmeter system. This is to measure one line surface potential exactly pass through the centre of discharge occur and transmits data to computer through an oscilloscope via GPIB. The sample was rotated at 4500 rpm by a stepping motor.

The surface potential was continuously measured and recorded. Surface potential was measured with interval time of 0.5 second and duration of 200 seconds. All operations were controlled by computer.

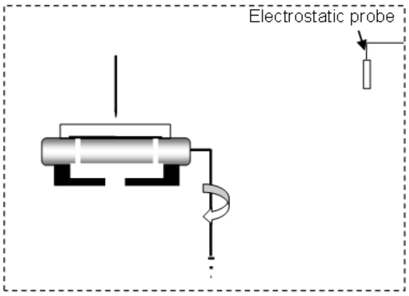

Figure 3. Experimental set-up for measurement surface potential

The surface conditions of sample after the PD was observed with digital camera with zoom 120 times with addition lens 0.6 time and Laser microscope (Keyence VK 8500). Since it is well known that potential decay depends on temperature and relative humidity, all experiment were carry out in the enclosure with the controlled temperature and humidity at 20 C to 25 C and 55% to 60% RH.

3. Result

3.1. Partial Discharge Characteristics

Figure 4 shows a result of number of discharge up to breakdown as function of frequency of pulse, this result have the same opinion with previous research that at large change number of discharge up to breakdown caused (threshold frequency) by heat accumulation makes the N_{BD} to small value. In addition, the N_{BD} did change significantly under threshold frequency. Figure 5 shows the comparison of three cases showing the effect of frequency of pulse on magnitude charge of partial discharge (PD) as a function number of pulse. For each frequency application, the result shows that the magnitude charge of PD with increase number of pulses was not change significantly and also the magnitude charge of PD in three cases was similar value.

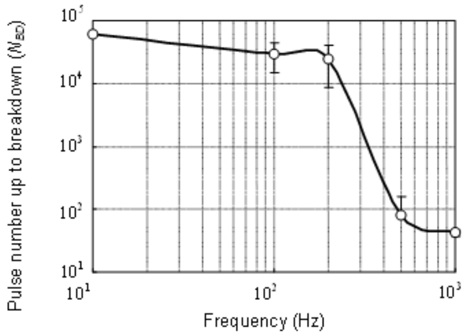

Figure 4. Frequency dependence of N_{BD} at 8 kV

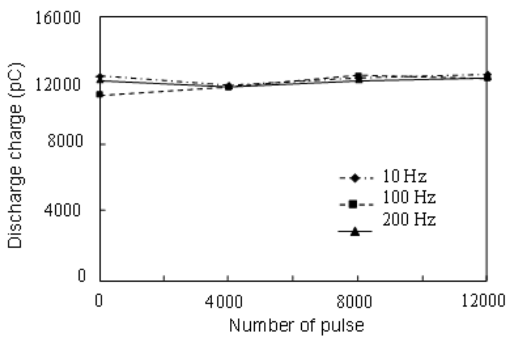

Figure 5. Charge of discharge as a function of number of pulse at 8 kV

Figure 6 shows the breakdown insulation due to PD with different pulse frequencies. In Figure 6 (a), the used pulse frequency is 200 Hz which is smaller than the threshold frequency. However in order to create the breakdown, it needs to increase the number of pulse of this frequency into a certain large number of values. Theoretically it is known that within a large number of pulses the possibility of surface degradation will be more clearly seen, because almost all breakdowns occur at the surface that has been degraded [14, 15]. In contrary, within the pulse frequency which is higher than the threshold frequency, the number of pulse is small (smaller than 1000 pulses) therefore the surface degradation cannot be clearly seen.

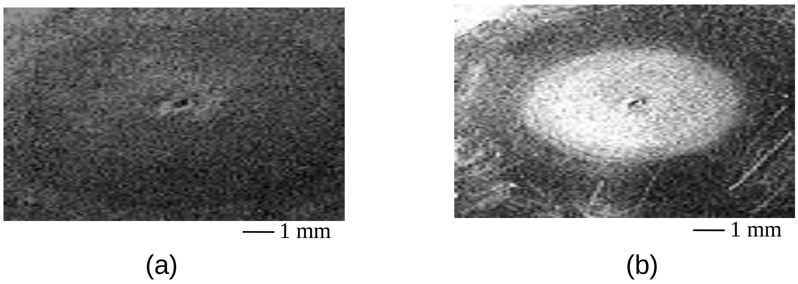

Figure 6. Photo micrograph of damage area (a) after breakdown at 500 Hz frequency of pulse (b) after breakdown at 200 Hz frequency of pulse

3.2. Potential Decay

Figure 7 shows contour of surface potential decay with pulse values difference at frequency of 200 Hz, pulse voltage of 8 kV as function of time. Surface potential decay of 8000 pulses is higher than the 200 pulses. The figure also shows the diameter of discharge area increased with increasing the number of PD, this indicates that, partial discharge not only occurred on central discharge but also expanded to horizontal discharge [16-18].

Figure 8 shows surface potential decay in central discharge function of time with difference number of discharge. Decay rate of surface potential increase with increasing number of discharge [19-22]. It is noted that, the rate of surface potential decay was dependent on number of pulses. However there is no significantly between 8000 and 10000 pulses of numbers of PD with surface potential decay value.

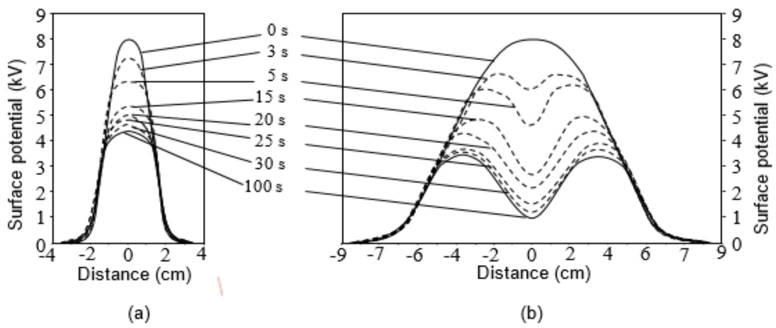

Figure 7. Centre line profiles of surface potential decay with different number of pulse function of time after PD exposure (a) 400 pulses of PD, (b) 8000 pulses of PD

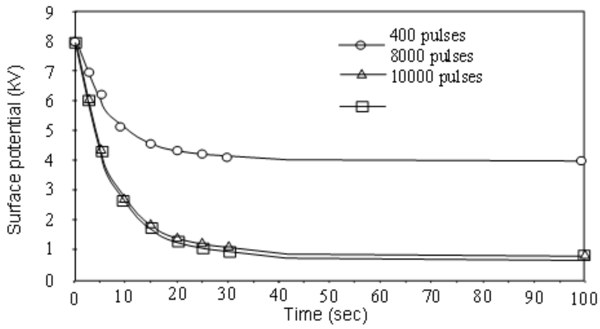

Figure 8. Potential decay on central discharge function of time with different number of discharge

3.3. Surface Morphology and Correlated electrical Observation

Figure 9 (a) shows the capture of micrograph photo of the damage area. This photo indicates that if the value of pulses equal or greater than 8000 pulses the surface of isolation will be degraded by the partial discharge. Most of breakdown is concentrated on the central discharge. However, the micrograph photo solely can not be used to investigate the surface degradation by the discharge. Scanning laser microscope is recommended for further observations. Detail investigations using this device show that when the pulses are less than 1000, the surface degradation is almost invisible as shown in Figure 9 (c). The surface condition, moreover, exhibits insignificant difference in comparison with the surface condition of the sample without discharge treatment as shown in Figure 9 (b). However, when the number of pulse is increased up to around 8000 pulses, some pits are observed on the surface as shown in Figure 9 (d). And the increment of the number of pulses tends to heighten the depth of these pits as shown in Figure 9 (e). It can be concluded that the increase of the number of pulses intensify of the depth of the pits resulting in outweighing the probability of breakdown to occur as shown in Figure 9 (f).

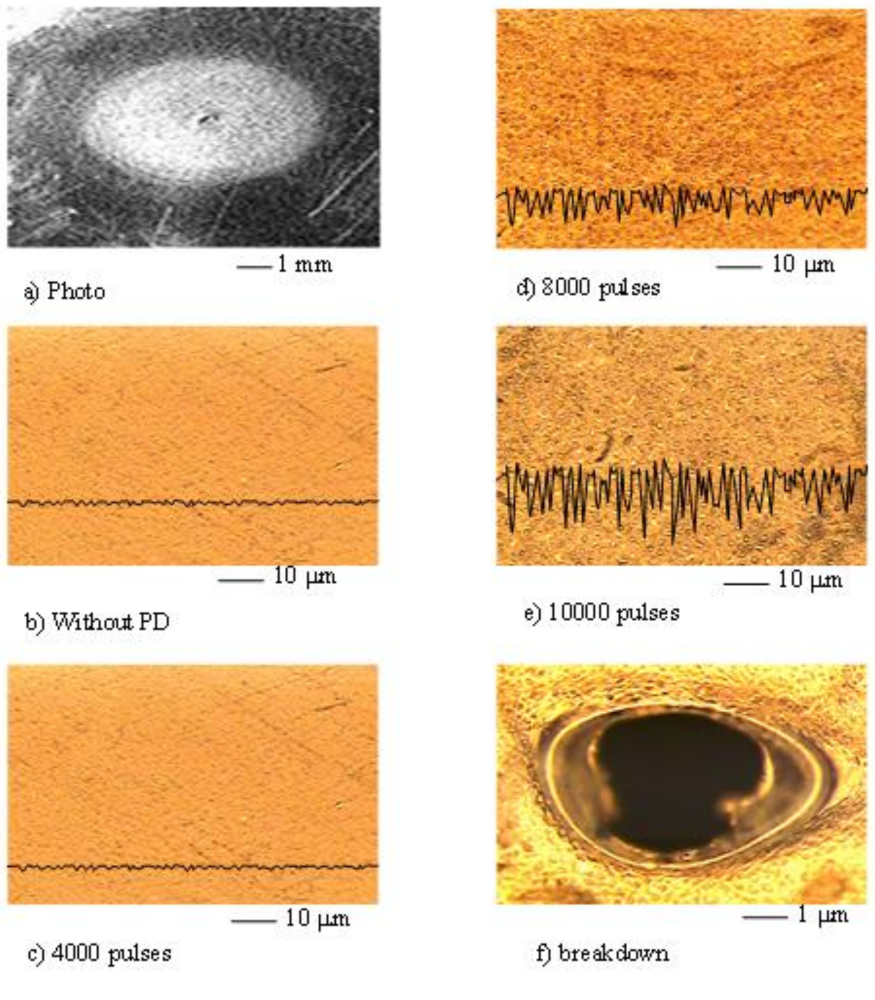

Figure 9. Evolution degradation on the surface due to PD exposure (a) photo micrograph of damage area (b)-(e) Scanning laser microscopy picture of the surface with different number of pulses before breakdown. f) Scanning laser microscopy at after breakdown condition caused by PD exposure

When the PD occurs, together with the deposition of charges on the material's surface, chemical transformations of polymers are to be expected, because highly reactive species originated by discharge reach on the surface [23]. Polymer chains are broken which caused by hot electron [24, 25]. Furthermore, void and pits are formed in insulation and on insulation surface (open air), respectively, as can be seen in Figures 9 (d) and 9 (e). Formation of pits on insulation surface affected the potential decay after PD exposure occurred as shown in Figure 8. The large number of PD, it means the formation of discharges area increase.

Breakdown occurs spontaneously after the large number of discharges. However, it is interesting to note that pits promoted by aggregation of chemical reaction site on the surface, formation of pits on insulation surface, expanding depth of pits will increase a strong distortion of local field, in certain value caused breakdown. A formation of the pits on surface insulation affected the potential decay after PD exposure occurred, it can be seen in Figure 8. The large number of PD caused the insulation surface degraded; consequently, the depth of pits will expand. The phenomena accelerated the surface potential decay. Furthermore, expanding the depth of pits caused the electric field toward to electrode. In certain time, the potential decay will saturate, although the number of PD increase

4. Conclusion

This work has revealed a significant correlation between the number of PD pulses and the potential decay and surface PD degradation of the LDPE film under threshold frequency. It is considered that the increasing of PD pulses number contributed in increasing the rate of surface potential decay and the surface degradation. The pits give more influence in these phenomena. This is interesting to note that pits promoted by aggregation of chemical reaction site on the surface, formation of pits on insulation surface, expanding depth of pits will increase a strong distortion of local field, in certain value caused breakdown.

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