Paper

Interrupting Phenomena of N_2-SF_6 Gas Mixture; Capacitive Current Switching

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We have studied interrupting phenomena with alternative gasses to SF_6, especially N_2-SF_6 gas mixture. This paper describes capacitive current switching phenomena and performance of the gas mixture. Capacitive current switching tests were performed with N_2-SF_6 gas mixture, N_2 and SF_6 in a 300kV class gas circuit breaker. Dielectric recovery characteristics have been calculated by combining breakdown field strength data with gas flow calculations and electric field calculations. Comparing both results, the influence of dielectric synergism and gas flow of the gas mixture on the performance is discussed. As a result it is found that capacitive current switching performance of N_2(85%)-SF_6(15%) gas mixture is almost 80% of that of pure SF_6. Consequently it will be possible to realize full performance with gas mixture by improvement of GCB design.

Keywords: gas circuit breaker, capacitive current switching, gas mixture

1. INTRODUCTION

Sulfur hexafluoride (SF_6), the superior insulating and interruption gas for high voltage gas insulated switchgear (GIS) and gas circuit breaker (GCB), has been regarded as a greenhouse gas. Recently it is the subject of political discussions to reduce SF_6 gas concentration increasing in the atmosphere. Utilities and manufactures have already started reducing leaks and losses and recycling the gas [1]. In addition, many researchers are studying alternative gases from the point of view of replacing all or part of SF6 gas in the GIS and GCB. However the most of work are concerned with static dielectric properties [2,3]. Some data had been established in 1980s [4,5] and a few data in 1990s [6] on interrupting phenomena. Recently, we have studied interrupting phenomena with alternative gases to SF_6, especially N_2-SF_6 gas mixture. Thermal interruption, dielectric interruption and capacitive current switching must be clarified for design of GCB at least. In this paper, capacitive current switching phenomena are described. We combined electric field calculations, gas flow calculations with the dielectric breakdown data and performed capacitive current switching test with some kinds of gasses in a high voltage GCB. In this work, the influence of dielectric synergism and gas flow on the performance of the gas mixture is emphasized.

2. CALCULATION METHOD

Dielectric recovery characteristics under capacitive current switching conditions were calculated by combining breakdown field strength data with dynamical gas flow calculations and electric field calculations.

In capacitive current switching, an electric field distribution between arcing contacts is approximated by a uniform field except considerably shorter gaps. The breakdown field strength data in uniform field have been reported by many groups. The values of 50% breakdown electric field as a function of gas pressure for N_2(85%)-SF_6(15%) gas mixture (see figure 1) are obtained on referring to Qiu's calculation [7].

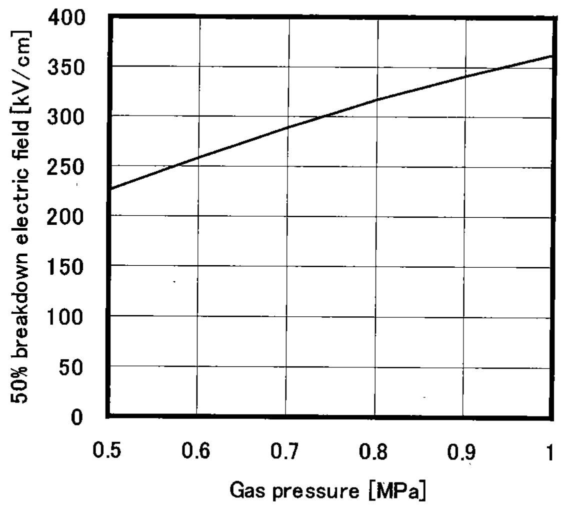


Fig.1 Calculated 50% breakdown electric field (N2(85%)-SF6(15%))
(uniform field under AC voltage)

The breakdown electric field depends on a gas temperature and pressure. The pressure on the surface of arcing contact and nozzle will not equal to the filling pressure of a GCB tank on an interrupting process. We obtained variation of the pressure distribution with time by the gas flow calculation. The breakdown electric field strength must be obtained taking into account of the deviation from the filling pressure.

Figure 2 shows a geometry of a 300kV GCB interrupting chamber for the gas flow calculations. In the geometry, the total travel was divided into forty steps and each step was calculated one by one in series. Influence of an arc existence on the gas flow field can be neglected because of small arc energy. The dynamic calculations were performed with FLIC program, the Euler equation solver [8].

Finally, static electric field distribution in the gap for each step was calculated with HSSSM program, High Speed Surface charge Simulation Method. The dielectric recovery characteristics were obtained comparing the breakdown field strength with the pressure deviation and the electric field distribution and taking into account of the opening velocity.

3 INTERRUPTING TEST

Capacitive current switching tests were performed for various gasses. Testing conditions and filling gas conditions are shown in table 1 and 2 respectively. In these test series, applied recovery voltage was increased by step and two or three shots were tested for each voltage.

Table 1. Testing conditions

Rating voltage	300kV
Recovery voltage (peak value)	1.6~3.2PU (50Hz) (negative)
Interrupting current	200A
Arcing time	nearly 1ms
Opening velocity (average)	1.0PU

Table 2. Filing gas conditions

	Gas	Pressure(abs)
(1)	SF_6	0.35MPa
(2)	N_2(85%)-SF_6(15%)	0.6MPa
(3)	N_2	0.75MPa
(4)	N_2	0.6MPa

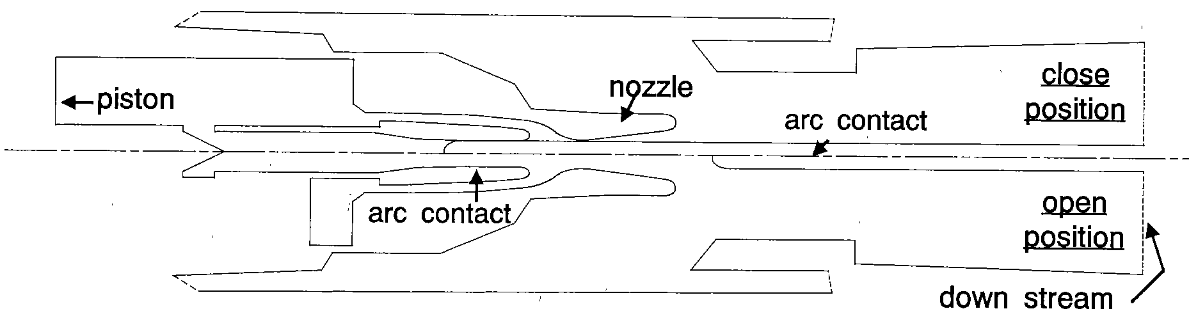


Fig.2 Geometry for gas flow calculation

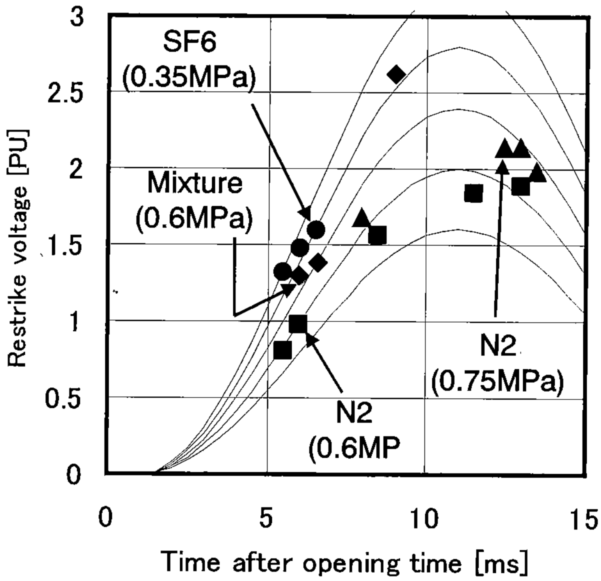


Fig.3 Restrike voltage and recovery volt age

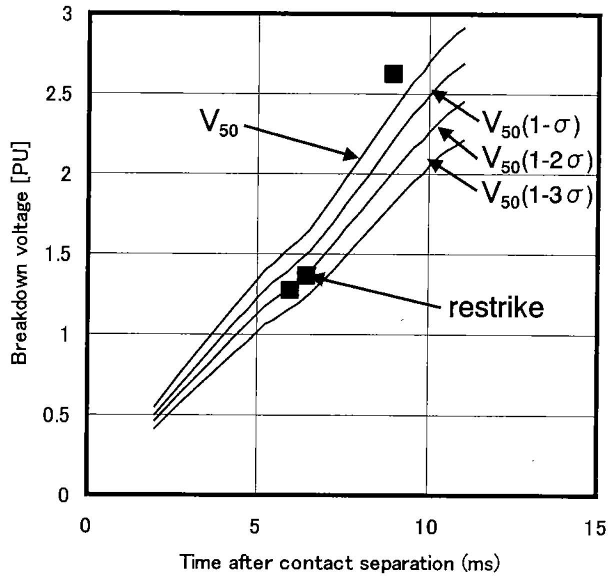


Fig.4 Dielectric recovery characteristics and restrike voltage

(N2(85%)-SF6(15%))

4 RESULTS

Firstly restrike characteristics are presented for the several gasses in the capacitive current switching tests in figure 3. The typical restrikes points are indicated but these are for several recovery voltage waves. Here, typical recovery voltage waves are also shown for 1.6, 2.0, 2.4, 2.8 and 3.2PU (peak value) with arcing time of 1ms. We searched for a maximum recovery voltage without restrikes in the capacitive current switching tests with each gas. The voltage values, summarized in table 3, are regarded as criteria of interrupting capabilities for capacitive current switching with the interrupting chamber. The capacitive current switching capability of N_2(85%)-SF_6(15%) gas mixture 0.6MPa is comparable to that of pure SF_6 0.35MPa and almost 80% of that of SF_6 0.6MPa in table 3.

Table 3. Interruption capability for capacitive current switching

Gas	Maximum recovery voltage without restrikes (peak value)
SF_6(0.6MPa)	2.90PU (100%)
SF_6(0.35MPa)	2.38PU (82%)
N_2(85%)-SF_6(15%)(0.6MPa)	2.34PU (81%)
N_2(0.75MPa)	1.96PU (68%)
N_2(0.6MPa)	1.78PU (61%)

The typical restrikes voltages in the tests are compared with the dielectric recovery characteristics of calculation results for gas mixture in figure 4. The average breakdown voltage curve V_{50} and deduced curves, $V_{50}(1-\sigma)$, $V_{50}(1-2\sigma)$and $V_{50}(1-3\sigma)$ are shown as the dielectric recovery characteristics. The σ denotes statistical standard deviation and is assumed to be 8% based on our insulation testing under uniform field with the gas mixture. The lowest restrike points are located on the -2σ curve in figure 4. That shows that the calculation method for the dielectric recovery characteristics of the gas mixture is appropriate practically.

5. DISCUSSION

5.1. Dielectric synergism of gas mixture

The interrupting capability (peak value of maximum recovery voltage without restrikes) at gas pressure of 0.6MPa is shown in figure 5 as a function of SF6 content. The following experimental formula was derived from these values.

$$\Delta U_{\max} = 2.9X_{SF6}^{0.35} + 1.8\left(1 - X_{SF6}^{0.35}\right) \text{ [PU]} \quad (1)$$

where $\Delta U_{\max}$ and X_{SF6} are the maximum recovery voltage (peak value) and SF_6 content

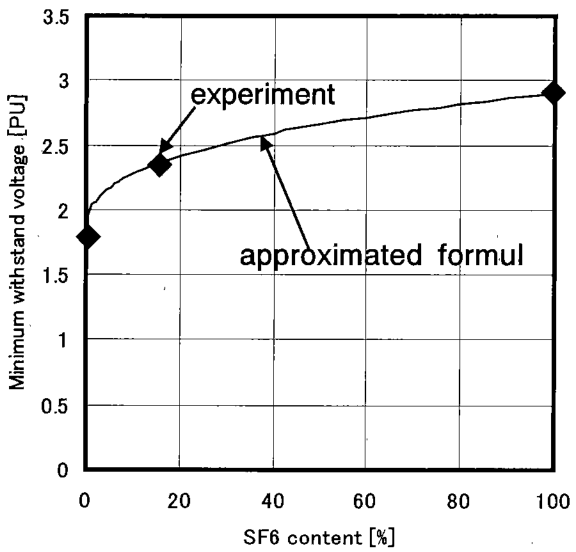


Fig.5 Interrupting capability and SF6 content in capacitive current switching

respectively. A power number of 0.35 indicates strength of dielectric synergism for gas mixture in the expression (1). We defined this number as a synergism factor. In the reference[7], Qiu proposed that relative insulation strength was proportional to $X_{SF6}^{0.18}$ for N_2-SF_6 gas mixture under uniform field. The power number of 0.18 corresponds to our synergism factor. Table 4 shows comparison of the synergism factors.

The factor of capacitive current switching is larger than the static dielectric factor in table 4. This fact indicates the synergism of capacitive current switching is weaker than that of the static insulation property in the N_2-SF_6 mixtures. The synergism for capacitive current switching depends on not only the static dielectric strength but also gas flow field. Disturbance in gas flow field is expected to weaken the synergism for capacitive current switching.

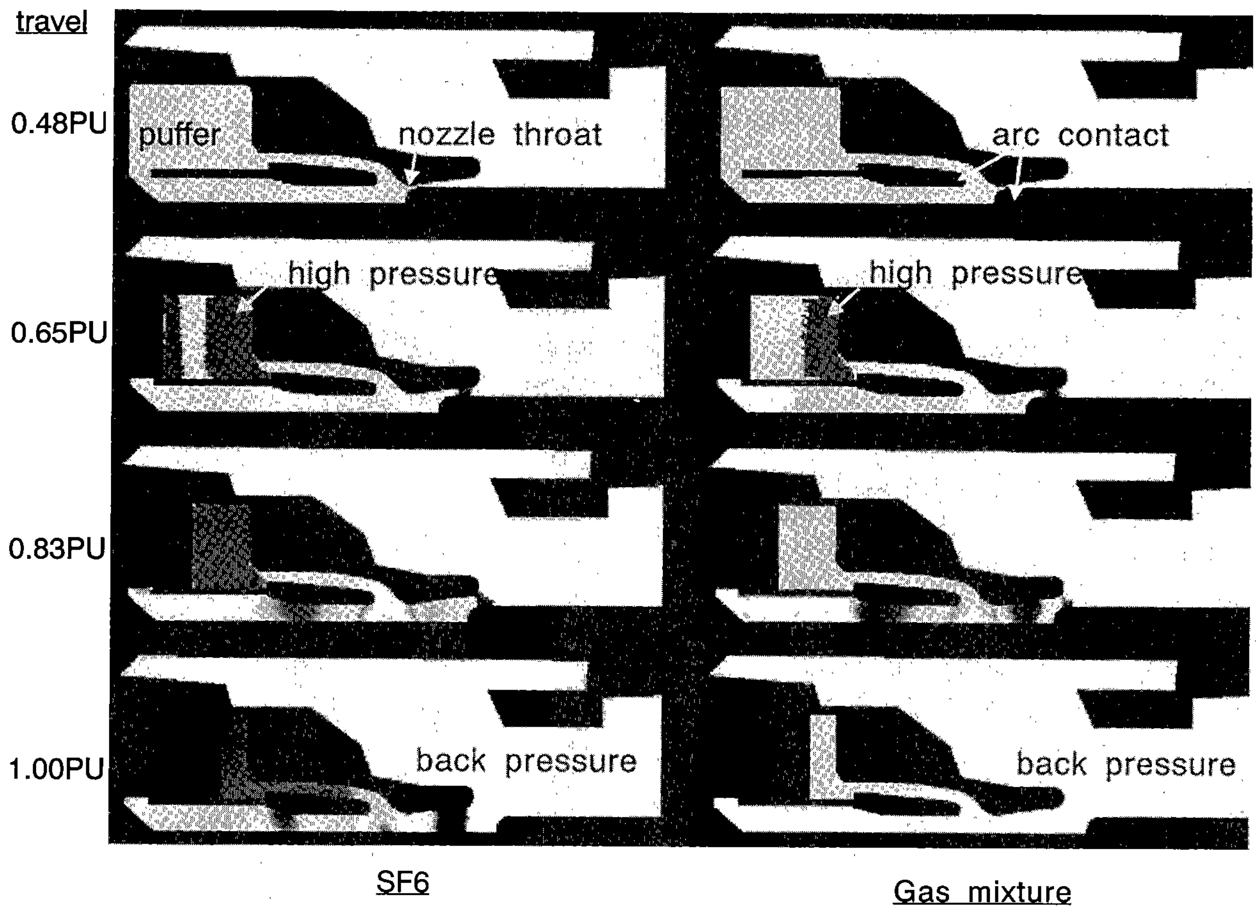


Fig.6 Variation of pressure distribution with time in interrupting chamber under capacitive switching condition

Table 4. Comparison of synergism factors

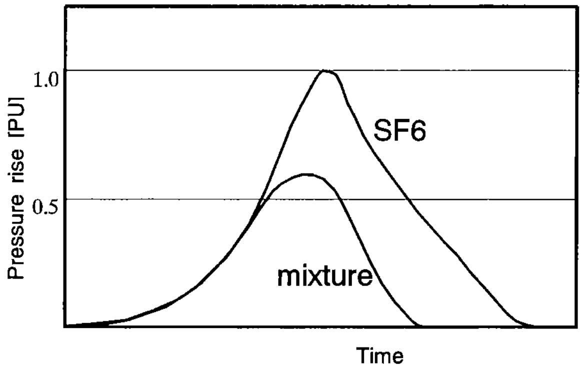
Static insulation strength under uniform field	0.18 (Qiu [7])
Capacitive current switching	0.35 (our result)

5.2. Influence of gas flow field

Small capacitive switching capability is somewhat lower than expected value based on static insulation property for any gasses. This decrease is mainly caused by "negatice effect" of dielectric electrification and gas flow field. However the effect of the dielectric electrification will be negligible in these test series because polarity of applied voltage was fixed negative. On the other hand, super-sonic gas flow and discontinuous field due to shockwave possibly cause drop in the pressure and density field.

The gas flow calculations were performed for SF_6 and N_2(85%)-SF_6(15%) gas mixture. The variations the pressure distribution with time in capacitive current switching are shown in figure 6. The pressure distribution of SF_6 and the gas mixture are identical while an arcing contact is inside a nozzle throat in the initial stage of opening motion (see travel of 0.48PU in figure 6). After the separation of the contact and the nozzle throat, pressure rise inside the puffer cylinder of the mixture more rapidly decreases than SF_6 because of smaller molecule mass and faster flow velocity. Comparison of the pressure rise characteristics of the mixture and SF_6 is verified in figure 7. Mach number of SF_6 is larger than the mixture near the nozzle throat area since the peak of the pressure rise is higher and pressure and density drop is larger. Thus, the "negatice effect" due to gas flow for SF_6 is somewhat stronger than the mixture. In addition, the "negative effect" increased gradually as SF6 content increases. However, it is necessary to note that "dominant effect" is insulation property of gas itself in capacitive switching capability.

In conclusion, the "negative effect" can bring the somewhat weakened synergism for SF_6 mixture.



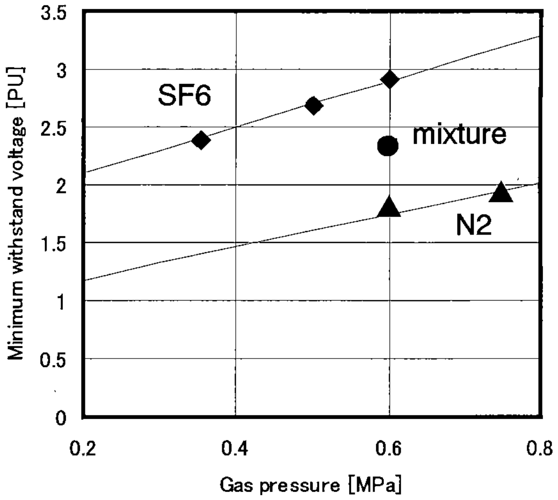


Fig.8 Interrupting capability and filling gas pressure in capacitive current switching

5.3. Opening velocity and filling pressure

The capability of N_2(85%)-SF_6(15%) gas mixture in capacitive current switching is almost 80% of that of SF_6. It is not impossible to realize the full performance for 300kV capacitive current switching with the gas mixture with the help of faster opening velocity and/or higher filling pressure. The maximum recovery voltages without restrikes are shown for SF_6, the gas mixture and N_2 in figure 8. The necessary opening velocity and filling pressure are summarized in table 5. For example, the increase of 12% in the velocity and 25% in the pressure are expected to enable the gas mixture to interrupt full duty in table 5. And besides, it is possible to improve electric field distribution between arcing contacts to reduce rising cost due to the increase of velocity and pressure.

Table 5. Necessary opening velocity and filling pressure for full performance

gas	Opening velocity (average)	Filling pressure (abs)
SF_6	1.0PU	0.6MPa
N_2(85%)-SF_6(15%)	1.0PU	0.9MPa
	1.12PU	0.75MPa
	1.24PU	0.6MPa

6. CONCLUSIONS

-Capacitive current switching tests were performed with N_2-SF_6 gas mixture, N_2 and SF_6 in a 300kV class gas circuit breaker.

-The dielectric recovery characteristics were obtained by combining the breakdown field strength data with dynamic gas flow calculations and electric field calculations.

-Capacitive current switching performance of N_2(85%)-SF_6(15%) gas mixture is almost 80% of that of pure SF_6.

-Influence of stronger super-sonic flow is somewhat negative to capacitive current switching capability of SF_6 gas mixtures and could bring the weakened synergism of SF_6 mixture.

-The results show the possibility to get over full duty with the gas mixture by the increase of 12% in the velocity and 25% in the filling pressure.

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