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An Experimental Investigation on the Lightning Impulse Breakdown Characteristics of SF_6-based Mixture Gases

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Abstract: - SF_6 is widely used as gas insulation medium because of having excellent dielectric and arc-quenching properties. However the use of it is getting to be suppressed from the viewpoint of mitigating global warming. For the development of environmentally-being electric power equipment and system, novel gases or mixture gases are strongly required as the substitute of SF_6 gas. In this study the authors constructed an experimental system to investigate insulation properties of the mixed gases composed of negative gas(SF_6) and electron deceleration gases(N_2 and CO_2). Breakdown and prebreakdown characteristics of $SF_6/N_2/CO_2$ mixture gases were investigated using the above mentioned system for different rates and gas pressures.

Key-Words: - SF_6, Environmentally-being electric power equipment and system, mixture gases, Breakdown characteristics, Prebreakdown characteristics

1 Introduction

The environment impact on the human activities has been much concerned in the world recently, and especially the impact of potential climate change due to the increase of greenhouse gases in the air is largely noted on the global environment side [1]. One of the gases is SF6 which is mainly used in the field of power industry. Especially, SF6 is the effective absorption to the infrared ray radiation composition of 10.5μm band [2]. In general, the substantial absorption and the re-emission to the earth by the greenhouse gases cause the average temperature rise in the atmosphere of the earth, and it is called Greenhouse Impact. The contribution impact of the artificial substance to the greenhouse impact is to cause "Global Warming" by transferring the equilibrium between incoming and outgoing of radiation energy, which is occurred at the uppermost of the troposphere of the earth to the atmosphere where green gases are existed. Furthermore, SF6 has chemical and photolysis flame immunity, being different from the other green gases (CO2, CF4, etc.) that are mostly occurred in nature, and its contribution impact to the global warming is accumulative and permanent in fact.In the case of SF6, not being specific for the dominant decomposition mechanism at present, it is difficult to determine the age (the time to be applied that SF6 is reduced to approx. 37% of the initial volume through the natural process) but it is estimated about 3,200 years in the longest [3]. SF6 has been evaluated to reserve high potentiality for global warming by the above mentioned two factors, namely strong infrared ray absorption and long age, so the electricity companies that are the main user of this gas have to suggest the justification for using SF6 gas and the reservation for the environment simultaneously [4]. Hence, gas insulation at present and in the future should be available to be accepted in surroundings. So, the best treatment to reduce the possible impact by SF6 to the global warming is to prevent outgoing of SF6, and the most efficient way is not to use SF6 at all. Such assertion seems to be attractive on the environmental side, but it is hard to be expected to exclude the use of SF6 totally in the near future on the industrial and social aspects. However, the investigation for the alternative gas and the necessity for the alternative technology for high voltage insulation use are increased by such assertion. In such a course, gas mixture by SF6/buffer gas is paid attention to the effective treatment for reducing usage volume of SF6. The bigger merit of this gas mixture including SF6 gas is that positive synergism is represented in the insulation faculty [5]. The research on the insulation characteristics between the gaps of SF6 alternative gas has been processed vividly in the center of the conventional SF6/N2 gas mixture [6-10], and CO2 is more positively reviewed as buffer gas. Qiu [11] reported that the insulation characteristics of SF6/CO2

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was superior to SF6/N2 in the case of applying it to GIT, also reported that gas mixture of SF6/Air and SF6/CO2 showed higher minimum breakdown value of shock voltage than pure SF6 in stronger non-uniform field. Meanwhile, Ohthuka et al. reported that maximum value of breakdown voltage was increased by 1.31 times and 1.25 times each in comparison with gas mixture of 50%SF6/N2 and net SF6.In this research, I investigated the insulation characteristics of 2-kind or 3-kind gas mixtures of SF6/N2 and SF6/N2/CO2 and reviewed it with pure SF6 gas in order to suggest the direction of the research for SF6 alternative gas in Korea in compliance with such social requirement.

2 Experiment & its result

In this paper, I investigated the insulation characteristics of 3 kinds of gases of pure SF6, SF6/N2 and SF6/N2/CO2 by an experiment applying standard lightning impulse voltage under 0.6MPa of gas pressure to review the insulation characteristics of gas under quasi-uniform field that is the basis of SF6gas and gas mixture by the statistical interpretation in accordance with Weibul distribution. Meanwhile, in the case of practical electric appliances, the insulation breakdown characteristics under non-uniform field was also compared and reviewed in this research as they had the possibility to be closed to the insulation through partial discharge of electricity being formed of non-uniform field in the appliances by the mixture of metal foreign matters.

2.1 Experimental Device and the experiment

In this experiment, I investigated the insulation characteristics for 3 kinds of gases of pure SF6, 50%SF6/50%N2, and 50%SF6/49%N2/1%CO2 by changing gas pressure under 0.6MPa, and the composition of the experimental device was showed in fig.1.A plane-to-plane electrode of stainless material (End surface treatment by diameter 40mm and the radius of curvature 5mm, level diameter: 30mm, electrode gap: 10mm) which was shown in fig.2 (a) was used to form uniform field, and the insulation characteristics by non-uniform field was experimented using needle-to-plane electrode in fig.2 (b). (The radius of curvature of needle end: 0.5mm, electrode gap: 10mm) Experimental gases were 3 kinds, in which SF6, SF6/N2 2-kind gas mixture with mixing ratio OF SF6 by 50%, and 3-kind gas mixture that was added CO2 1% to SF6/N2 2-kind gas mixture with mixing ratio of SF6 by 50%. Mixing ratio of the experimental gases was fixed to the pressure ratio in normal temperature using fixation pressure sensor (PTX610, Druck) and indicator (DPI145, Druck).

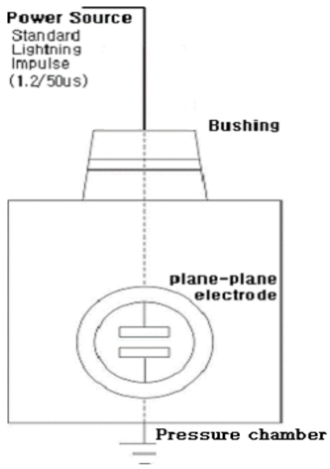


Fig. 1 Experimental setup for lightning impulse characteristic

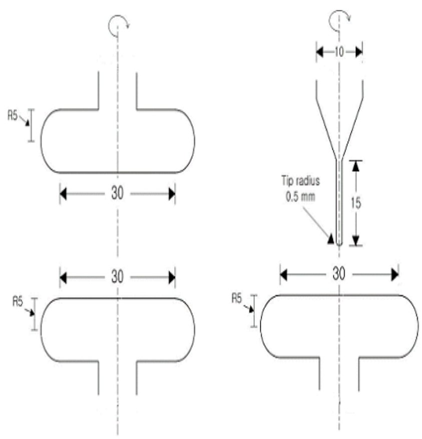


Fig. 2 Tested electrode structure. (a) Plane-to-plane electrode, (b) Needle-to-plane electrode.

In order to secure the mixture degree of gas mixtures, gas mixtures are left by 24 hours after the mixing gases so that sufficient gases may be mixed by natural dispersion. Flashover voltage under uniform field was measured under the same condition in accordance with rising method (step gap: 2kV) applying standard lightning impulse voltage (1.2/50 μs). In the meanwhile, gas pressure was once experimented in the status of high gas pressure (0.6MPa), the gas in the container was exhausted for reducing gas pressure, and the experiment was repeated under setup pressure condition. So, 50% of flashover voltage was measured by the statistical interpretation in accordance with

Weibul distribution applying such result of measurement. Flashover voltage under non-uniform field was measured in the same way in the case of measurement experiment of flashover voltage under uniform field applying standard lightning impulse voltage to the needle electrode in needle-to-plane electrode.

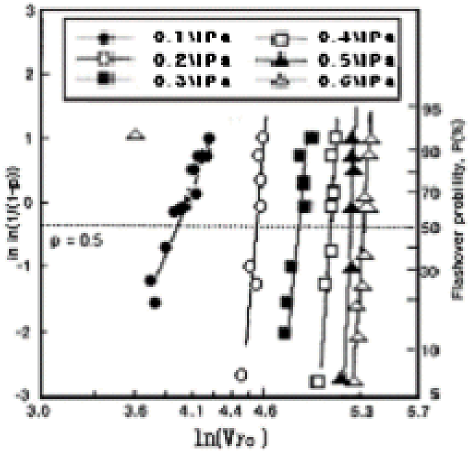
2.2 Experiment result

2.2.1 Insulation characteristics under uniform field

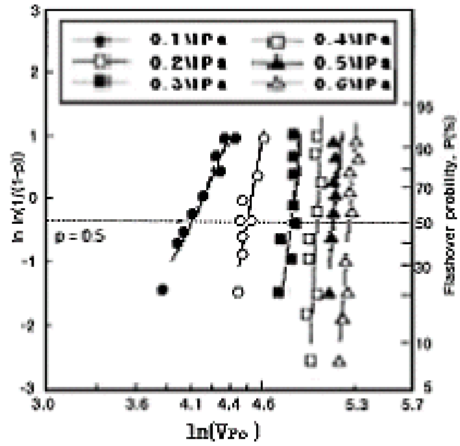
Characteristics of flashover voltage (VFO) in each gas pressure of SF6, 505SF6/50%N2, and 50%SAF6/49%N2/1%CO2 (3-kind gas mixture) was displayed on Weibul plot in fig.3. Calculating this result by Weibul distribution function, the relationship between accumulative breakdown probability and insulation breakdown voltage in every gas was possible to linear approximation, that is, VFO was in accordance with Weibul distribution. The slope of regression lines in Weibul plot is applied to shape parameter m that indicates the degree of dispersion of VFO, and the intersection point between regression lines and breakdown probability p=0.5 indicates 50% flashover voltage. In addition, it is shown that V50 is increased in case that gas pressure is higher, and then the slope of regression lines bigger, and the degree of dispersion less in this figure.

2.2.2. Insulation characteristics of SF6 gas under non-uniform field

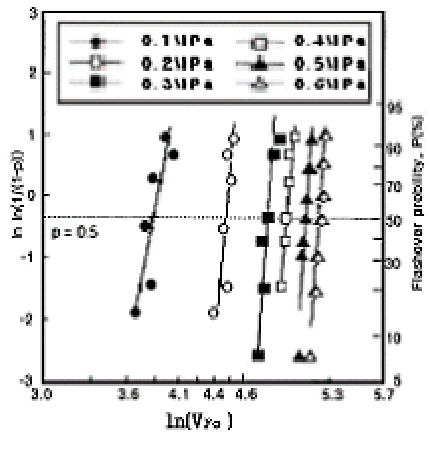
Accumulative breakdown probability of insulation breakdown voltage in applying positive polarity and negative polarity standard lightning impulse voltage for SF6 gas under non-uniform field, which was gotten by using needle-to-plane electrode with gap in 10mm, was shown on Weibul plot in fig.4.From this figure, it is shown that accumulative breakdown probability is in accordance with Weibul distribution in the same way with uniform field even under non-uniform field. From fig.4, it is shown that dispersion of breakdown voltage in each gas pressure in the case of applying positive polarity lightning impulse voltage is big, and the dispersion is small in the case of negative polarity in comparison with positive polarity.



(1) SF_6

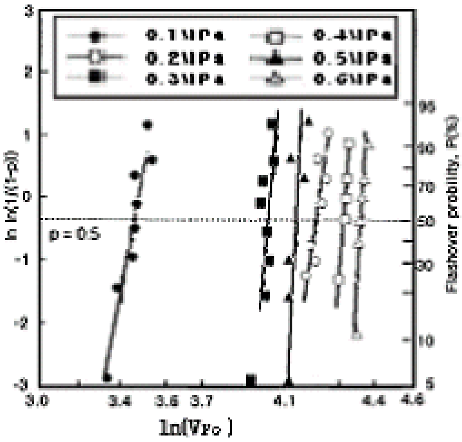


(2) $50\%SF_6/N_2$

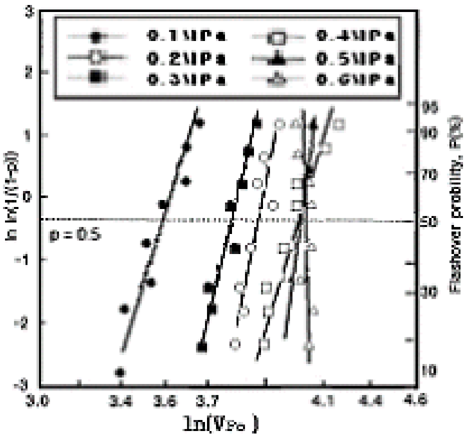


(3) $SF_6/N_2/CO_2$

Fig. 3 Weibul plot of flashover voltage for each tested gases



(1) Positive lightning impulse



(2) Negative lightning impulse

Fig. 4 Weibul plot of flashover voltage of pure SF6 gas for lightning impulse under non-uniform field. (a) positive polarity and (b) negative polarity

3 Reviewing the experimental result

3.1 Insulation characteristics of SF6 gas under uniform field

Insulation breakdown in gas is caused by weak point destroying, so the phenomenon is understood to follow Weibul distribution. In this research, Weibul distribution function was applied for getting 50% insulation breakdown voltage in applying lightning impulse voltage.

The following formula is given by Weibul distribution function.

$$p = 1 - exp\{-(\frac{V}{V_0})^m\} \quad (1)$$

Here, p: accumulative breakdown probability, V: insulation breakdown voltage, Vo: scale parameter, m: shape parameter.

Hence, 50% breakdown voltage V50 is gotten by inputting p=0.5 to the above formula, it is indicated as the following formula.

$$V_{50} = V_0 \times 0.693^{\frac{1}{m}} \quad (2)$$

In fig.5, gas pressure dependence of positive polarity V50 that was gotten by the formula (2) in applying lightning impulse voltage among pure SF6 gas, 50%SF6/N2 gas mixture, and SF6/N2CO2 gas mixture under uniform field.

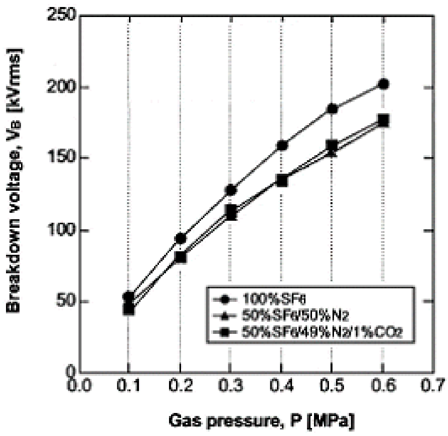


Fig. 5 V50 characteristics of pure SF6 gas, 50%SF6/N2 and SF6/N2/CO2 gas mixtures under uniform field.

V50 in each gas is monotonously risen following the gas pressure is rising, and saturation is shown in high gas pressure area. Here, it is found that V50 in pure SF6 gas is the highest one, and characteristics of 2-kind and 3-kind gas mixture is almost the same, however, the synergism of insulation staying power in 3-kind gas mixture that is not shown under non-uniform field in applying AC voltage.

The noticeable result especially in fig.5 is V50 characteristics that was followed whether to mix CO2 gas (i.e. 2-kind and 3-kind gas mixture) in the case of mixing SAF6 gas almost the same ratio. Glancing at the result in figure at first, distinguished difference between 2-kind and 3-kind gas mixture is hard to find, but looking at it in detail, V50 in 3-kind gas mixture is higher approx. 5% than 2-kind gas mixture in every pressure range excluding pressure condition of 0.1MPa.

3.2 Insulation characteristics of SF6 gas under non-uniform field

Gas pressure dependence of V50 in applying positive polarity and negative polarity lightning impulse voltage for pure SF6 gas under non-uniform field using needle-to-plane electrode was shown in fig.6.

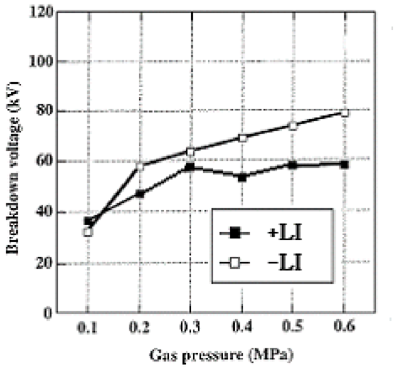


Fig. 6 Lightning impulse breakdown characteristic of SF6 gas as a function of gas pressure under non-uniform field.

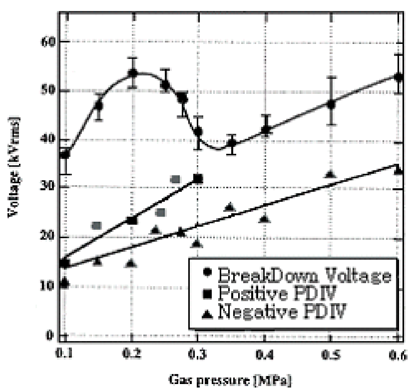


Fig. 7 AC BDV and PDIV characteristics of SF6 gas as a function of gas pressure under non-uniform field.

In this result, 50% breakdown probability voltage V50 in both polarities was shown almost same value in the case of 0.1Mpa of gas pressure. However, following the gas pressure, it was monotonously increased in negative polarity, but it was saturated in positive polarity at gas pressure of over 0.3Mpa.

Meanwhile, gas pressure dependence of AC insulation breakdown voltage (BDV) and partial discharge initial voltage (PDIV) of pure SF6 gas under non-uniform field was shown in fig.7. As shown in fig.7, maximum value is indicated in characteristics of gas dependence of insulation breakdown voltage in SF6 gas, and if gas pressure is more increased, insulation breakdown voltage once lowered and then it rises again. Such phenomenon is known as N-characteristics in general, and it is called corona stabilization that is occurred relaxing the field of needle polarity end by space load which was made per electrical discharge. So, if partial discharge was occurred in the low range of gas pressure, insulation breakdown voltage is increased by relaxing the field from this corona stabilization, however, if bigger partial discharge in high range of gas pressure, insulation breakdown is occurred. So, insulation breakdown voltage and positive polarity partial discharge initial voltage are met together in high gas pressure as shown in figure.

In the experiment result, as shown in fig.6, N-characteristics such as in AC insulation characteristics was not indicated in the insulation breakdown characteristics of net SF6 gas in applying lightning impulse voltage; it is considered that the above corona stabilization is weak in the case of applying lightning impulse voltage. Comparing fig.6 with fig.7, positive polarity partial discharge initial voltage and insulation breakdown voltage in applying AC voltage met together, so positive polarity V50 of lightning impulse voltage is higher than AC insulation breakdown voltage in the area where to approach direct insulation breakdown simultaneously in the occurrence of partial discharge. Generally, comparing impulse voltage with AC breakdown voltage, the former is higher than the latter in V-t surface characteristics. Hence, in the case of pure SF6 gas, it is considered the reason why positive polarity impulse breakdown V50 is higher than AC insulation breakdown voltage in high gas pressure area is for being caused by V-t characteristics.

4 Conclusion

In this research, I investigated breakdown characteristics of impulse voltage in uniform field to be basic for GIS design with 2-kind gas mixture of 50%SAF6/N2 and 3-kind gas mixture of 50%SF6/49%N2/1%CO2 for the purpose of developing new insulation medium to alternate SF6 gas which is regulated against exhaustion by

designating the gas occurring to greenhouse warming, and reviewed it in comparison with insulation breakdown characteristics of pure SF6 gas.
In addition, I investigated insulation breakdown characteristics of impulse voltage of pure SF6 gas in non-uniform field also, and compared it with AC breakdown characteristics. Hence, the following result was gotten.

(1) Impulse insulation breakdown characteristics for all 3-kind testing gases under uniform field and non-uniform field condition is in accordance with Weibul probability distribution.
(2) In applying lightning impulse voltage, V50 of 3-kind gas mixture under uniform field was approx. 5% higher than 2-kind gas mixture in every pressure range excluding pressure condition of 0.1MPa. However, it showed approx. 10 to 15 % lower value in every pressure range in comparison with pure SF6 gas.
(3) Synergism impact of insulation breakdown voltage of 3-kind gas mixture of 50%SF6/49%N2/1%CO2, which was known to be shown in no relation to uniform field in applying lightning impulse voltage and in the condition of non-uniform field in applying AC voltage, was not shown.
(4) Breakdown voltage of pure SF6 gas under non-uniform field in applying lightning impulse voltage was monotonously increase following the increase of gas pressure in the case of negative polarity, while it was saturated in the pressure range of over 0.3MPa in the case of positive polarity.

Acknowledgment

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