AN EFFECT OF INSULATION COVER ON SPARKOVER VOLTAGE IN DRY AIR

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Abstract: The insulation strength in pressurized dry air with a dielectric cover is examined by changing the configuration of the electrodes. A hemisphere high voltage electrode of 40 mm in diameter with a 10 mm-thick insulation cover of epoxy resin and a grounded plane electrode were set in a tank and the lightning impulse voltage (1.3/66 μs) was applied under a pressure of 0.1, 0.2, 0.4, or 0.6 MPa (abs). The insulation strength against impulse voltage was evaluated by measuring 50% sparkover voltage, V_{50}, which was obtained through the up-down method. The V_{50} increases almost twice by the presence of an insulation cover on the high voltage electrode under 0.1MPa pressure. When the gas pressure increases, little difference is observed between V_{50}s of the covered and the uncovered electrodes.

1 INTRODUCTION

SF_6 has been used as the insulation medium for gas insulated switchgears (GIS). In these days, however, it has been pointed out that SF_6 has a large greenhouse effect and the development of the alternative gases has been required. Dry air, which is safety for human and the ecological, has been investigated as one of alternative gases to SF_6 [1,2].

The insulation strength of dry air is about only a third of that of SF_6, so it is indispensable to understand the pressure dependence of dry air insulation strength in detail for applying it to apparatus of higher voltage. The authors have also focused on composite insulation system with dielectric barrier/cover [3]. In this paper, the insulation strength in pressurized dry air with a dielectric cover is measured by changing the configuration of electrodes.

2 MEASURING SYSTEM

2.1 Experimental Setup

Figures 1(a) and (b) show the schematic diagram of experimental setup and the close-up of discharge gap, respectively. A high voltage electrode and a grounded electrode were set in a tank and a lightning impulse voltage (1.3/66 μs) was applied through a bushing. The applied voltage for this experimental setup was limited up to ±350kV.

The tank had an observation window and the luminescence of discharge was observed through it. The tank was filled with dry air up to 0.6 MPa abs. after evacuated below 0.5 kPa.

Impulse voltage was applied by the up-and-down method to obtain 50% breakdown voltage. Impulse voltages were applied over 30 times in each experiment. Breakdown phenomenon was monitored through the waveform of the applied voltage using an oscilloscope and the luminescence of discharge.

2.2 Electrode Configration

A hemisphere-to-plate electrode system with an insulation cover was used in this study as shown in Figure 2.

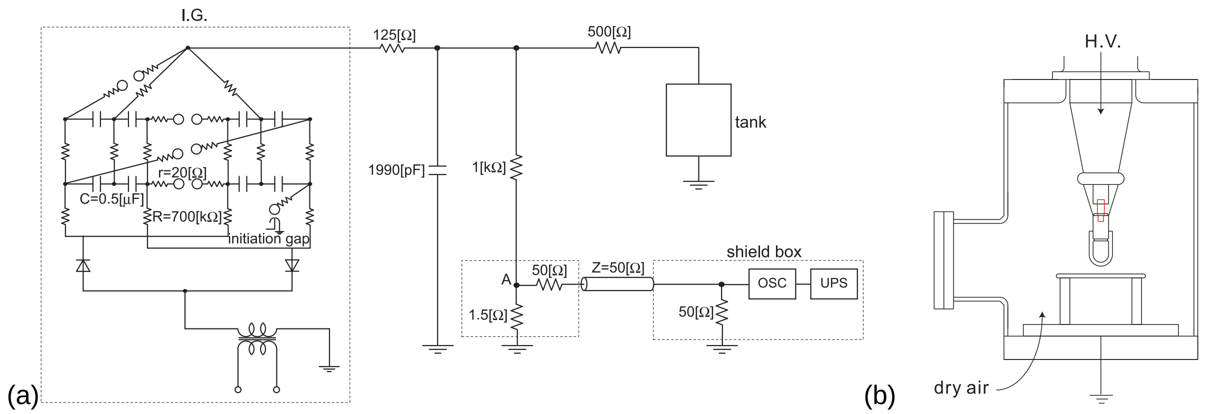


Figure 1: Experimental Setup, (a) Power Circuit , and (b) Tank

The plate electrode was grounded and impulse voltage was applied to the hemisphere electrode. These electrodes were made of aluminium and their surfaces were finished to 10μm. The initial electron was supplied by a radiation source of ^{60}Co behind the grounded electrode.

The hemisphere electrode had an insulation cover of epoxy resin, whose relative permittivity is 4.2. The thickness *t* and the length *h* of the insulation cover were 10mm and 90 mm, respectively. The curvature of the hemisphere electrode R was 20mm, and the distance between electrodes *d* was

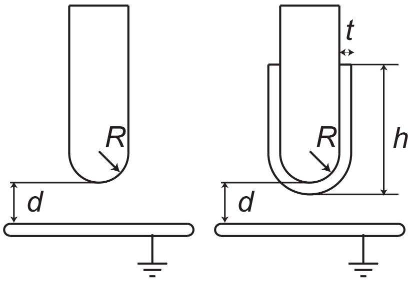
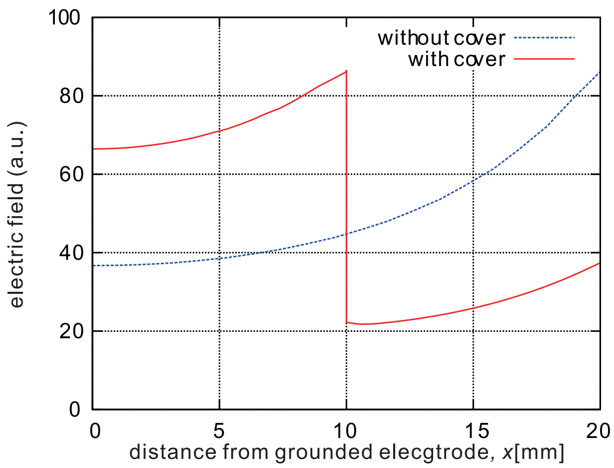
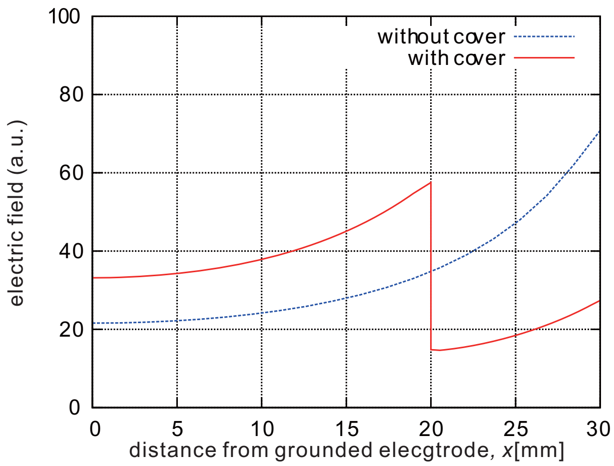


Figure 2: Electrode Configuration



(a) *d* = 20 mm



(b) *d* = 30 mm

Figure 3: Electric Field Distribution

20 mm or 30 mm. The electrode system without insulation cover was also used for reference.

Figure 3 shows numerically computed electrostatic field distribution along centre axis when a certain voltage is applied to the high voltage electrode. For every case, the electric field takes its minimum on the grounded electrode and increases monotonically with the distance from the grounded electrode.

The averaged field in the air gap is enhanced by putting the insulation cover. On the other hand, the maximum electric field in the air gap, which corresponds to the electric field on the tip of the covered/uncovered electrode, is reduced. When *d* = 30 mm, for example, the maximum electric field in the air gap is reduced by 80% by putting the insulation cover.

3 EXPERIMENTAL RESULTS AND DISCUSSIONS

3.1 Sparkover Voltage

Figure 4 shows 50% impulse sparkover voltage V_{50} for each electrode. The error bar of each symbol corresponds to the standard deviation σ obtained by the up-and-down method.

When the uncovered electrode is used, V_{50} increases in proportion to 0.8 ~ 0.9th power of the pressure, and there is little polarity effect especially at lower pressure.

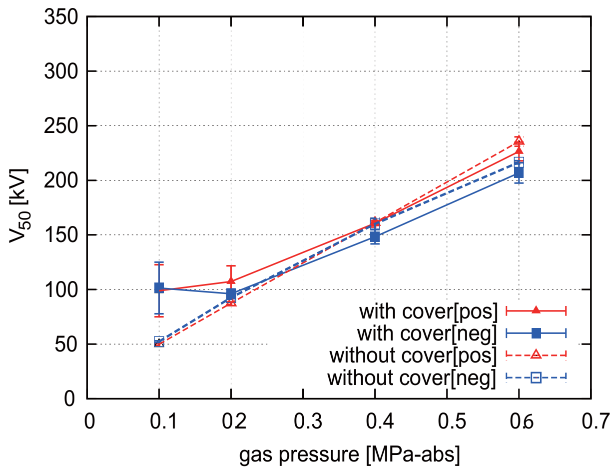
In 0.1-MPa or 0.2-MPa air, V_{50} increases by putting the insulation cover on the high potential electrode. For both cases of *d* = 20 mm and 30 mm, V_{50} in 0.1-MPa air is almost doubled by putting the insulation cover although with a larger σ. On the other hand, when the gas pressure is high, the insulation cover has little influence on both V_{50} and σ.

When the covered electrode is used, the polarity effect of the application voltage is hardly recognized on the sparkover voltage at any air pressure.

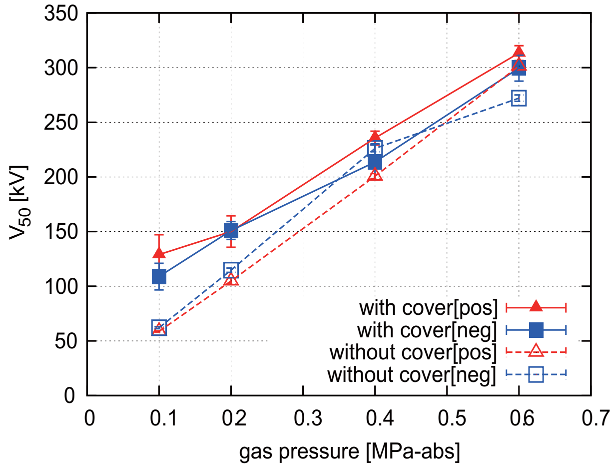
3.2 Discharge Path

Figure 5 shows a still photograph of discharge in 0.1 MPa pressure air with the uncovered electrode. One large discharge bridges the electrodes along the central axis. With the uncovered electrode, the discharge bridges them along the central axis at any pressure.

On the other hand, most discharges in 0.1- or 0.2-MPa pressure air bridge a path between the covered electrode and the grounded electrode in an off-axis region as shown in Figure 6(a). At higher pressure, a part of discharge appears in the



(a) d = 20 mm



(b) d = 30mm

Figure 4: Gaseous Pressure Dependence of Sparkover Voltage V50, (a) for d = 20 mm Gap, (b) for d = 30 mm Gap.

air gap along its central axis as shown in Figure 6 (b).

It is possible to explain the large σ of V_{50} with the covered electrode in lower pressure air, which was pointed out in the previous subsection, by this fluctuation of the discharge path. In case of the negative voltage application, few initial electrons are supplied from the covered electrode. Thus, there is a larger statistical dispersion in the generation position and time of the initial electron. In case of positive voltage application, some electron avalanches, which are initiated not enough far from the high voltage electrode and are not grown up sufficiently to be transformed into corona discharge, drift and reach the covered electrode. Their residual charges on the surface of the cover distort the electric field distribution, resulting in the variation of the discharge path and the discharge voltage.

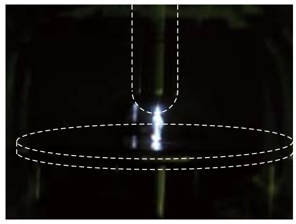


Figure 5: Still photograph of Discharge with Uncovered electrode in 0.1-MPa Air for d=20 mm Gap.

(a) 0.1 MPa (b) 0.4 MPa

Figure 6: Still Photograph of Discharge with Covered Electrode in (a) 0.1-MPa and (b) 0.4-MPa Air for d=20mm gap.

3.3 Corona Inception Voltage

An electron avalanche drifting in the field direction converts to a streamer-type discharge when its charge amount reaches a certain threshold. This is called the streamer-inception criteria and is expressed as

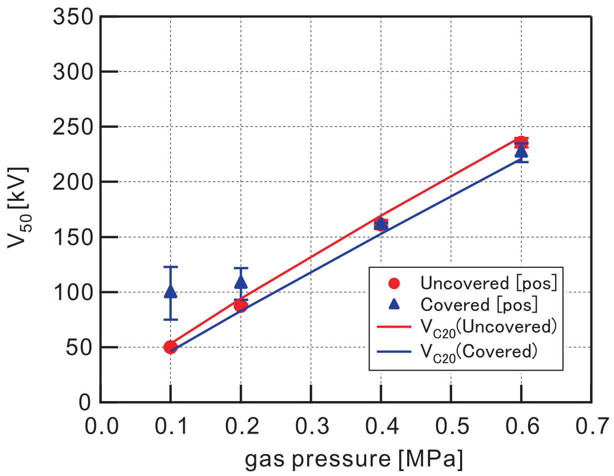
$$\int_{x0} \alpha^* dx = K \quad , \qquad (1)$$

where α^* is the effective ionization coefficient, x_0 is the critical avalanche length. The constant K is commonly assigned a value of 20 for air at atmospheric pressure based on experimental results. Based on this criteria, it is possible to calculate the corona inception voltage in a non-uniform gap. It is also well known that the sparkover voltage in a uniform gap is almost equal to the corona inception voltage.

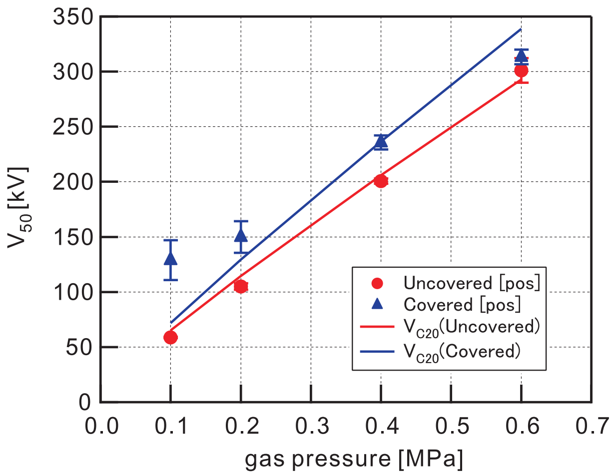
The corona inception voltage, V_{C20}, for each electrode system is shown in Figure 7 in comparison with V_{50} under the application of positive impulse voltages. The x_0 for each case is listed in Table 1.

The electron avalanche integrated over the region near the high potential electrode satisfies the above-mentioned criteria, and thus, the calculated corona inception voltage for negative impulse is almost the same as that for positive impulse.

When the uncovered electrode is used as the high voltage electrode and the gas pressure is 0.1 or 0.2 MPa, V_{50} coincides well with V_{C20}. At higher



(a) d = 20 mm



(b) d = 30mm

Figure 7: Corona Inception Voltage V_{C20}, (a) for d = 20 mm Gap, (b) for d = 30 mm Gap.

Table 1: Critical Avalanche Length, *x*0

(a) d = 20 mm

	0.1MPa	0.2MPa	0.4MPa	0.6MPa
Uncovered	9.8mm	7.2mm	5.4mm	4.6mm
Covered	10.0mm	10.0mm	10.0mm	10.0mm

(b) d = 30 mm

	0.1MPa	0.2MPa	0.4MPa	0.6MPa
Uncovered	8.9mm	6.8mm	5.2mm	4.4mm
Covered	17.3mm	10.8mm	7.7mm	6.4mm

pressure, V_{50} is bigger than V_{C20} and shows a little polarity effect. This fact can be explained as follows: The critical avalanche length decreases with the increase of the air pressure, and the discharge phenomenon at higher pressure tends to resemble that in a non-uniform gap.

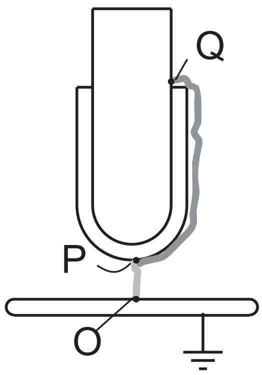


Figure 8: DIscharge model

When the covered electrode is used, the critical avalanche length becomes long and it is possible to regard the discharge bridging the air-gap part, as the discharge in a uniform gap.

3.4 Sparkover Model with Covered Electrode

The sparkover phenomenon with the covered electrode is expressed as the summation of the sparkover of the air gap and that along the surface of the covered electrode.

Figure 8 shows a simplified model of the sparkover phenomenon with the covered electrode. When an impulse voltage V_{APP}, which is higher than V_{c20}, is applied to the covered electrode, a streamer discharge bridges an air gap between points O and P. The voltage V_{PQ}, that is given by subtracting a voltage drop across the air gap V_{DROP} from V_{APP} is applied between points P and Q.

$$V_{PQ} = V_{APP} - V_{DROP} \qquad (2)$$

If V_{PQ} is higher than a critical voltage V_s for making surface discharge bridge a path between P and Q along the insulator surface, sparkover occurs. If not, the streamer discharge initiated in the air gap is not transformed into the sparkover phenomenon:

$$\text{If } V_{PQ} > V_s, \text{ sparkover occurs.} \qquad (3)$$

Assuming that V_{DROP} is given by

$$V_{DROP} = E_g L_g p, \qquad (4)$$

where E_g is the averaged electric field along the streamer discharge in gap, L_g is the distance between points O and P, and p is the pressure, the sparkover voltage V_{spark} is given by the following equation:

$$V_{spark} = \mathrm{MAX}\,(V_s + E_g L_g p,\ V_{c20}) \qquad (5)$$

It has been reported that there is little difference among the AC flashover voltage in 0.6-MPa N_2, 0.9-MPa N_2, 0.6-MPa SF_6, and 0.9-MPa SF_6 when the insulator length is 100 ~ 200 mm[4]. Thus, it is

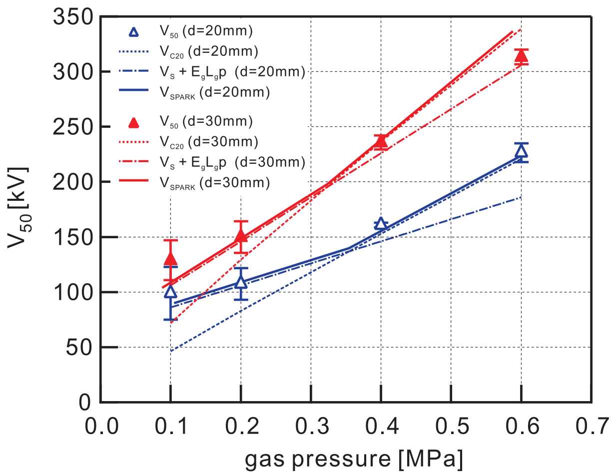


Figure 9: Sparkover Voltage Calculated with Simplified Discharge Model.

possible to approximately ignore the pressure dependence of V_s in this study.

According to the work by M. Toepler [5], the relationship between the impulse flashover voltage V and the insulator length L is denoted by the following experimental equation:

$$V = \frac{K_a L^{1/4}}{C^{3/8}}, \tag{6}$$

where C is the intrinsic capacitance of the insulator, and K_a is a constant.

M. Chiba has reported that the surface discharge propagates up to 120 mm on a 2-mm thick PMMA pipe with the grounded back electrode under the application of 40 to 42 kV impulse voltage in atmospheric air [6]. The relative permittivity of PMMA is 2.7 to 3.0. Using equation (6) it is estimated that 62 to 68 kV is necessary for making surface discharge propagate up to 120 mm on a 10-mm thick epoxy resin.

There are some reports on the numerical simulation of the streamer propagation in atmospheric air. The electric field on the streamer axis are calculated to be around 50 to 100 Td [7-9].

Figure 9 shows V_{spark} which was obtained by setting V_s = 66 kV and E_g= 2 kV/mm/atm. The V_{spark} coincides well with V_{50}.

4 CONCLUSION

The insulation strength in dry air with a dielectric cover is measured by changing the gap length and the pressure of air. In 0.1-MPa or 0.2-MPa air, V_{50} is increased by the use of the covered electrode. On the other hand, when the gas pressure is high, the insulation cover has little influence on V_{50}.

A simplified model of discharge was also proposed. In this model, the sparkover voltage is given by the larger value between the corona inception voltage and the summation of voltage drop along a discharge in an air gap and the requisite voltage for making a surface discharge propagate over the insulation cover. The calculated sparkover voltage based on this model coincides well with the measured value.

5 REFERENCES

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