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Breakdown characteristics of SF_6/N_2 in severely non-uniform electric fields at low temperatures

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Abstract. SF_6 has good electrical insulating properties, which is widely used as an insulating medium of GIS, GIL and other electrical equipment. However, the reliability of electrical equipments´ insulated gas is greatly challenged in cold areas, since SF_6 more readily liquefies. To solve the problem, SF_6 can be mixed with N_2 to maintain the insulating properties, and reduce its liquefaction temperature. Such practice has certain application prospect. In this paper, a breakdown experimental platform was built to study the insulating property of SF_6/N_2 at low temperature, wherein the temperature of the platform can be adjusted. A severely non-uniform electric field was generated by a rod-plate electrode. The breakdown characteristics of SF_6/N_2 with different mixing proportions at low pressures and low temperatures were measured. The result showed that the mixed gas was not liquefied within the temperature range. Temperature had insignificant influence on the insulating property thereof. The result in the paper has certain guiding significance for applying SF_6/N_2 mixed gas in high latitude areas.

1. Introduction

SF_6, as an electronegative gas with good insulating properties, is widely applied in GIS (Gas Insulated Switchgear), GIL (Gas Insulated Line), etc. However, SF_6 still has some disadvantages during application though it is widely used in electrical equipment, such as high molecular mass, easy liquefaction and insulating properties degradation at high pressure and low temperature. Therefore, the properties of SF_6 are affected in high altitude and alpine areas. High operation and maintenance cost is required for gas insulating electrical equipment in cold areas. N_2 has advantages of easy acquisition, low cost and low liquefaction temperature. SF_6 can be mixed with certain N_2 to maintain the most of the insulating properties of SF_6. For example, 50/50 SF_6/N_2 mixed gas still can maintain about 89% insulating properties of pure SF_6. The liquefaction temperature of the mixed gas is much lower than that of pure SF_6. Siemens and other companies have applied SF_6/N_2 mixed gas in electrical equipment practically [1-2]. Therefore, SF_6/N_2 mixed gas can be used as an insulating medium of electrical equipment for adapting to long-term low temperature operation environment at high altitude areas. It is of important practical significance to study the insulating properties of SF_6/N_2 mixed gas at low temperature.

The research methods of mixed gas insulating properties are divided into experimental research and theoretical research. The experimental research is applied widely with relatively fixed methods. The non-uniform electric field [3] generated by asymmetry electrodes is usually used for simulating the discharge structure in practical application environment. Power supply excitation includes DC, power frequency AC [4], lightning impulse [5], pulse [6], etc. High atmospheric pressure is mainly applied.

The breakdown characteristics of insulating gas with different mixing proportions are studied under various discharge condition [7-8]. Theoretical research is rarely applied with diversified methods, such as artificial neural network computation, FEM-FCT method [9], Boltzmann method [10], Monte Carlo method [11], etc. Existing research content is mainly concentrated at room temperature though it is of very important practical and theoretical significance to study the insulating properties of SF_6/N_2 mixed gas under extremely cold and highly cold conditions at room temperature to -60 ^oC [12]. The research on the insulating properties at low temperature is rarely reported [13], and related research is not comprehensive.

In the paper, a low-temperature breakdown experimental platform was built to study the breakdown characteristics of SF_6/N_2 mixed gas at low temperature. The temperature can be adjusted between 0 and -15 ^oC. A severely non-uniform electric field was generated by a rod-plate electrode. The breakdown voltage of mixed gas with different mixing proportions between 15 and 60kPa was measured, thereby the influence of low temperature on breakdown characteristics of SF_6/N_2 mixed gas was analyzed.

2. Experiment design and method

A breakdown experimental platform was built as shown in figure 1. It was used for measuring the breakdown voltage of SF_6/N_2 mixed gas at different temperatures, pressures and mixing proportions. The experimental platform was composed of a breakdown chamber, a cooling system, a gas distributing system and a measuring system. The breakdown chamber was cooled by liquid nitrogen. The temperature scope between 0 and -15 ^oC was selected in the breakdown experiment.

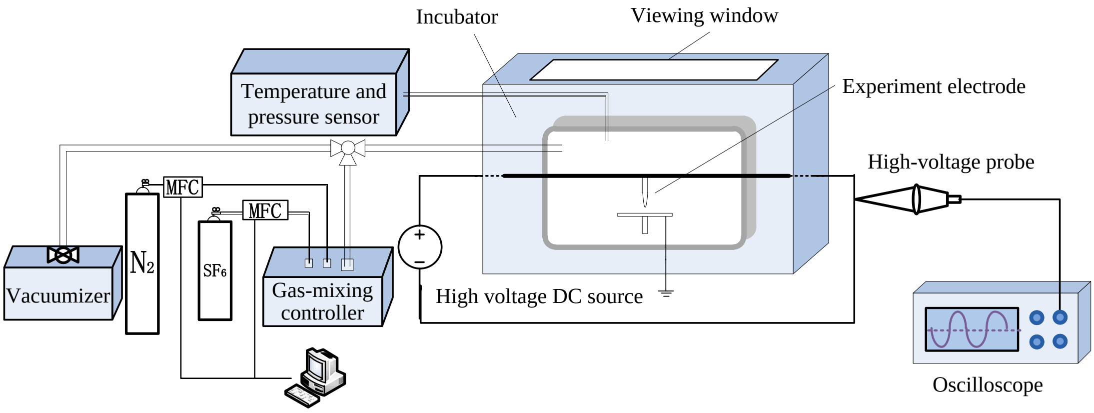
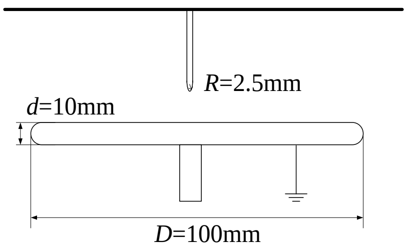
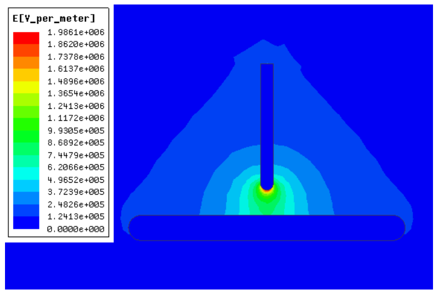


Figure 1. Diagram of devices for breakdown experiment.

Insulating gas discharge occurred between metal burr and metal plane usually in GIS. It belonged to point-to-plate discharge. To simulate the discharge condition, a rod-plate electrode was applied to generate the severely non-uniform electric field in the breakdown experiment. The electrode structure thereof was shown in figure 2(a). A copper electrode with tip radius of 2.5mm was applied as the rod electrode. A Rogowski electrode with radius of 100mm was selected as the plate electrode for eliminating the edge effect, wherein the electrode was made of copper. According to the definition of electric field non-uniformity, a severely non-uniform electric field was generated when the electric field non-uniform coefficient was greater than 4. The electric field non-uniform coefficient was 4.1265 when the electrode gap was set as 10 mm, and a severely non-uniform electric field was generated. The electric field distribution simulation results by Ansoft Maxwell thereof were shown in figure 2(b).



(a) Electrode structure diagram



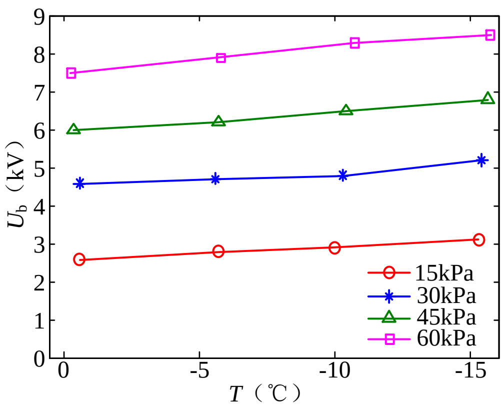
(b) Electric field distribution simulation diagram

Figure 2. Design of electrode for the experiment and electric field distribution simulation diagram.

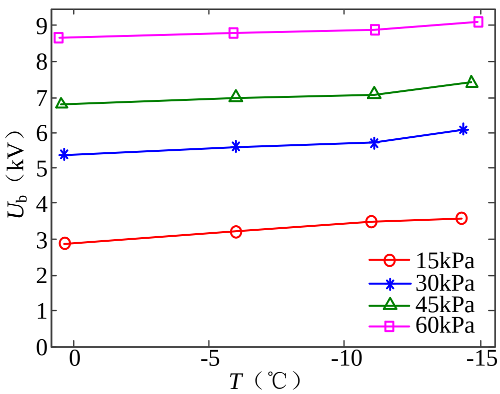
Negative DC high voltage excitation was used in the experiment. Voltage was applied on the discharge electrode from zero and increased slowly according to 'High Voltage Experimental Technique' [14]. The voltage was increased according to the rate of 2% per second after the applied voltage reached about 75% of the estimated withstanding voltage. A sampling resistance was utilized for sampling the discharge current in the experimental circuit. The resistance was connected with the oscilloscope through a current probe. Breakdown was defined when the current waveform was distorted seriously. Corresponding voltage was defined as breakdown voltage.

3. Experimental results and analysis

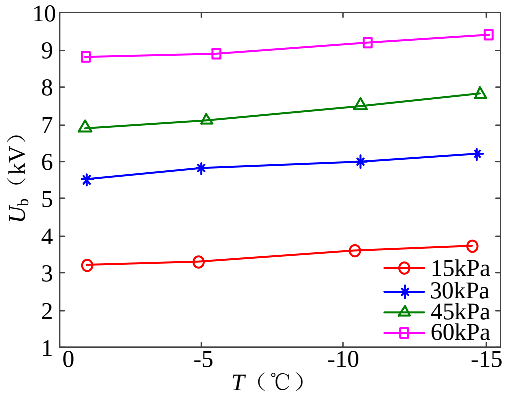
3.1. Breakdown voltage at low temperature



(a) SF_6/N_2:25/75



(b) SF_6/N_2:50/50



(c) SF_6/N_2:75/25

Figure 3. Breakdown voltage of SF_6/N_2 mixed gas in the severely non-uniform electric field.

Figure 3 indicated the measured breakdown voltages of SF_6/N_2 mixed gas under different conditions. The overall curve trend in the diagram showed that the breakdown voltage of mixed gas was changed slowly with temperature at different mixing proportions and pressures. The breakdown voltage was increased by about 0.75kV on average if the temperature was decreased by 15 ^{o}C. The breakdown voltage was increased slightly with temperature decrease because the mixed gas was not liquefied within the temperature scope. The influence of temperature on discharge was reflected in the microscopic process mainly, such as deceleration of particle Brownian motion [15], etc. However, the influence was very insignificant. Therefore, the breakdown voltage was not changed prominently with temperature decrease. In addition, relative distance among curves in the diagram indicated that the influence of gas pressure on the breakdown process was more significant than that of temperature in the scope.

It can be seen from figure 3 that the breakdown voltage of SF_6/N_2 mixed gas was linearly related with temperature and pressure. Therefore, corresponding linear fitting formula by polynomial fitting method and goodness of fit were obtained as shown in table 1. The goodness of fit of mixed gas breakdown voltage fitting formula was all above 0.98.

Table 1. Fitting formula of mixed gas breakdown voltage under severely non-uniform electric field.

Mixing proportion of mixed gas (SF_6/N_2)	Fitting formula	Goodness of fit
25/75	U_b=0.883+0.121p-0.048T	0.9869
50/50	U_b=1.474+0.122p-0.050T	0.9878
75/25	U_b=1.568+0.124p-0.051T	0.9879

[a] Wherein, U_b -- breakdown voltage of mixed gas, kV;
p-- pressure of mixed gas, kPa;
T -- temperature of mixed gas, ^{o}C.

The fitting formula in table 1 indicated that temperature coefficient was negative. The mixed gas breakdown voltage was increased with temperature decrease. The absolute values of the coefficient were 0.048, 0.050 and 0.051 respectively. It was obvious that when SF_6 content is increased, the temperature sensitivity was further enhanced slightly. However, the enhancement was insignificant. The pressure coefficient of the fitting formula was positive under three mixing proportions. The breakdown voltage of the mixed gas was increased with pressure increase. The value was 0.121, 0.122 and 0.124 respectively with little difference. The breakdown characteristics of mixed gas with three mixing proportions were affected by atmospheric pressure similarly.

3.2. Change law of SF_6/N_2 breakdown voltage with SF_6 content at low temperature

Figure 4 showed the change curve of SF_6/N_2 mixed gas breakdown voltage with SF_6 percentage content at different temperatures and different pressures in the severely non-uniform electric field. The sub-graphs in the diagram indicated that the breakdown voltage was linearly increased at the beginning with the increase of SF_6 percentage content in the mixed gas. The voltage tended to be saturated gradually after SF_6 was increased to certain percentage content. However, the saturation process lasted for relatively long time. The breakdown voltage of mixed gas containing 40% SF_6 was equal to about 80% voltage of mixed gas containing 75% SF_6. The curve increase trend was relatively similar. The change law of breakdown voltage with SF_6 percentage content was affected by temperature insignificantly.

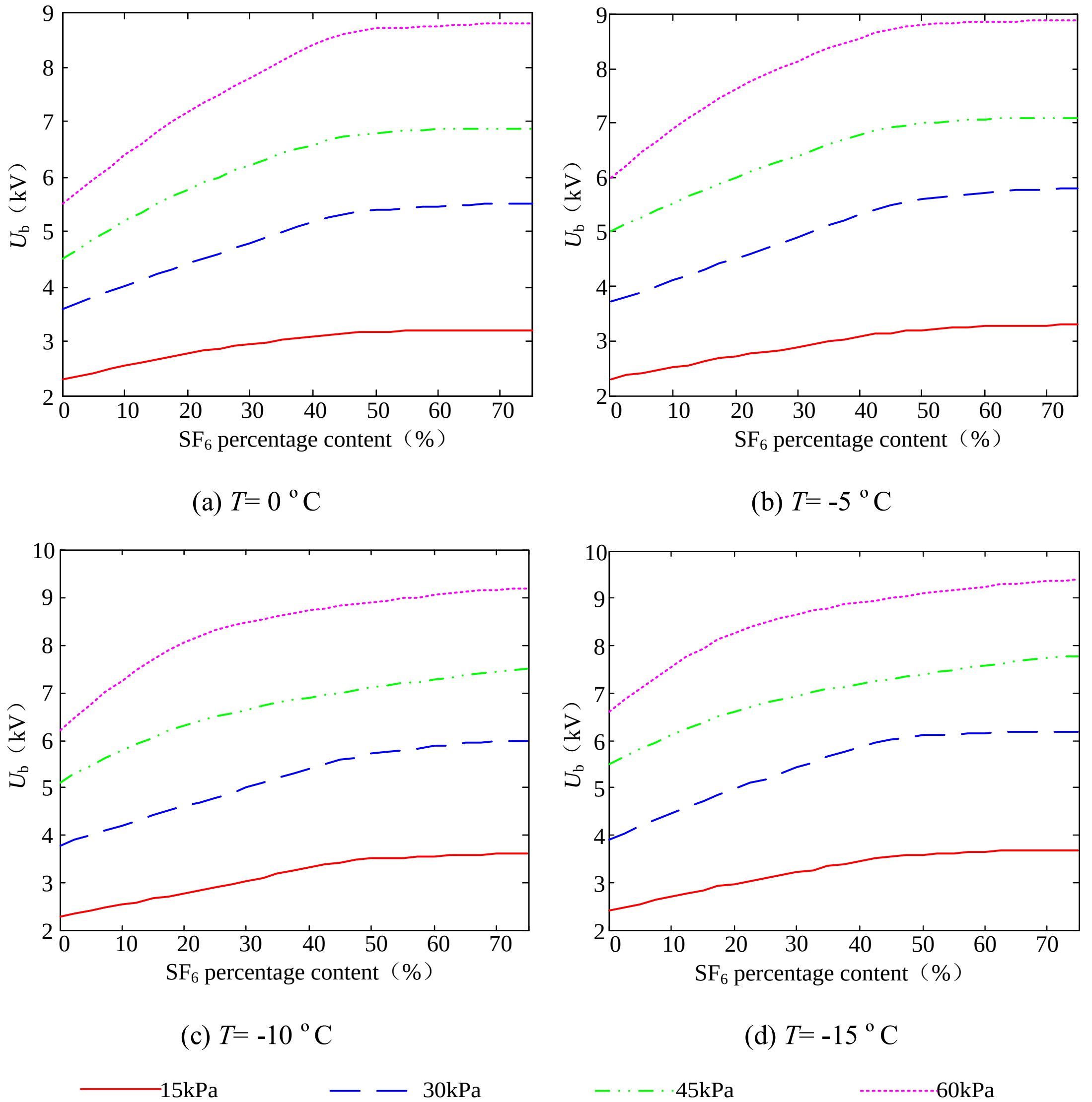


Figure 4. Change law of mixed gas breakdown voltage with SF_6 percentage content.

4. Conclusion

In the paper, a gas breakdown experimental platform was designed, wherein temperature can be adjusted. The breakdown voltage of SF_6/N_2 mixed gas at different temperatures, gas pressures and mixing proportions was measured. The following conclusions are obtained:

(1) The breakdown voltage of the SF_6/N_2 mixed gas is hardly affected by temperature regardless of SF_6 content thereof between 0 and 15 °C;

(2) The influence of gas pressure on SF_6/N_2 mixed gas breakdown voltage is more significant than that at 0~-15 °C and 15~60kPa;

(3) The insulating properties are increased firstly, which tends to be more and more saturate subsequently with increase of SF_6 content in the mixed gas. The change law of voltage with SF_6 percentage content was less affected by temperature.

References

[1] Xiao Dengming 2016 The development prospect of environment-friendly insulating gas *High Voltage Engineering* **42(4)** 1035-1046 (in Chinese)

[2] Dissenter A, Finkel M, and Grund A et al. 1999 Dielectric properties of N_2/SF_6 mixtures for use

in GIS or GIL *Eleventh International Symposium on High Voltage Engineering Conf. Publ. No. 467, UK* **(3)** 67-70
[3] Mahdy A M 2011 Assessment of breakdown voltage of SF_6/N_2 gas mixtures under non-uniform field *IEEE Transactions on Dielectrics & Electrical Insulation* **18(2)** 607-612
[4] Lee B T, Huh C S and Chang Y M 2010 AC breakdown voltage characteristics simulation of SF_6/N_2 in non-uniform field and extra high voltage *PEOCO* **2010** 210-214
[5] Zhang Lu, Zhang Qiaogen, and Yin Yu, etc. 2013 SF_6 long-gap volt-second characteristics under very fast transient over-voltage and lightning impulse *High Voltage Engineering* **39(6)** 1396-1401 (in Chinese)
[6] Wen Tao, Zhang Qiaogen, Guo Can, Zhang Lu, Ma Yi and Tan Xiangyu 2015 Reversal phenomenon of SF_6 rod-plane gap discharge polarity effect under impulse voltage *High Voltage Engineering* **01** 275-281 (in Chinese)
[7] Qiu Yuchang and Feng Yunping 1993 Research on SF_6/N_2 mixed gas insulating medium *Journal of Xi'an Jiaotong University* **(1)** 1-6 (in Chinese)
[8] Sato Hitoshi, Morita Keiichi, Kikkawa Takashi,Hayakawa Naoki and Okubo Hitoshi 2002 A fundamental study on electrical insulation of N_2/SF_6 gas-insulated electric power apparatus *Electrical Engineering* **139(4)** 449-454
[9] Li Xintao, Lin Shen, and Xu Jianyuan, etc. 2014 SF_6 gas breakdown characteristics under uniform electric field based on FEM-FCT method *High Voltage Engineering* **40 (10)** 3046-3053 (in Chinese)
[10] Liu Zirui and Li Yanming 1997 Solution of gas discharge Boltzmann equation Computational *Physics* **(3)** 325-332
[11] Liu Xueli 2008 Monte Carlo simulation and experimental research on SF_6 alternative gas *Shanghai Jiaotong University* (in Chinese)
[12] Yang F, Chen Z, and Wu Y, etc. 2015 Two-temperature transport coefficients of SF_6-N_2 plasma *Physic s of Plasmas* **22(10)** 665-666
[13] Tang Xin, Liao Sijun and Yang Xin 2014 Research progress of SF_6 mixed/alternative gas insulating property *Insulation Materials* **06**18-22 (in Chinese)
[14] Zhang Renyu, Chen Changyu and Wang Changchang 2009 High voltage experimental technology *Tsinghua University Press* (in Chinese)
[15] Yang Jinji 1983 Gas discharge Beijing: *Science Press* (in Chinese)