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Time Lag in CM-II Electrode System Attributed to Dielectric Surface Conditioning

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Abstract—**This paper deals with a digest on discharge time lag characteristics in a cylindrical void bounded polymethyl-methacrylate (PMMA) and metal using the CIGRE method II (CM-II) electrode system. The specimens were treated by plasma irradiations (0, 3, 6, 11, 16, 21 seconds) simulating material ageing in service which are very difficult to measure. It was found that, under room temperature, the longer plasma irradiation to the void surface will result in higher degree of surface roughness indicated by the increase of surface protrusion sizes. The statistical discharge time lag (SDTL) has been studied using square pulse voltage with rising time 40 μs, through 64 pulses. The SDTL value is inversely proportional to the surface conditioning. For a particular time period of plasma irradiation (3 s) , the specimens seem to recover its insulating property after given recovery time of 20, 60, and 180 minutes compared to that of without recovery time.**

Keywords-CM-II electrode system; PMMA; plasma irradiation; square pulse voltage; SDTL; recovery times

I. INTRODUCTION

The breakdown due to rapidly changing voltages or impulses voltages is of great importance in the selection of outdoor insulation system for high voltage application when taking into consideration the phenomena in the outdoor insulation systems [1]. It has been seen that there is time deference between the application of a voltage sufficient to cause breakdown and the occurrence of the breakdown itself. This time difference is called statistical time lag. Most of electrical apparatus use air as the insulating medium. Statistical discharge time lag (SDTL) is very important in practical engineering designs of high voltage apparatus and measuring equipment. In insulation coordination especially, the volt-time characteristics of different electrical apparatus are very importance to identify [1]. The requirement for the protective devices is that their volt-time curve must be lie below the withstand level of the protected insulation within the time region in which the protection is intended [2]. If the protective device for instance rod gap, the margin of the two curve must be adequate to allow for the effects of distance, polarity, variation in relative air density, humidity and aging of the insulation. SDTL test on protective devices subjected to deterioration such as surface erosion in real situation suffer from the difficulty, due to the continuously ongoing development in insulator design and use of new material formulations, the tests would be expensive and long-lasting field investigation that may not always be effective. Thus, simulation testing in field conditions for short periods of time in laboratory scale may provide an alternative possibility for obtaining faster useful results. This paper illustrates such an approach, which is aimed at finding an explanation for PD characteristics change such as SDTL with respect to void surface roughness. In addition, the surface conductivity of the rough and smooth insulation surface has also been measured. An artificial small size of gap has been successfully employed using the CM-II electrode system [3]. In that paper, it was concluded that SDTL has been affected by the roughness of insulation surface in which the void was bounded. However, some new results have been added in the present paper to a give better explanation.

II. EXPERIMENTAL

A. Specimen Preparation

The employed specimen was the CIGRE Method II electrode system. One side of the flat gap was in contact with a metallic electrode, and the other side with insulation. The insulation was a 1 mm thick plate of PMMA, as shown in Figure 1.

Figure 1. CM-II Specimens

The insulation surface was roughened by plasma. Before plasma treatment, the sample surface was cleaned by ethanol. Then the samples were subjected to arc plasma using a plasma sprayer (Keyence ST-7010). The exposure time was 3, 6, 11, 16 and 21 seconds. Soon after stopping the plasma exposure the sample was assembled into the CM-II electrode system.

B. Experimental Procedures

The voltage was applied to the spherical electrode side of specimen, while the lower was connected to the measurement system. The output of Function Generator was square low voltage, while HV Amplifier was square high voltages. In the measurement system, the discharge current through the specimen was integrated by means of the CR circuit and was digitised using the peak detecting function of the digitising oscilloscope. The SDTL at a 7 kV-step voltage was measured by applying periodical square HV pulses with 10 ms in the pulse width. The interval of pulse application was 20 ms, and was corresponded to 50 Hz, as shown in Figure 2.

$$f = 50\ \mathbf{Hz} = 50\,\frac{\mathbf{waves}}{\mathbf{s}} = \frac{\mathbf{50\ waves}}{\mathbf{1000\ ms}} = \frac{\mathbf{5\ waves}}{\mathbf{100\ ms}}$$

$$T - \frac{1}{f} - \frac{\mathbf{100\ ms}}{\mathbf{5\ waves}} - \mathbf{20\ ms\ (period\ of\ a\ wave)}$$

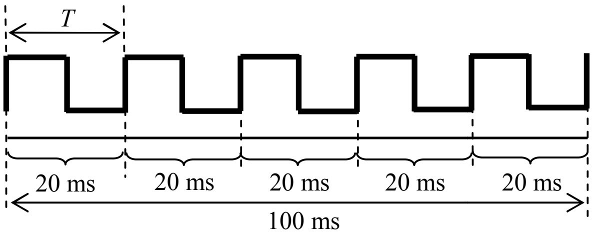

Figure 2. Step voltage applied in this experiment

The measurement is done by applying 64 pulses (64 positive pulses and 64 negative pulses). A wave is consist of 2 pulses i.e. one positive and one negative. In addition, the surface resistivity is also measured using concentric ring probe geometry as shown in Figure 3 [4]. Where Z_1 is outer radius of the center concentric electrode, Z_2 is inner radius of the outer concentric ring electrode. Surface resistivity is related to the surface resistance by a constant that depends on geometry of the electrodes only:

$$\rho_s = R_s\,\frac{2\pi}{\ln\left(\frac{Z_2}{Z_1}\right)} = \frac{V}{I_s}.k \quad \ldots\ldots\ldots.. (1)$$

where k is frequency called a geometry coefficient. Then the surface resistivity is measured directly by the resistivity meter, by utilizing various configurations of electrodes. Meter provides a constant voltage V and measures the current I_s flowing between electrodes. The value of resistivity is equal to the value of resistance multiplied by the geometry coefficient. Usually electrodes are especially constructed to simply calculations of surface resistivity and the geometry coefficient is equal to a simple integer. Most of industrial standards use this simplified approach [5-7]. All experiments were performed at ambient condition.

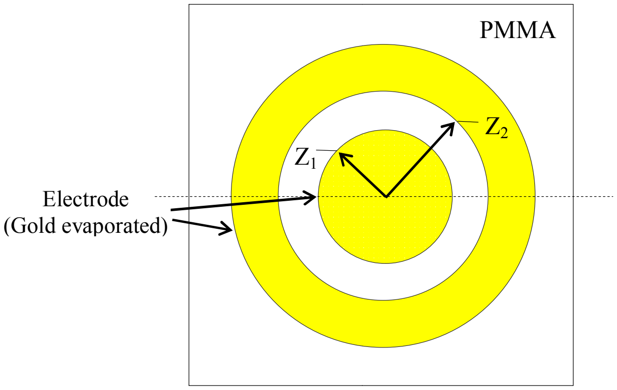

Figure 3. Surface resistance measurement configuration for concentric ring electrodes

The wide application to determine the surface property and the chemical and physical changes that occur during the lifetime of the insulator can only be made after a thorough understanding of the dependence of the surface resistance on all parameters affecting it [8].

III. RESULTS AND DISCUSSION

In order to explain the phenomenon, the SDTL of each level of the exposure time soon after exposed by plasma was investigated. According to the previous result [3], the PD magnitude decreases with the increase of the exposure time; however, the number of PD pulse increases with it, because, in the roughened surface, PD tends to occur at many places somewhat apart from the sphere electrode. In the case of a smooth surface, the PD tends to occur at one place on the specimen surface right under the sphere electrode. It is considered that PD is easily occurs with a higher number of pulses when the surface of a specimen was degraded by plasma. This result is in agreement with Ishida T., Nagao M., and Kosaki, M. [9]. The surface potential distribution of smooth PMMA specimen has only one peak. On the other hand, the roughened one has a couple of peaks. These results show that in the case of roughened surface specimens, the PD occurred at more than one place. It suggests that the PD easily occurs if the dielectric materials were roughened due to intensification of the local field. It is assumed that the surface roughness intensifies the local electric field and increases the supply of the initial electrons. The period between the applied PD inception voltage and the occurrence of PD is called time lag. The SDTL is obtained at first experimentation [3] whose result generates the cumulative probability of time lag. Afterward, it is often converted into Laue plot, i.e., residual probability (L). In this plot, log L is made the vertical axis, and the time lag is the horizontal axis. Actually, this change has no special meaning except that the parameter of time lag could be shown more clearly than if we used the cumulative probability plot.

I would like to thank to Honda Denshi Corporation, Japan for their technical assistance in which the author could use Plasma Sprayer Keyence ST-7010.

According to that paper [3], the SDTL at 40 % residual probability 60 minutes after exposure by plasma tends to take longer time than that of 20 minutes. The time lag becomes longer probability related to the recovery time of material properties. Collections of ions and electrons remove gradually from the void surface. The ions and electrons are accompanying the exposure should be disappear gradually. It means that, following the time the effect of plasma exposure should be disappear. When the plasma effect was disappearing, it would make possible the discharge occur with longer time lag. This clarified that, for short exposure time the plasma treatment changes the surface properties of material only, not the bulk properties.

However, these results just only clarified that for typical short exposure time of 3 s, plasma treatment changes the surface properties of material only, not damage in deep of bulk specimen. It might be of somewhat speculated, since there was not enough data for 3 s exposure time. That is why in the present paper a new data has been added, as shown in Figure 4 to give more information about recovery times.

Figures 4 shows the typical Laue plots of SDTL for 3 s of exposure time. In this investigation, the recovery times of 20, 60, and 180 minutes were compared. As shown in Figure 4, the 3 s exposed specimen seems to have longer time lags as the increase of recovery times. It is considered that the specimens that already exposed by plasma radiation for 3 s, seems to be recover its insulating property after given recovery times of 20, 60, and 180 minutes compared to that of without recovery time. This result is in agreement with the previous results [3].

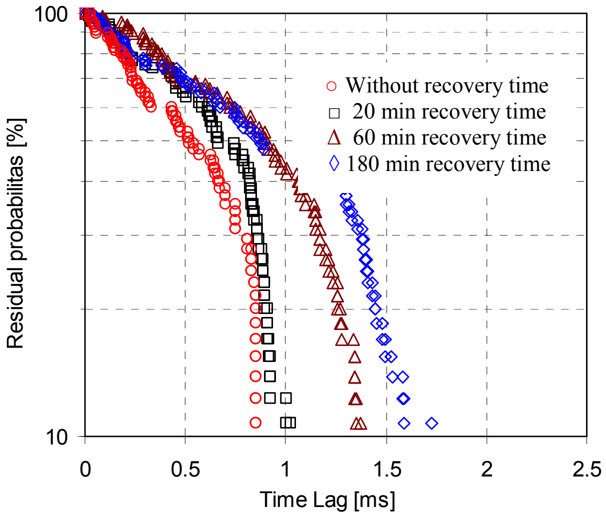

Figure 4. Laue plots of a 3 s plasma exposed specimen after 0, 20, 60, and 180 minutes of recovery times

Another result shows that PD easily occurs with a higher number of pulses when the surface of the specimen was degraded by plasma. This phenomenon may be due to surface change by plasma exposure, including an increase of surface roughness in combination with an increase of surface conductivity, as shown in Figure 5.

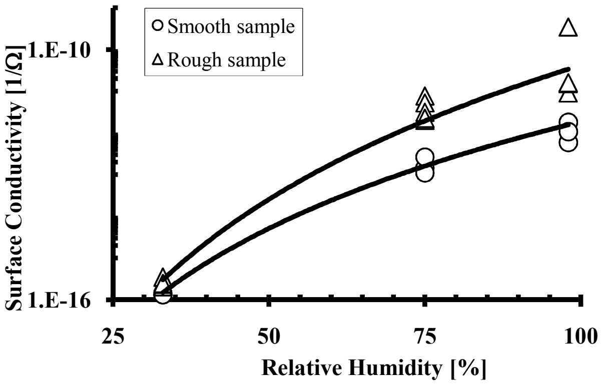

Figure 5. Surface conductivity of smooth and rough surfaces

A rough surface brought by plasma exposure would emphasize the electrical field so that the discharge with longer exposure time would more easily take place. Decrease in SDTL would make possible the PD occurring with a large number of small discharges. To ensure this effect, topographical images and profiles of surface roughness can be traced along the centre line of the eroded specimen by a laser microscope (Keyence VK-8510) to give the erosion profile shown in Figure 6 [10]. To give more detail information, one more image has been added in the Figure. It is recognized that the erosion increases as ageing time increases from 3 s to 21 s. The roughness of 3, 6, and 21 s of exposure time were 1.5, 6.3, and 8 μm, respectively. In addition, many bumps were seen on the material surface. There is data scatter in the short range of position at the edges of micrographs. This is considered to be caused by original surface roughness of the specimens. This scatter had been extremely small compared to the erosion due to plasma exposure, thus it was assumed neglected.

IV. CONCLUSIONS

The SDTL due to deteriorations of high humidity of void space and dielectric surface in which void is bounded has been carried out using the CM II electrode system. The main results are summarised as follows.

(1) In both polarities, the time lag becomes shorter as the RH increases from 33 % to 98 %.

(2) The characteristic SDTL of positive polarity was shorter than that of negative polarity. This means that the SDTL with positive polarity was more sensitive to the applied voltage than with negative.

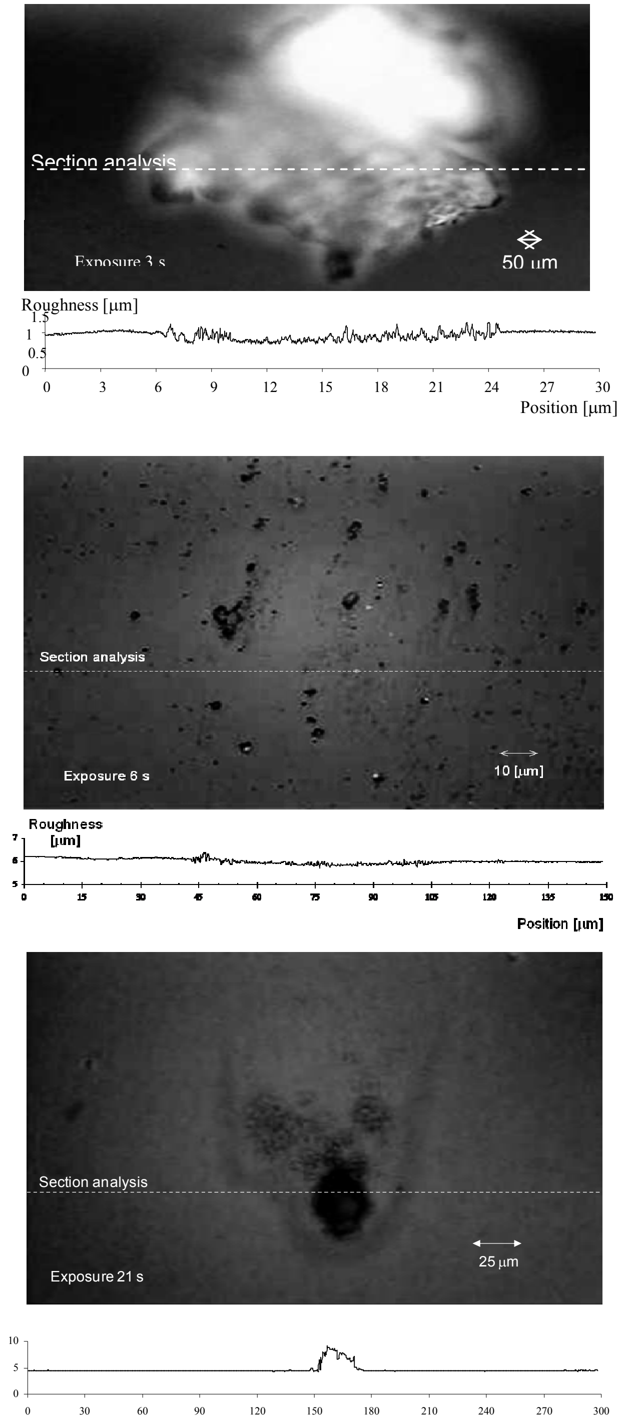

Figure 6. Topographical images and profile of surface roughness of the specimens after being exposed by plasma for 3, 6, and 21 s, respectively.

(3) The SDTL also becomes shorter with increasing plasma irradiation time. It seems the initial electrons are more easily supplied from a metallic electrode. A rough surface brought about by plasma irradiation would emphasize the electrical field so that the discharge (with a longer irradiation time) would more easily take place. Decrease in SDTL would make possible the PD occurring with large number of small discharges.

(4) In case of SDTL for 3 s exposures, the longer recovery time is given, the higher the specimen to recover its insulating property.

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