攪亂된 平等電界에서 高氣壓 SF_6가스의 연속절연 파괴강도에 관한 硏究

論 文
29—2—3

A Study on the Repeated Breakdown Field Strength of Compressed SF_6 in Uniform Field Perturbed by Protrusion

李 東 仁*
(Dong-In Lee)

Abstract

For large gas-insulated systems, the conductor utilized possess some degree of surface roughness which locally enhances the applied field at highpressure in SF_6. In order to investigate the effect of field enhancement on the breakdown field strength, the spheric protrusion was employed which gives a quantitative analysis on field enhancement. For further investigations on the breakdown level and polarity effect in SF_6, the repeated breakdown tests were performed with d.c. voltage at pressures up to about 4 bar.

The experimental results show that the breakdown level does vary noticeably due to successive voltage applications, and the breakdown field strength measured for a test gap with the cathode protrusion is markedly lower than that determinded from the identical anode protrusion.

1. Introduction

Cenerally investigations concerning the breakdown field strength in gas were carried out with highly polished electrdes obtainable in practice under laboratory conditions. For large gas-insulated systems, however, such uniformly highly polished electrode are not practicable and consequently the conductors utilized possess some significant degree of surface roughness which locally enhances the applied field.

The effect of this field enhancement on the breakdown field strength can be described in terms of the Pedersen roughness factor[1], ζ, which is a function of the parameter pR (p=pressure, R=height of a protrusion). It can be seen that when pR exceeds about 45 barμm, ζ is theoretically less than unity and the macroscopic field strength at breakdown, E_{os}, is consequently lowered[1][2]. For strictly uniform fields of practical dimensions at high pressures, breakdown occurs when E_o/p (E_o=macroscopic field strength) just exceeds the limiting value and so at high values of pR the breakdown field strength[3]

$$E_{os}=\zeta\cdot(E/p)_{lim}\cdot p/z(p) \qquad (1)$$

where $(E/p)_{lim}$=the measurable low-pressure value of 8.84kV(bar·mm)$^{-1}$

$Z(p)$=compressibility

Therefore the breakdown field strenth can be estimated by calculating equation (1) at a given value of pR.

In this paper in order to compare the measured values with the theoretically calculated breakdown feild strengths, the effects on the breakdown field strength of repeated sparking, polarity of highly stressed electrode, and number of protrusions are basically investigated up to pressure of about 4 bar in uniform field perturbed by protrusions.

* 正會員：嶺南大 工大 電氣工學科敎授・工博
接受日字：1980年 1月 9日

2. Apparatus and Experimental Techniques

The apparatus used for the determination of static breakdown voltages and associated high voltage supply have been fully described previously[3]

2.1 Choice of the protrusion

In order to perform the investigation in the high pR range (pR≥45 barμm), precise tungsten carbide spheres were usedas protrusions. Precision made spheres are more easily obtained than other artificial protrusion shapes and allow a quantitative account of breakdown phenomena. The spheres had a 0.013m C.L.A.(center line average) surface finish and, therefore, the value of pR on the surface of the spheres themselves was less than 45 barμm even at the present maximum pressure of 4 bar. The spheres conveniently available had radii of 500μm and so, when placed on one of the electrodes in the test gap, allowed the simulation of roughness corresponding to valves of pR up to a few thousand barμm.

2.2 Determination of test gap spacing

It was shown that the gap spacing should be limited to one fifth of the overall diameter of the electrode in order to exclude the possibility of avalanche development outwith the nominally uniform region of the test gap[4][5]. In addition, in order to calculate the breakdown voltage of the gap perturbed by the spherical protrusion it is assumed that the gap spacing is large in comparison to the height of the protrusion. With these two restrictions the test gap spacing(d) was always operated in the following range:

$8\times$height of protrusion$\lesssim d \lesssim 0.2\times$overall diameter of electrode For these tests, electreods of 180 mm overall diameter were used.

2.3 Test procedure

Before mounting spheres on the electrode, they were cleaned ultrasoncally and with acetone. The electrodes were polished to a surface roughness center-line-average value of less than 0.5 μm with different grades of diamond paste. After mounting the protrusions on the electrode the continuity between the electrode and each protrusion was checked electrically. The gap spacing was rechecked after allowing a suitable time for mechanical stabilization, whenever the pressure of the vessel was changed. By changing the polarity of the upper electrode, the effect of placing identical spherical particles on both cathode and anode could be determined.

3. Results and Discussion

Successive voltage applications to smooth electrodes may lead to a fairly constant value of the breakdown level[6][7]. In this case breakdown normally takes place evenly in the center part of the electrode unless the gap spacing is long enough for edge breakdown to occur. On the other hand, such repeated sparking of the gap can also lead to a decreased breakdown performance due to the damage caused during previous breakdowns, particularly at high pressure[8][9]. In the present measurements, as breakdown will always occur to the protrusions, a relatively large number of samples of the breakdown voltage are initially required in order to assess the importance of repeated sparking to the later investigations.

Figure 1 presents the effect of successive voltage applications on the breakdown level with a single cathode protrusion. It is interesting to note that the scatter of 1.4%(standard deviation) observed at 0.5bar increased to 6% at 1bar but decreased to 1.5% at 4bar. Figure 2 shows results obtained in a similar test to that of Figure 1 except with an increased number of protrusions (5 protrusions). Except at 0.5bar,the scatter in breakdown voltages was reduced but the maximum again at 1bar.

Figure 3 and 4 present the repeated breakdown voltages obtained with a single anode protrusion and 5 anode protrusions with increasing pressure for both cases the scater, was 1.1% at 0.5 bar rising to~2.4% with the single protrusion, but only 1.6% with the multiple protrusions.

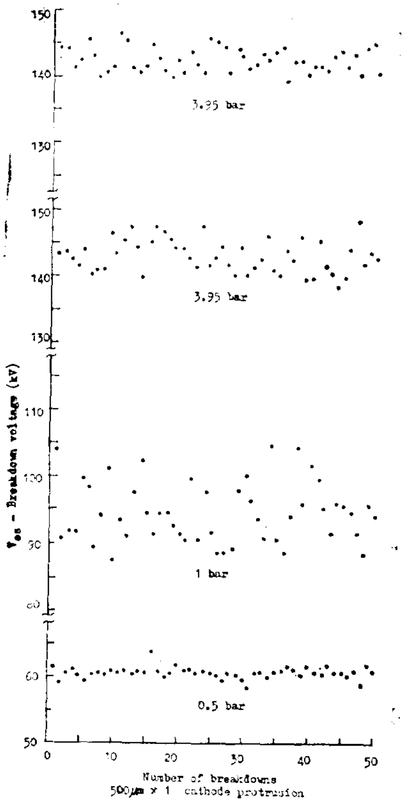

Fig. 1. Effect of repeated sparking on the breakdown level with a single cathode protrusion

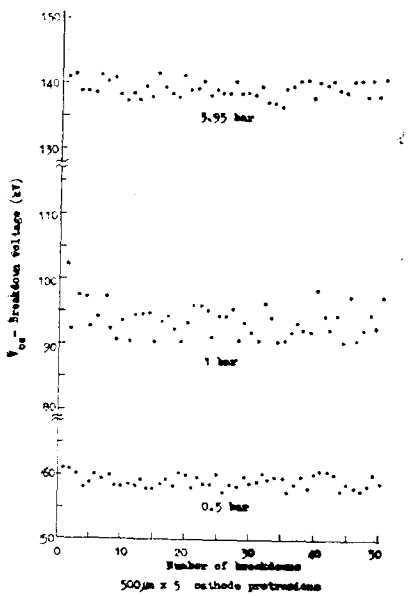

Fig. 2. Effect of repeated sparking on the breakdown level with 5 cathode protrusions.

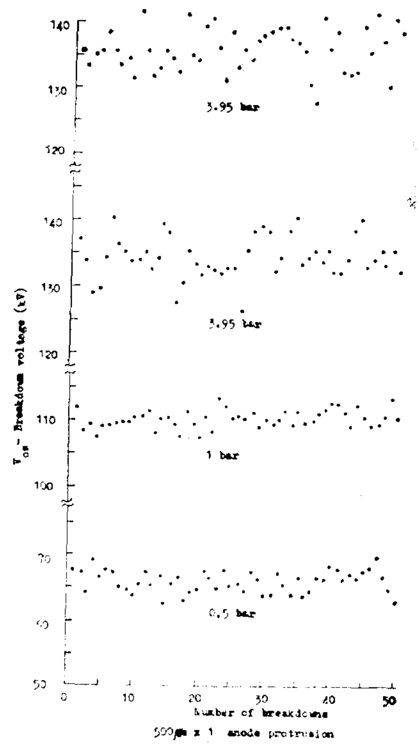

Fig. 3. Effect of repeated sparking on the breakdown level with a single anode protrusion

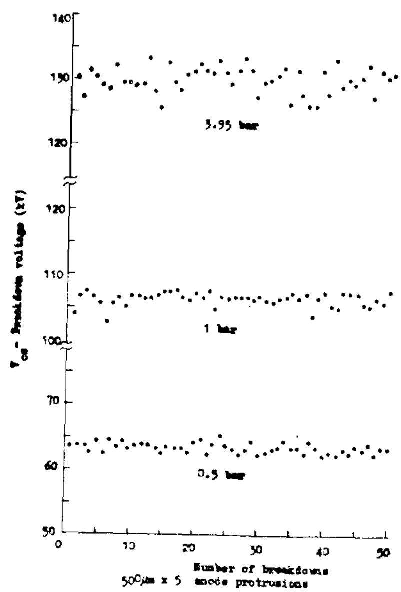

Fig. 4. Effect of repeated sparking on the breakdown level with 5 anode protrusions.

These tests show that the breakdown level does not vary noticeably due to successive voltage applications (100 breakdowns) and so allow the breakdown voltage in the following investigations to be adequately determined from about 10 measurements.

Some information was also obtained on the first breakdown level but not enough tests of this type were performed to give statistically significant observations. However, there was a tendency for the first breakdown observed to be above the average level for the rest of the test.

Comparing the results presented in Figure 1 and 2 shows that the breakdown level measured for a test gap with the highly stressed protrusion positive is markedly higher than that found for the identical cathode protrusion.

4. Conclusions

The interesting conclusions to be drawn from the results presented in this basic study to assess the importance of repeated sparking to the later investigations are that the breakdown level does not vary significantly due to successive breakdown tests and therefore the breakdown voltage in the later investigations can be adequately determined from about 10 measurements. The breakdown level obtained from a test gap with the cathode protrusion is markedly lower than that determinded from the identical anode protrusion. At pressures above 1bar, the scatter in breakdown voltages is reduced by increasing number of protrusions placed on the electrode.

Details for qualitative and quantitative analysis on the theoretical breakdown level, polarity effect, and irradiation effect shall be presented in the later publication.

References

1) Pedersen, A.: The Effect of Surface Roughness on Breakdown in SF_6, IEEE Trans. PAS 94, p.1749 (1975)
2) Dong-in Lee: Thoretical Investigation of Electrical Breakdown in Compressed SF_6, KIEE Vol. 27, No. 2, p.160 (1978)
3) Dong-in Lee: The Effect of Compressibility on Breakdown and Modification of the Surface Roughness Factor in Compressed SF_6, KIEE Vol. 27, No. 1, p.45 (1978)
4) Karlsson, P.W. and Pedersen, A.: Inherent Limitation in Uniform Field Discharge Data for SF_6, IEEE Trans PAS 91, p.1597 (1972)
5) Chalmers, I.D. and Tedford, D.J.: Spark Breakdown in Sulphur Hexafluoride and Arcton 12, Proc. IEE. Vol. 118, No. 12, p. 1893 (1971)
6) Philp, S.E.: Compressed Gas Insulation in the Millionvolt Range, IEEE Trans PAS 66, p.356 (1963)
7) Goldspink, G.F., Cookson, A.H. and Lewis, T.J.: Spark Conditioning Effects in Compressed Nitrogen and Sulphur Hexafluoride, J. of Appl. Phys. Vol. 40, p.328 (1969)
8) Cooke, C.M.: Ionization, Electrode Surfaces and Discharges in SF_6at Extra-High-Voltages, IEEE Trans PAS 94, p.1518 (1975)
9) Nitta, T., Yamade, N. and Fujiwara, Y.: Area Effect of Electrical Breakdown in Compressed SF_6, IEEE Trans PAS 93, p.623 (1974)