Anomalous Creeping Flashover Characteristics in N_2/SF_6 Gas Mixtures under Nonuniform Field

Hideki Ueno and Hiroshi Nakayama
Department of Electrical Engineering, Faculty of Engineering
Himeji Institute of Technology
2167 Shosha, Himeji 671-2201, Japan
Tel:+81-792-67-4863, Fax:+81-792-67-4855
E-mail: ueno@elct.eng.himeji-tech.ac.jp

SF_6 gas has excellent dielectric insulating properties, and the application as an insulating medium to electric power apparatuses such as a gas insulating switchgear has contributed to the improvement of the reliability and miniaturization of them [1]. However, it is known that a significant decrease in the dielectric strength of SF_6 gas is induced by a nonuniform electric field resulting from the existence of a projection on the conductor or a metal particle in the gas, or by invasion of unusual surge voltage with steep front [2]. Furthermore, recently the discharge of SF_6 gas is regulated just like as CO_2 gas, because the ability of the contribution to the green-house effect is about 25000 times as high as that of CO_2 gas [3]. Therefore, there have been some requirements to decrease its discharge to air and its usage for the environmental considerations. From above points of view, intensive investigations have been carried out for the characteristics of dielectric insulation in a mixed gas insulator composed of an electronegative gas such as SF_6 and a buffer gas such as N_2 [4]. And the application to the power apparatuses taken in place of SF_6 gas insulating system is expected for the insulating medium with N_2/SF_6 mixed gas.

In general, an insulating configuration on the power apparatuses has been consisted of a solid dielectric and an insulating gas. We have investigated creeping flashover characteristics under a nonuniform electric field for a composite insulating system consisting of a small gap filled with gas mixtures, and a considerable decrease in creeping flashover voltage has been found for the composite insulation with gas mixtures of small amount of electronegative gas (SF_6 and O_2) in N_2 [5-7]. In this work, the creeping flashover characteristics of the composite insulating system by inserting a solid dielectric between needle and plane electrodes with N_2/SF_6 gas mixture have been studied. We describe the origin of the anomalous creeping flashover behavior for N_2/SF_6 has been discussed.

The electrode configuration for the present work is shown in Fig.1. The gap was composed of a steel needle electrode with a tip of 35 μm radius of curvature and a brass plane electrode. A solid dielectric (18 x 18 mm^2) with thickness a of 0.5 mm as a barrier was placed on the upper surface of the plane electrode. A μs-order rectangular pulse voltage with a maximum peak value V_p=35 kV was applied.

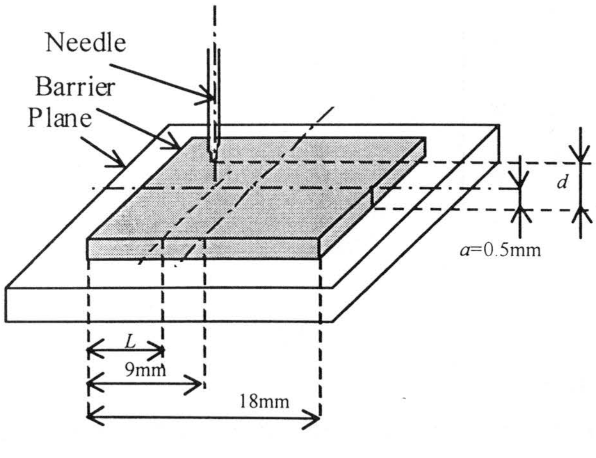

Fig.1 Electrode configuration.

The dependence of negative flashover voltage

(FOV) on SF_6 gas content D into N_2 gas for the configuration with the gap length of d=1.0 mm for various creeping distances L is shown in Fig.2 under the pressure of P=0.3 MPa. For L=0~1 mm, the FOV was markedly increased by the addition of the SF_6 gas (D<10 %) just like as that seen under the quasi uniform field [4]. On the other hand, for L=3~9 mm the decrease of the negative FOV was induced by the addition of 3% of SF_6. This means that the mixture of small amount of SF_6 gas on the negative FOV turns from positive effect (enhancement of FOV) into negative effect (reduction of FOV) by increasing creeping distance L. In the case of P=0.2 MPa, the positive and negative effects were obtained for L=0~1 mm and for L=5~9 mm, respectively. So, the threshold creeping distance was affected by the gas pressure. This result suggests that the negative effect is related to the creeping corona extension depending on the gas pressure.

For the investigation of the mechanism for the decrease of negative FOV, at first, the voltage-time characteristics of FOV and corona onset voltage (COV) have been studied. The voltage-time (V-t) characteristics of the negative FOV and COV for L=9 mm under P=0.3 MPa are shown in Fig.3. In the case of N_2/SF_6 (D=3%) and SF_6 (D=100%) the FOV did not change remarkable or decreased slightly with increasing wavefront duration T_f. On the other hand, the V-t characteristics for N_2 (D=0%) were different from those obtained for N_2/SF_6 (D=3%) and SF_6 (D=100%), and the FOV indicated a maximum value at around 10 μs. The reason why the V-t characteristics in N_2 (D=0%) has maximum value is not clear in this stage. At least, in our investigated wavefront duration, this fact suggests that the negative gas mixture effect in SF_6 gas content dependence of FOV in negative polarity should not result from the time lag in discharge process. The V-t characteristics on the COV obtained optically, an initial photon emission detected by using a photomultiplier, are also indicated in Fig.3 for N_2 (D=0%), N_2/SF_6 (D=3%) and SF_6 (D=100%). In all cases, the COV did not change or slightly decreased by increasing wavefront duration. Furthermore, this SF_6 gas content dependence of corona onset voltage is opposite to that of the negative FOV under the same condition seen in Fig.2, namely the COV increases with increasing SF_6 gas content. Our results on FOV and COV suggest that the corona extension process might play an important role in the decrease of negative FOV induced by SF_6 admixture.

Gas pressure dependence of the negative FOV for L=3mm in N_2, N_2/SF_6 (D=3%) and SF_6 gas is shown in Fig.4. The effect of SF_6 gas mixture on the negative FOV in the low SF_6 content region strongly depended on the gas pressure P under this condition. Namely, the effect turned from positive to negative

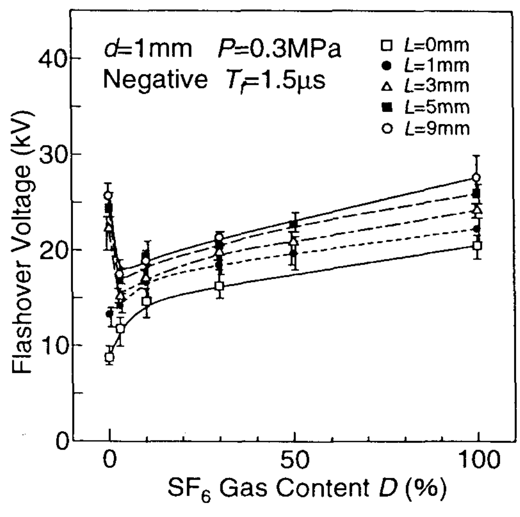

Fig.2 SF_6 gas content dependence of negative flashover voltage at various creeping distances for d=1.0 mm under P=0.3 MPa.

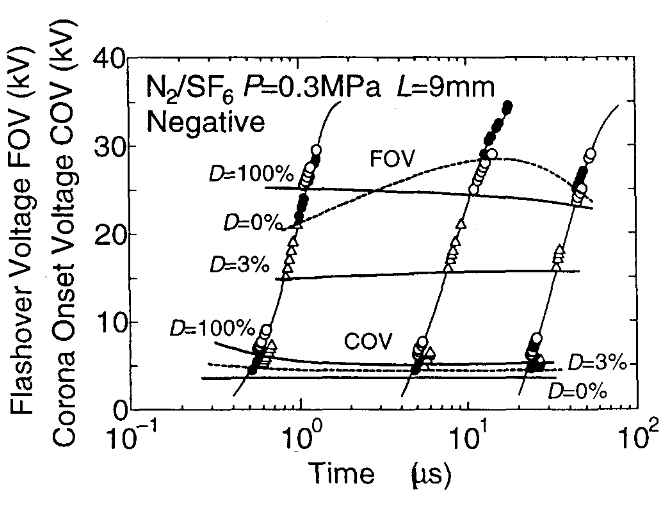

Fig.3 Voltage-time characteristics on flashover and corona onset in negative polarity for N_2/SF_6 gas mixtures under P=0.3 MPa.

upon increasing gas pressure. In addition, though the negative FOV increased with increasing the gas pressure P for the investigated gas mixtures, only for the case of N_2/SF_6 (D=3%), the pressure dependence of negative FOV was considerably small. These findings on the considerably small pressure effect on the FOV in N_2/SF_6 (D=3%) mixed gas should result in the negative effect of SF_6 gas mixture on the FOV at longer creeping distances and higher pressures (P=0.2 and 0.3 MPa).

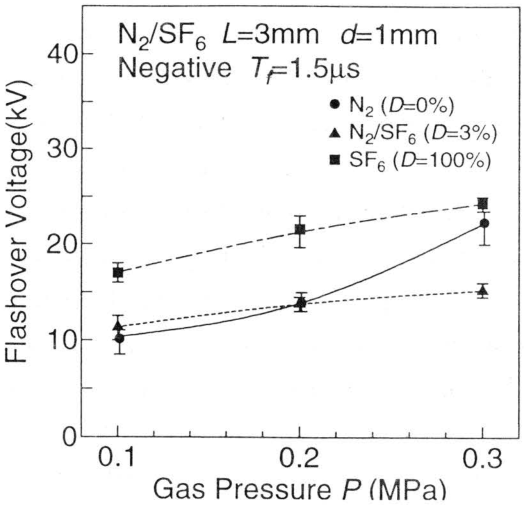

Fig.4 Gas pressure dependence of negative flashover voltage for L=3 mm in N_2, N_2/SF_6 (D=3%) and SF_6.

The creeping coronas in N_2/SF_6 mixtures were imaged with an adequate exposure time (typically 50 ns). The creeping corona images viewed diagonally from above just before the flashover for L=3 mm are shown in Fig.5. A wide and broad photon radiation extended on the barrier surface was observed in the creeping corona image in N_2/SF_6 (D=3%) under P=0.1 MPa, in which condition the negative FOV was enhanced by the admixture of SF_6, and this creeeping corona image was very similar to that observed in N_2 (D=0%) under P=0.3 MPa. On the other hand, for the creeping corona image in N_2/SF_6 (D=3%) under P=0.3 MPa, and the FOV was reduced by the small amount of SF_6 addition in this condition, the creeping corona paths propagated radially on the barrier surface and the highly intense photon emissions at the tip of the creeping corona paths were found. This creeping corona image in N_2/SF_6 (D=3%) gas is quite different from those obtained in N_2 (D=0%) and SF_6 (D=100%). Furthermore, the creeping corona image under P=0.2 MPa was an intermediate of them. Though no significant difference was observed among the negative FOVs in N_2/SF_6 (D=3%) under P=0.1~0.3 MPa (only 3 kV), a large difference was found in the creeping corona extension. This change in creeping corona behavior upon increasing gas pressure is well corresponding to the turn from positive effect to negative one on the SF_6 gas content dependence of the negative FOV. It suggests that the N_2 gas ionization in front of the creeping corona will be activated by the addition of SF_6 gas to N_2 gas, resulting in the top of the creeping corona having strong photon emission intensity.

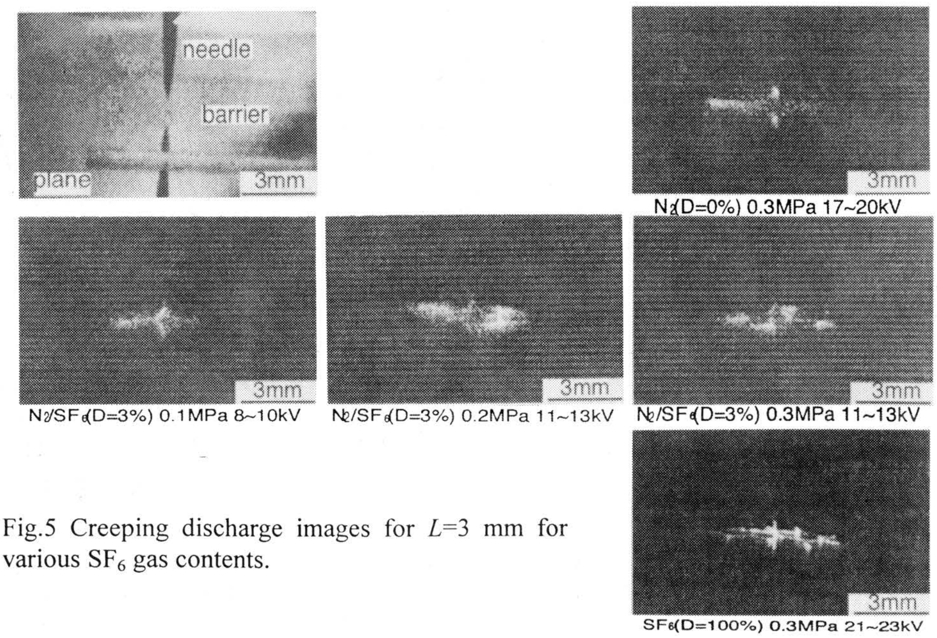

Fig.5 Creeping discharge images for L=3 mm for various SF_6 gas contents.

The fact that the pressure dependence of FOV is very small at the low SF_6 content suggests the effective ionization coefficient $\alpha-\eta/P$ is insensitive to the gas pressure. The ionization of N_2 molecules will be activated by the electrons in front of streamer on the barrier surface. Because the electron-ion recombination will mainly proceed on the barrier surface in the gas mixture containing electronegative gas. At this time, a large number of photons will be generated on the barrier surface. Furthermore, the absorption coefficient in the ultraviolet region is enhanced by the admixture of SF_6 into N_2 [8], so that the photons will be absorbed effectively. Therefore, the photoionization will be activated in front of the streamer. Upon increasing gas pressure, the density of electrons and ions in front of the streamer before and after the photoionization will be higher; and it might affect to the flashover process. In addition, the electric field at the top of the streamer should be very high, so that the electrons might not always attach to SF_6 molecules, because the electron attachment strongly depends on the electron energy [9]. And then, the effect of the suppression of creeping corona extension should not be effective by the SF_6^-. By taking the above mentioned processes into consideration, the value of $\alpha-\eta$ at low SF_6 content will increase greatly compared with that for pure N_2 system, and this activated N_2 ionization process should result in the easier creeping corona extension and the reduce of the negative FOV.

In conclusion, creeping flashover characteristics in N_2/SF_6 under nonuniform field have been studied. Upon increasing gas pressure, the creeping corona has been changed from broad and wide corona extension to an extension with clear paths and an intensive region at the tip of creeping corona. This change has been well corresponding to the turn from positive effect to negative one for SF_6 gas content dependence on FOV. The effect of the suppression of creeping corona extension should not be effective by negative ions generated by the electron attachment. The photoionization of N_2 molecules in front of a streamer would be activated by the addition of SF_6 gas to N_2 gas, resulting in the anomalous decrease of FOV.

References

[1] W.T.Shugg, *Handbook of Electrical and Electronic Insulating Materials*, IEEE Press, NY, 1995.
[2] A.H.Cookson and O.Farish, IEEE Trans., **PAS-92** (1973) 871.
[3] L.Niemeyer and F.Y.Chu, IEEE Trans., **EI-27** (1992) 184.
[4] L.G.Christophorou and R.J.Van Brunt, IEEE Trans., **DEI-2** (1995) 952.
[5] H.Ueno, K.Watabe, K.Tada, M.Onoda and H.Nakayama, Jpn.J.Appl.Phys., **37** (1998) 6595.
[6] H.Ueno, H.Ohnishi, K.Tada, M.Onoda and H.Nakayama, Jpn.J.Appl.Phys., **38** (1999) 4182.
[7] K.Watabe, K.Shinomiya, H.Ueno, M.Onoda and H.Nakayama, Trans.IEE Jpn., **119A** (1999) 6 [in Japanese].
[8] D.T.A.Blair, N.M.MacLeod and J.S.Orr, Proc.4th.Int.Conf. Gas Discharge, IEE London, p.401 (1978).
[9] S.R.Hunter, J.G.Carter and L.G.Christophorou, J. Chem. Phys., **90** (1989) 4879.