Study of the Feasibility of CF_3I/CO_2 Substituting SF_6 in GIS by Partial Discharge Experiment

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SF_6 has a high greenhouse effect, a high sensitivity to non-uniform electric fields and has a highly toxic decomposition. Without these weaknesses, CF_3I gas has good insulation properties and may replace SF_6 in GIS. In this study, the partial discharge inception voltage (PDIV) of CF_3I/CO_2 is measured under different gas pressures, mixing ratios (*k*), and gap distances. The results show that the PDIV of CF_3I/CO_2 is approximately 1 to 1.2 times that of SF_6/CO_2 at different *k* (10-30%) between 0.1-0.3 MPa. The PDIV of these two mixed gases exhibit similar variation trend with gas pressure when the mixing ratio is more than 20%. There is positive synergistic effect on the PDIV of CF_3I and CO_2, especially at *k* (20-30%). The analysis result indicates that CF_3I/CO_2 (20-30%) may be used to replace SF_6 gas in GIS.

1. Introduction

SF_6 has a good property of insulation and arc resistance which has been widely used as the most mature and reliable gas in gas insulated switchgear (GIS) [1]. In use, however, pure SF_6 has limitations which are difficult to remedy in use. [2]. Pure SF_6 gas is very sensitive to non-uniform electric fields and requires high-quality equipment. SF_6 gas discharge decomposition products contain many highly toxic substances which can severely corrode organic insulating medium and metal materials and even significantly harm human health [3]. Furthermore, SF_6 gas is a kind of powerful greenhouse gas. Recent studies are currently looking for an environmentally friendly gas that can substitute SF_6 as a new medium in electrical equipment [4].

CF_3I is a kind of colorless, odorless, nontoxic, and non-flammable gas that has a very short lifetime in the atmosphere (only 0.005 yea)r. Its GWP is less than 5. Its ozone depleting potential is close to zero [5]. However, the boiling temperature of CF_3I is high, so it must be mixed with buffer gases. The pressure of SF_6 used in electrical equipment is universally 0.5 MPa. When the proportion of CF_3I in mixture is 30% and the whole mixture bears 0.5 MPa gas pressure, CF_3I only bears 0.15 MPa gas pressure. The boiling temperature of CF_3I is approximately –12.5 °C in 0.15 MPa [6], which can be used in most electrical equipment at this boiling temperature. Several studies have investigated the interrupter performance and insulating properties of the gas mixture of CF_3I [5-7]. Many of them have shown that the buffer gas CO_2 can reduce the boiling temperature and improve the discharge characteristics and dielectric strength of CF_3I. Most accidents occurring in electrical equipment are due to insulation faults. These faults generally associate with partial discharge (PD). And PD can aggravate those insulation faults. Therefore, a study of the PD property of CF_3I gas mixture under the common defects of electrical equipment will have great practical significance.

Discharge physical model of metallic protrusion is one of the most common deficiencies in gas insulated electrical equipment. In his study , electric fields with different uniformities are created by needle-plate electrodes with gap distances of 5, 10, and 15 mm in this study. The influences of the mixing ratio *k* (the percentage of CF_3I or SF_6 content in mixed gas), pressure, and gap distance on the PDIV were discussed and the experimental results were compared with SF_6/CO_2.

2. Experimental methods

Figure 1 shows the laboratory PD measurement circuit for this study. The pulse current method in this experiment was based on the IEC60270 standard.

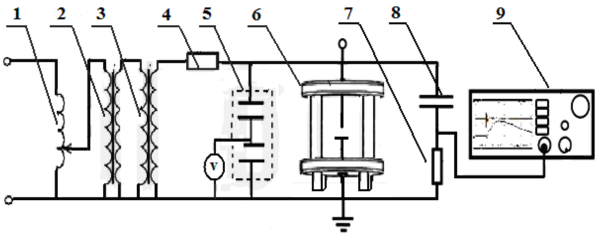

Fig.1. Experiment circuit.

We simulated the electric field of needle-plate electrodes shown in figure 2 and its intensity. Moreover, the figure shows that the area having the strongest electric field in metallic protrusion is in needle-plate gap where the PD is most likely to occur.

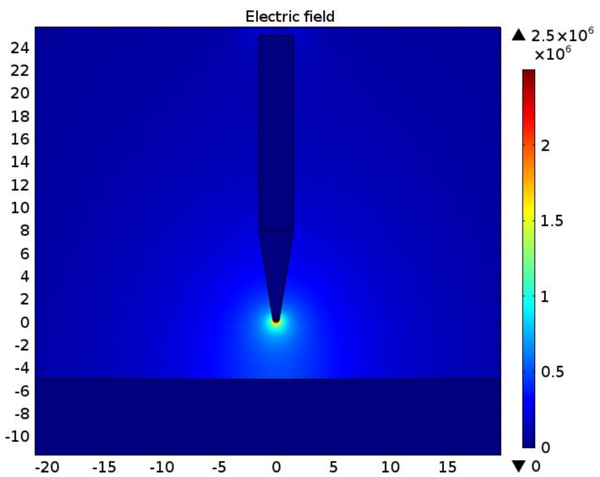

Fig.2. The electric field intensity.

CF_3I/CO_2 and SF_6/CO_2 were used in the experiment. *k* were 0, 10, 20, 25, 30 and 100% and the gas pressures of the mixed gases were 0.1, 0.15, 0.2, 0.25 and 0.3 MPa. The gap distances were 5, 10 and 15 mm.

3. Results and analysis

Figure 3 shows the plots of power frequency PDIV with the changes in gas pressure when *k* of CF_3I/CO_2 and SF_6/CO_2 are 10, 20, 25 and 30% and the gap distance is 5 mm. The ratios of PDIV of the two types of mixed gases with different *k* under different gas pressures are presented in Table 1.

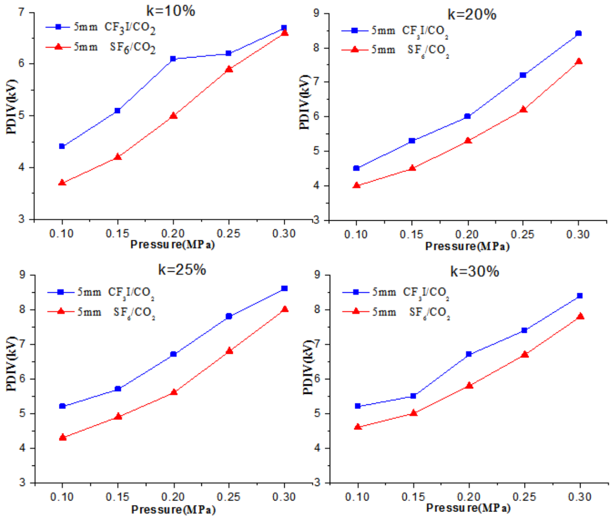

Fig.3. The changes of PDIV of CF_3I-CO_2 and SF_6-CO_2 (5 mm).

Tab.1. PDIV of CF_3I-CO_2/ PDIV of SF_6-CO_2.

Pressure (MPa) / *k*	0.1	0.15	0.2	0.25	0.3
10%	1.19	1.21	1.22	1.05	1.02
20%	1.13	1.18	1.13	1.16	1.11
25%	1.21	1.16	1.20	1.15	1.08
30%	1.13	1.10	1.16	1.10	1.08

Table 1 shows that the PDIV of CF_3I/CO_2 is approximately 1.2 times that of SF_6/CO_2 under low *k* of 10-25% in low gas pressure of 0.1-0.2 MPa, where CF_3I bears a gas pressure between 0.01-0.05 MPa. The ratio slightly declines with the increase of gas pressure and *k*. Generally, the PDIV of CF_3I/CO_2 is approximately 1 to 1.2 times that of SF_6/CO_2 at different *k* under the same conditions.

The PDIV of CF_3I/CO_2 and SF_6/CO_2 linearly increases with the increase of gas pressure under a certain *k* and gap distance, indicating that the relationship between PDIV V_{PD} (kV) and gas pressure *P* (MPa) can linearly fit. Figure 4 shows that the slope rates of PDIV fitting lines of these two mixed gases are approximately equal to the gap distances of 5 mm. Only with low *k* (10%), SF_6/CO_2 is affected by barometric change more obviously than CF_3I/CO_2. The measurement results with gap distance of 5, 10 and 15 mm are shown in Table 2.

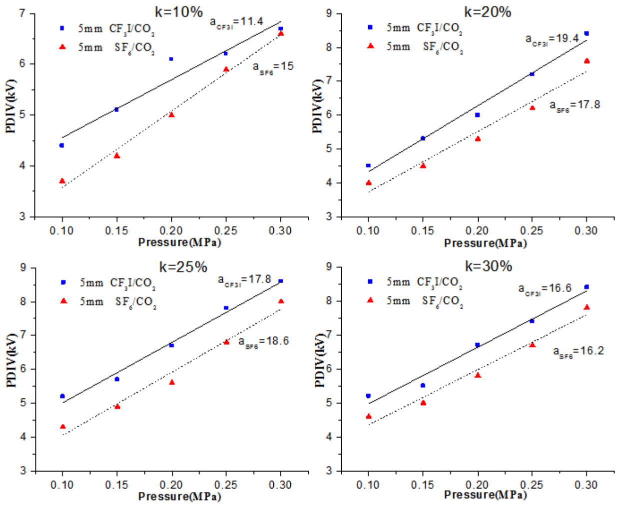

Fig. 4. The linear fitting of the changes of PDIV of CF_3I/CO_2 and SF_6/CO_2 (5 mm).

Tab. 2. The rate of PDIV of CF_3I-CO_2/ The rate of PDIV of SF_6-CO_2.

Gap Distance (mm) / ***k***	**5**	**10**	**15**
10%	0.76	0.67	0.68
20%	1.09	1.23	1.10
25%	0.96	1.05	1.08
30%	1.02	1.13	1.17

Table 2 shows that the change rate ratio slightly fluctuates with the increase of gap distance at the same *k*, which remains at about 1 with the increase of *k*. The two PDIV curves of the mixed gases that vary with the change in gas pressure show a rather similar trend.

The results indicate that the PDIV of CF_3I/CO_2 is higher than that of SF_6/CO_2 when *k* is 10-30% at 0.1-0.3 MPa. The insulation performance of CF_3I/CO_2 in these conditions is close to or even better than that of SF_6/CO_2.

When electronegative gas mixes with additive gases (N_2, CO_2, air etc.), the insulation performance of the mixed gas usually changes with the synergistic effect [8]. The synergistic effect can be calculated using equation (1) as follows:

$$V_m = V_2 + \frac{k(V_1 - V_2)}{k + (1-k)C} \quad V_1 > V_2 \quad (1)$$

Equation (1) describes the synergistic effect of mixed gases, where V_1 and V_2 represent the PDIV of pure gas. V_m is the PDIV of the mixed gas, *k* is the mixing ratio, and *C* is a constant. The value of *C* indicates the nonlinearity of the increase and also the result of the synergistic effect: Smaller *C* indicates greater nonlinearity and more obvious synergistic effect.

The synergistic effect value (*C*) of different ratio mixtures (CF_3I/CO_2) under different pressures are presented in Table 3, which is between 0.24 and 0.7. *C* decreases with the rise of the gas pressure, indicating that the synergistic effect of the CF_3I/CO_2 is obvious when pressure increases. According to equation (1), the more obvious synergistic effect is, the higher the PDIV of mixed gas is. This indicates that the smaller *C* is, the higher the PDIV of CF_3I/CO_2 is. Due of this, the property of CF_3I/CO_2 (20-30%) about synergistic effect is much better than CF_3I/CO_2 with low *k*.

Tab. 3. Synergistic effect of CF_3I and CO_2 in 10 mm gap.

Pressure (MPa)	*k* (%)			
	10	**20**	**25**	**30**
0.1	0.58	0.70	0.62	0.68
0.15	0.45	0.64	0.67	0.65
0.2	0.42	0.60	0.65	0.62
0.25	0.24	0.58	0.57	0.54
0.3	0.25	0.56	0.35	0.38

4. Conclusions

The PDIV of the CF_3I/CO_2 is approximately 1-1.2 times that of SF_6/CO_2 when *k* is high. However, the changes of PDIV of the two mixed gases with gas pressure are almost the same, which is suitable for different gap distances. The physicochemical features of CF_3I are improved because of the synergistic effect between CF_3I and CO_2. Its insulation performance is close or superior to that of the SF_6/CO_2 when *k* is between 20-30%, therefore meeting the requirements of boiling temperature and insulation performance.

5. References

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