論 文
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미소방전 존재시의 SF_6에 대한 교류절연 파괴특성

A.C Breakdown Characteristics in SF_6 in the Presence of A Small Discharge

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요 약

SF_6 개스에 있어서 교류절연파괴에 대한 미소방전의 영향이 연구되었다. 봉대평판 전극의 거리, 개스압력 그리고 미소방전전류의 크기 변화에 따른 여러실험이 검토되었다. 또한 확실한 연구를 위하여 방전로의 위치가 관측되어졌다. 본 연구의 결과로, 필자들은 R_n 비율(실내온도의 E/N 분포에 대한 미소방전에 기인한 어떤 더 높은 온도에서 E/N 분포의 비, E : 전계강도, N : Particle number density)로서 방전로 위치의 이동 기구를 명확하게 하였다. 또한 미소방전 존재시의 교류절연파괴 전압의 감소이유가 연구되어졌다.

Abstract- **The effect of a small discharge on the A.C.(60Hz) breakdown characteristics in SF_6 gas has been studied. Various experiments were investigated while varying distance of the rod-plane electrode, the gas pressure, and the magnitude of the small discharge current. Also, the position of the discharge path was observed for the purpose of evident investigation. As the results of this study, authors clarified the shifting mechanism of the position of discharge path with the ratio Rn(E/N distribution at a certain higher temperature due to the small discharge current to E/N distribution at room temperature, E: electric field strength, N: particle number density). Also, the reason for the reduction of the A.C. breakdown voltage was investigated in the presence of a small discharge current.**

1. Introduction

Sulphur-haxafluoride (SF_6) is frequently used as an insulation medium for substation components and gas insulated devices because of its high dielectric strength and good heat transfer properties. In addition, SF_6 is attractive because of its low toxity (it is "toxic" only as an asphyxiant) and relative chemical inertness[1～3].

Many experimental and theoretical investigations have been reported in the literature describ-

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接受日字 : 1989年 7月 31日
1次修正 : 1990年 1月 15日

ing the breakdown behavior of SF_6 under direct, alternating and impulse voltage[4~7].

Eliasson and Schade[8] measured the breakdown voltage of hot SF_6 Nagata et al. [9] used an electrically heated oven and worked at relatively low gas pressure.

Nevertheless, the A. C(60Hz) discharge characteristics in SF_6 gas in the presence of a small descharge(SD) are not sufficiently studied

Considering these, the effect of a SD on the A. C breakdown (breakdown between rod-rod and plane electrode, BD)characteristics has been investigated.

As a result of our investigation, we found that the reduction of breakdown voltage between rods and plane electrode (V_{BD})in presence of the SD current(I_d)is greater for high pressure, large I_d, and rods-plane electrode distance (d), and also clarified shifting-mechanism for the position of the discharge path with the ratio Rn.

2. Experimental Apparatus and Techniques

Figure 1 shows experimental circuit and gap configuration. We used the test gap as shown in Fig 1.a, which consists of two horizontal, opposed rods(rod-rod distance $\ell = 3\times10^{-2}$ cm), with a plane electrode parallel to the rod-rod gap. The electrodes were finely polished with sand paper (No. 1200)and metal polisher(ALBON)prior to measurements.

We installed the gap in a cylindrical stainless steel chamber 25(cm) in diameter and 65(cm) in length, and performed various experiments while varying the d(0.6cm~2cm at 0.5 atm 0.6cm~1.6 cm at 1atm), the p(0.5 and latm)and magnitude of the small discharge current (I_d). I_d divided about 0.3A(I_s)and 1A(I_1). The magnitude of small discharge currents indicate peak value.

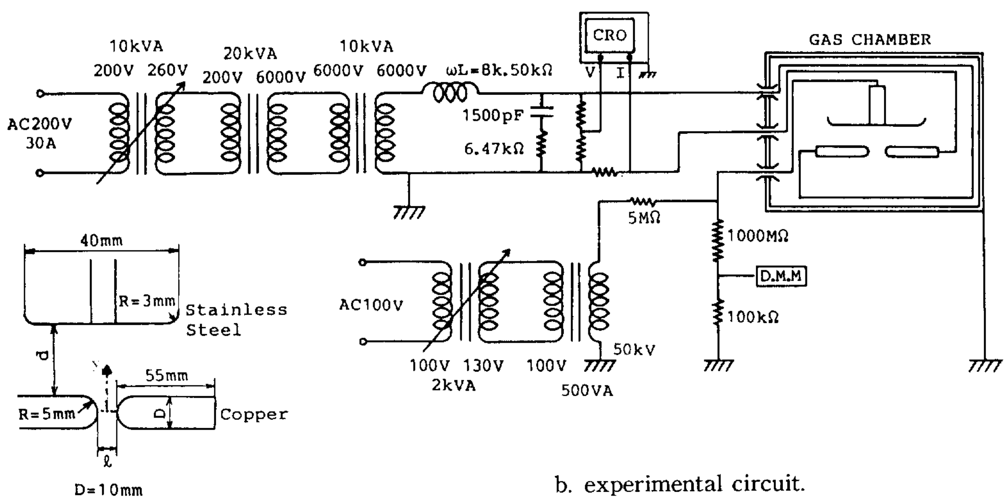
The discharge paths were observed through the circuler observation window 11(cm) in diameter. The CCD camera, the video tape recorder (SL-HF3000, Sony Co.)and colour video printer (GZ-p11 sharp Co.)are used to observe the BD paths.

Digital multimeter (DMM)as shown in Fig. 1 is used to measure the V_{BD}.

The main breakdown characteristics were investigated with gas pressure (p), I_d, d and discharge paths under the condition that ℓ/D is 0.03 (rod-rod distance(ℓ) $=3\times10^{-2}$ cm, rod diameter(D) $=1$cm).

The values of V_{BD} were determined by arithmetical meanvalue from the values of breakdown voltages for ten times measurements.

3. Results and Discussion



a. gap configuration.

b. experimental circuit.

Fig. 1 Experimental circuit and gap configuration.

3.1 Temperature distribution in the gap by high temperature

Approximate equation for temperature $T(°K)$ of the theoretical heat flow from the heating body [10, 11] is

$$\frac{\partial T}{\partial t}=K\left(\frac{\partial^2 T}{\partial r^2}+\frac{2}{r}\frac{\partial T}{\partial r}\right) \quad (1)$$

where, K = thermal conductivity (cm²/h),
r = distance of radial direction (cm),
t = time (h)

In case of steady state, we find from equation (1) that the solution for y-axis direction is

$$T(y)=\frac{A}{y}+B \quad (2)$$

where, A and B are constant derived from boundary condition. Y is vertical axis as shown in Fig. 1. a.

Gas temperature distribution on following condition a) and b) is

$$T(y)=\frac{r_a(T_s-T_o)}{y}+T_o \quad (3)$$

where,
condition a) ; The gas temperature is T_o on condition that y is ∞,
condition b) ; Arc surface temperature is T_s on condition that y is r_a,
r_a; radius of arc column,
$y > r_a$

3.2 E/N Distribution and Ratio R_n in the Gap

In case where high temperature gas are existed in rod gap, we evaluate E/N distribution.

Gas equation for the stationary state is

$$P=N_o\ k\ T_o=Ny\ k\ Ty \quad (4)$$

From equation (4), $N_o\ T_o=Ny\ Ty$ (5)

where, P = gas pressure (dyne/cm²),
N_o = particle number density (cm^{-3}) at the room temperature (293°K),
Ny = particle number density (cm^{-3}) at a certain temperature,
T_o = temperature in the gap at the room temperature (293°K),
Ty = gap temperture derived from equation (3) (°K)
k = Boltzmann constant (erg/°K).

Accordingly, in case where high temperature gas are existed in the gap, we find from equations (3) and (5) that E/N distribution E/N_y is

$$\frac{E}{N}=\frac{E}{N_y}=\frac{E}{N_o}\cdot\frac{\frac{r_a(T_s-T_o)}{y}+T_o}{T_o} \quad (6)$$

From previous equation (6), the ratio Rn of E/N_y to E/N_o is

$$R_n=\frac{E/N_y}{E/N_o}=\frac{\frac{r_a(T_s-T_o)}{y}+T_o}{T_o} \quad (7)$$

3.3 General Discussion for the Results

Fig. 2 shows the characteristics of V_{BD}-d. To help reader's comprehension it is timely to show the following characteristics. In case where the SD does not occur the V_{BD} shows the highest value among the three characteristics. On the other hand the V_{BD} shows the lowest value among the characteristics when the SD current I_d is I_1.

Based on the results of this observation and previous papers [12~17], possible mechanisms by which the SD could initiate the BD may be explained as follows. The first, we belive that the V_{BD} decreases with decreasing the gas density of the circumference of the gap. The gas density decreases with increasing the temperature of the circumference of the gap due to the SD current.

The second, the distribution of equipotential lines changes from radial to axial of rod-rod gap due to the SD.

Therefore, the electric line of frce direct from the rod electrode or the discharge path of SD to the plane electrode. As the result, the breakdown easily occur.

Another version has it that the possible mechanism by which the SD initiates the BD would seem to be associated with the high local electric field around the SD channel enhanced by streamers protruding from its surface [13].

In case where SD current is I_1, the V_{BD} is lower than that of I_s.

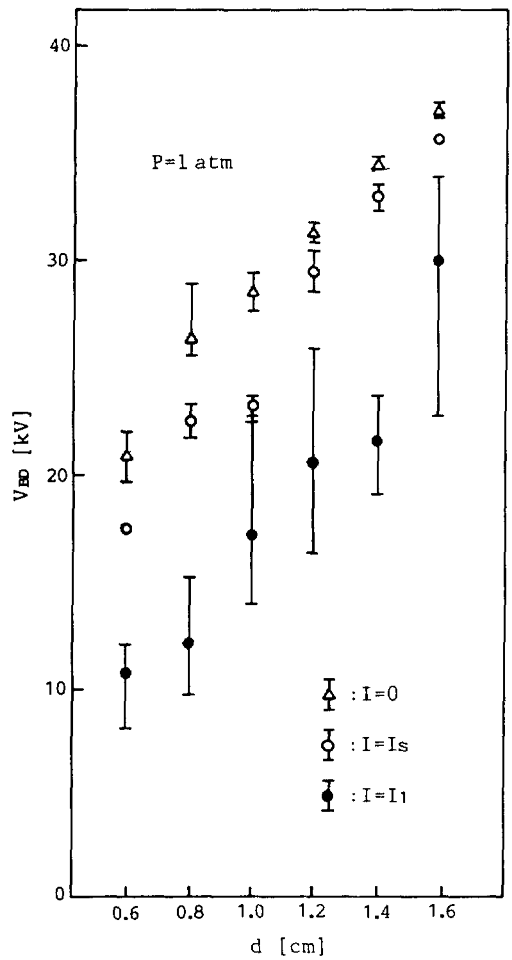
The reasons are as follows. The first reason is that large heat generation occur when the SD current is I_1 more than that of I_s.

The second reason is that relative gap length when the SD current is I_1 shorter than that of I_s. Because, the diameter of discharge path increases with increasing the discharge current[16, 18~20].

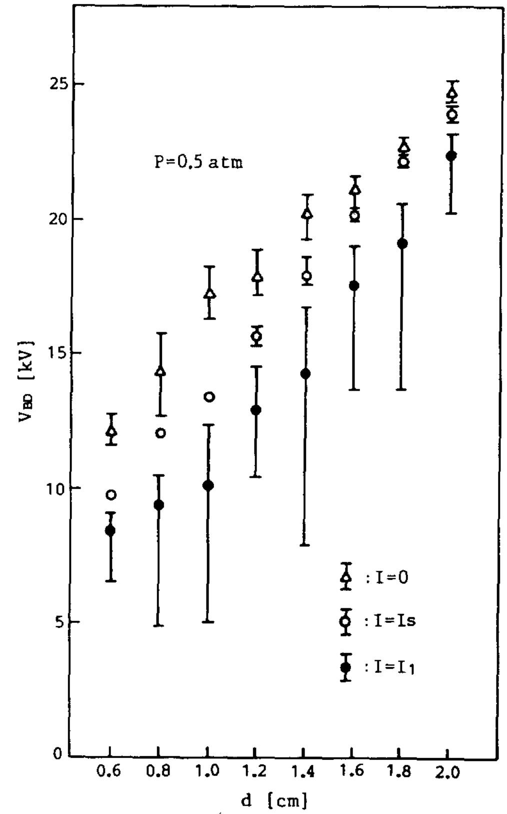
3-4 Discussion for the Results with K, Rn and Discharge Pattern.

Fig. 3 shows the relation for the decrease factor K of V_{BD} and rod-plane distance d. The decrease-factor K is determind by

$$K=\frac{V_{BD0}-V_{BD1}}{V_{BD0}}\times 100$$



(a : p=0.5atm)



(b : p=1atm)

Fig. 2 Characteristics of V_{BD}-d. (a:p=0.5atm, b : p=1atm)

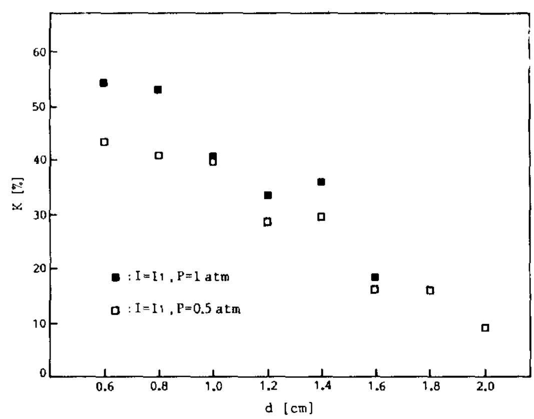


Fig. 3 Relation for the decrease-factor K of V_{BD} and rod-plane distance d.

wher V_{BD1}=mean value of V_{BD} when the SD current is I_1.

V_{BD0}=mean value of V_{BD} when the SD current

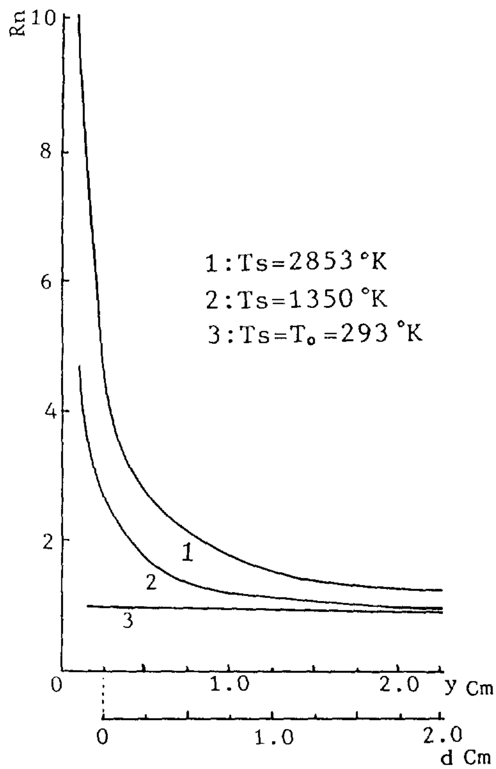


Fig. 4 Relation between Rn and d.

Table 1 Table of discharge pattern for the discharge paths ($p=0.5$ atm).

I_d \ d	0.8	1.0	1.2	1.4	1.6	1.8	2.0
0	I	I	II	II	II	III	III
I_s	I	I	II	II	II	II	III
I_1	I	I	I	I	II	II	II

is zero.

The characteristic of Fig. 3 is summarized as follows. The decrease-facrot K decrease with increasing the rod-plane distance d. We believe this relation as follows.

In case of this experimental condition ($ra=0.1$cm), we graphed from equation (7). The graph is Fig. 4. The boiling point (2853°K), the melting point (1350 K) of the electrodes copper and room temperature (293°K) are used in Fig. 4. In case I_d is zero, that is. T_s is T_o. The Rn is constnt on this condition as shown in Fig. 4 But, the ratio Rn increase with decreasing d in the condition that T_s is 2853°K and 1350°K. Therefore the BD easily occur with increasing Rn. As this result, K increase with decreasing d as shown in Fig. 3.

As this result. we found that position of the discharge path change from plane electrodes edge to center or near center of the plane electrode as shown in Fig. 5 and Table 1. Figure 5 shows discharge pattern and typical photographs of the discharge paths. We obtained a table of discharge pattern from observation of the discharge paths as shown in table 1.

In case where we tried breakdown with 10 times, we statistically determined the discharge pattern. Thé modes of discharge path are as follows.

(1) Pattern I : $N_1 \geqq 7$ Times,
(2) Pattern II : $N_2 \geqq 4$ Times or $4 \leqq N_{13} \leqq 6$,
(3) Pattern III : $N_3 \geqq 7$ Times.

where, N_1 is number of occurrence with I-configuration,
N_2 is number of occurrence with II-configuration,
N_{13} is number of occurrence with I or III configuration,
N_3 is number of occurrence with III-configuration as shown in Fig. 5,a.

The features of the pattern are

(1) Pattern I easily occur with increasing I_d.
(2) Pattern I easily occur with decreasing d.
(3) Pattern III easily occur with decreasing I_d.
(4) Pattern III easily occur with increasing d.
(5) Pattern II is transition pattern between I and III pattern,

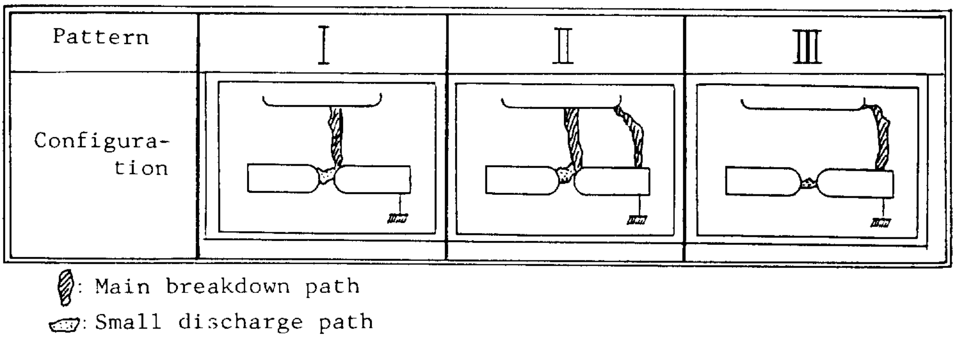
The reasons are as follows.

Generally speaking, the BD process in SF_6 depends very strongly on E/N.

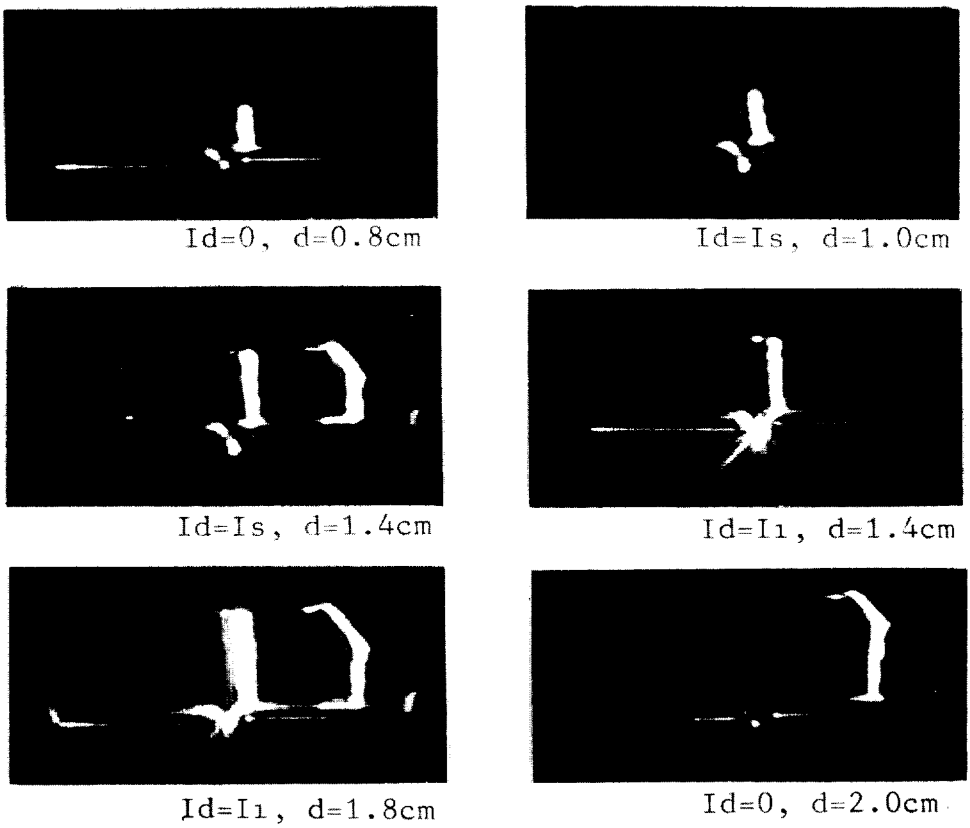
(1) In the case where I_d is zero, discharge path is decided by E because of constant N.

Position of the highest E change from center of the gap to edge of the plane electrode with increasing d. Therefore, the pattern change from I to II and III with increasing d.

(2) In the case where I_d is I_1, the BD depends



a. Pattern of discharge path.



b. Typical photographs of the discharge paths.

Fig. 5 Discharge pattern and typical photographs of the discharge paths at 0.5 atm.

very strongly on the N of the E/N due to the I_1.

Therefore, the pattern shows I Pattern on the d (=0.8~1.4cm).

Though d are 1.6, 1.8 and 2.0cm, the pattern is II in this case

(3) In the case where I_d is I_s, the discharge pattern is intermediate pattern between patterns for $I_d=0$ and I_1.

Form results of this section, slope of the R_n rapidly increase with decreasing d. Therefore, in case where the d is small, the effect of SD current is higer than that of large d.

Also, the R_n increase with increasing I_d.

Therefore, the effect of SD current for the I_1 is higer than that of I_s. As these results, diuscharge pattern was shifted with decreasing d the next. sequence. In case where the I_d is zero and I_s, the pattern is Ⅲ → Ⅱ → Ⅰ.

Also in case where the I_d is I_1, the pattern is Ⅱ → Ⅰ.

3.5 Discussion for the pressure characteristic

The decrease-factor K when the gap pressure p is 1 atm higher than that of 0.5 atm. Result of this, the mean decrease-factors K were 26.0% (p=0.5atm) and 38. 1% (p=1atm). This tendency is similar to the previous papers[12, 13]

According to these papers, the time interval from the start of the rod discharge to the completion of the breakdown decreases with the increase in gas pressure. This result indicate the influence of the samll discharge on BD.

Also the phenomenon is similar to the "triple junction effect", in which a partial discharge occurring on a solid insulator at a gas-electrode-insulator junction leads to flashover over its full length at higher pressure of SF_6 gas[21].

However, the breakdown mechanism above is not clear because of their comnplexity, and further investigation is required.

4. Conclusions

The important results obtained from this investigation are as follows.

The reduction of the V_{BD} is greater for high pressure, large SD current and small gap distnace. As this result, the decrease-factor K decreases with increasing the rod-plate distance d. Results of these, the mean decrease-factors K were 26.0% (p=0.5atm) and 38.1% (p=1atm).

Shifting of discharge path-position due to the SD current I_d and gap distance d can be explained by the ratio Rn.

ACKNOWLEDGEMENT

The authors wish to thank Dr. Hosokawa and mr. Yukimitsu Kawada (Department of Electrical and computer Engineering, Nagoya Institute of Technology), for their support as well as many helpful discussions.

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