CIGRE PARIS 2022

Study Committee D1

Materials and Emerging Test Techniques

Paper D1-PS2-10279

Research of Environmentally Friendly Insulating Gas CF3I for Its Application in Electric Power Apparatus

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Motivation

SF6 is widely used as insulation medium in electrical equipment. However, SF6 has strong greenhouse effect and many countries has set limitations to the use of SF6. Trifluoroiodomethane (CF3I) has been proposed as a potential replacement for SF6. It is nonflammable, colorless, and odorless. The global warming potential of CF3I is less than 5 and its atmospheric lifetime is estimated to be less than 2 days. However, in spite of its environmental advantages, CF3I has high boiling point and not suitable to be directly used in power equipment. The application of CF3I for insulation medium inevitably needs it to be mixed with some natural gases such as N2, CO2 and air.

In this paper, the insulation performance of CF3I-N2 mixture under different electric conditions was studied. The mixing ratio of CF3I is 5%-30% and the tests were conducted under quasi-uniform and non-uniform electric field. The breakdown voltage under AC source and lightning impulse was analyzed and compared with SF6 gas. All the tests were carried out in a self-designed experimental chamber, although it is far away from real electrical equipment, the test data may provide some useful information for electrical equipment designers.

Experimental setup

The test chamber is a magnesium-aluminium alloy vessel with an inner diameter of 600mm and a height of 760mm. Before test, the inside of the chamber and electrodes will be cleaned thoroughly by alcohol. A vacuum pump was used to vacuum the chamber before gas filling. CF3I gas was first filled into the chamber and then N2. Each AC breakdown test was repeated for at least five times and the average breakdown voltage was taken as the recording data. In the impulse test, up and down method was used to obtain the 50% breakdown voltage and the effective data of each test is more than 30. There was an interval of 5 minutes after each breakdown to eliminate the influence of the previous breakdown on the test results.

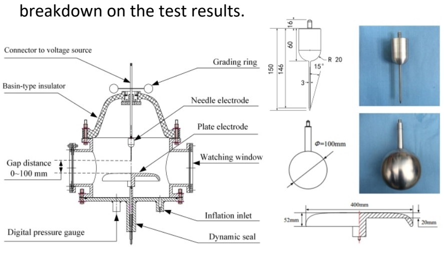


Figure 1. Structure of test chamber and electrodes

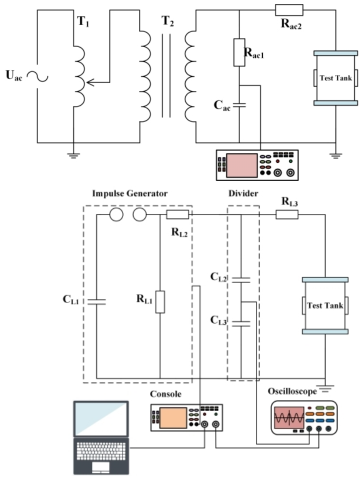
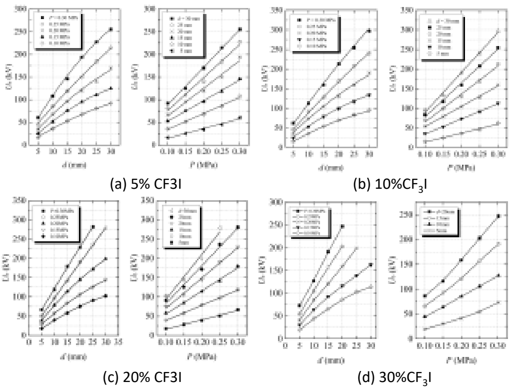


Figure 2. Schematic diagram of experimental circuit

Discussion

Insulation characteristics of CF3I-N2 under quasi-uniform electric fieldgive interpretation of results

The AC breakdown voltage (U_b) of CF3I-N2 mixed gas with CF3I ratio from 5% to 30% under quasi-uniform electric field is shown in Figure 3. It can be seen from the figure that the U_b of the mixed gas increases with the increase of gap distance and pressure. The AC breakdown voltage shows different degrees of saturation with the increase of gap distance, especially in 0.1~0.2MPa.



(a) 5% CF3I (b) 10%CF_3I

(c) 20% CF3I (d) 30%CF_3I

Figure 3. AC breakdown voltage of CF_3I-N_2 in the condition of quasi-uniform electric field at different gap distance *d* and gas pressure *P*

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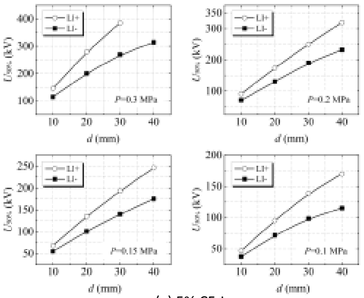
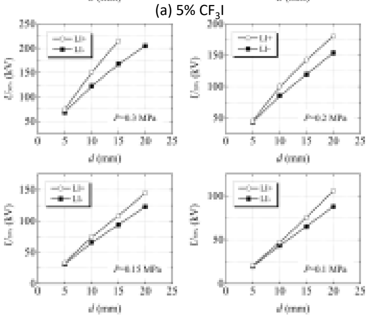
(continued)

Discussion

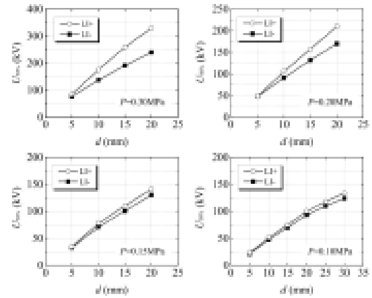
The 50% lightning impulse breakdown voltage ($U_{50\%}$) of the CF3I-N2 mixed gas increases with the gap distance and pressure. The $U_{50\%}$ under positive polarity is higher than that of the negative and the differences increases with the increase of the gap distance and pressure. Another notable feature is that the positive $U_{50\%}$ gradually becomes saturated with the increase of gap distance. Comparing the $U_{50\%}$ of mixed gas at different ratios, it can be seen that as the content of CF3I increases, the polarity effect of CF3I-N2 mixed gas becomes indistinctive.



(a) 5% CF_3I



(b) 20% CF3I

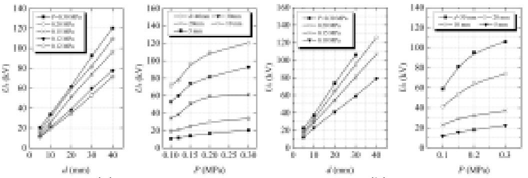


(c) 30% CF_3I

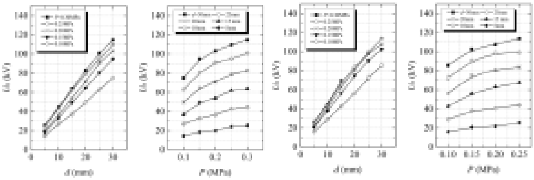
Figure 4. 50% impulse breakdown voltage of CF_3I-N_2 in the condition of quasi-uniform electric field at different gap distance *d* and gas pressure *P*

Insulation characteristics of CF3I-N2 under non-uniform electric field

The breakdown voltage of CF3I-N2 mixed gas in non-uniform electric field are shown in Figure 5. Although the breakdown voltage increase with the increase of pressure, the growth trend is non-linear. Taking a 20mm gap with 5% CF3I content as an example, when the pressure increases from 0.1 MPa to 0.2 MPa, the breakdown voltage increases 26.2kV. However, when the pressure continues increase to 0.3 MPa, the breakdown voltage shows saturation and only increases about 1.5kV compared with 0.2MPa.



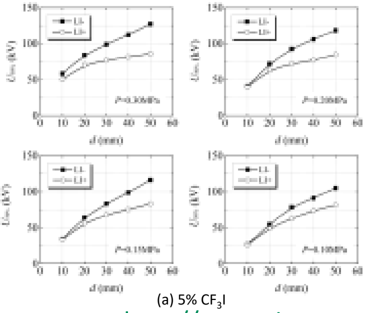
(a) 5% CF_3I (b) 10%CF_3I



(c) 20% CF_3I (d) 30%CF_3I

Figure 5. AC breakdown voltage of CF_3I-N_2 in the condition of non-uniform electric field at different gap distance *d* and gas pressure *P*

Figure 6 shows the impulse characteristic of CF_3I-N_2 mixed gas in non-uniform electric field. It can be seen from the figure that $U_{50\%}$ under negative polarity is higher than that under positive polarity, which is opposite to the situation in quasi-uniform electric field. When the gap distance is small, the difference between the two is minimal. As the gap distance increases, the differences between the two increases rapidly. It can be seen from the figure that $U_{50\%}$ does not increase linearly with the increase of the gap distance and saturation phenomenon appears.



(a) 5% CF_3I

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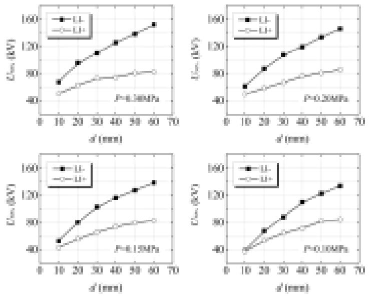
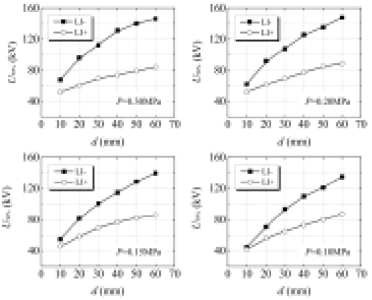


(b) 20% CF3I



(c) 30% CF_3I

Figure 6. $U_{50\%}$ of CF_3I-N_2 in the condition of non-uniform electric field at different gap distance d and gas pressure P

Compare tests with SF6 and N2 under quasi-uniform electric field

The insulation characteristics of SF6 was tested in the same experimental setup under quasi-homogeneous electric field, the comparison of the insulation strength of SF6 , 20%SF6-80%N2, 20%CF3I-80%N2, 30%CF3I-70%N2 and pure N2 under AC voltage is shown in Figure 7. It can be seen from the figure that the insulation strength of 20% CF3I-80% N2 mixture can reach 50% of that of pure SF6 in quasi-homogeneous electric field. When the mixing ratio of CF3I is increased to 30%, the insulation strength of CF3I can reach 55% of pure SF6 and 20%SF6-80%N2 respectively.

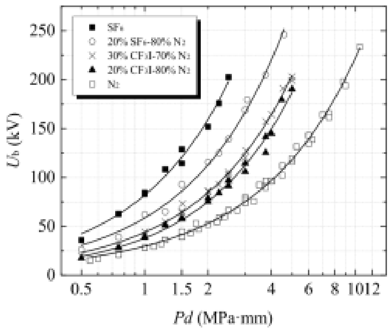


Figure 7. Comparisons of the insulation strength of CF_3I gas mixtures with SF_6 and SF_6-N_2 gas mixture in the condition of quasi-homogeneous field

Conclusion

Under quasi-uniform electric field, 20% and 30% content CF3I-N2 gas mixtures can achieve nearly 50% and 55% insulation strength of pure SF6, the AC breakdown voltage of CF3I-N2 mixed gas increases linearly with the increase of gas pressure and gap distance. Under non-uniform electric field, the AC breakdown voltage gradually saturates with the increase of pressure.

The 50% lightning impulse breakdown voltage of CF3I-N2 increases with the increase of the gap distance and pressure under quasi-uniform electric field, saturation occurs with the increase of gap distance. U50% under negative polarity is lower than that of the positive polarity and the impact coefficient β ≈ 1. Under non-uniform electric field, the saturation trend of U50% with the increase of gap distance is more significant and the increase in pressure will not improve the insulation performance as much as in the quasi-uniform electric field.