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Experimental Study on Performance of SF_6+N_2 Mixed Gas Insulation

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Abstract. This paper designed and constructed a 126kV GIS partial discharge test platform, performed frequency breakdown tests and lighting impulse tests at temperature of -30~20℃to SF_6/N_2 gas mixture. The present experiment studied frequency breakdown tests in different temperatue and slightly inhomogeneous electric field, obtained change in frequency breakdown voltage as a function of temperature; Analysed positive and negative lightning impluse test in gas mixture, in which SF_6 had a propotion of 30%~60%, in different temperature. Results indicated 50% probability breakdown voltage variation in positive lightning impluse tests, and in a low temperature environment, the breakdown voltage increased at negative lightning impulse, the polarity effects varied with condition of pure SF_6 gas. The experimental results showed implement of SF_6/N_2 mixed gas with 30% SF_6 supersedespure SF_6 gas, could effectively reduce the consume of SF_6, and remit greenhouse efect.

1 Introduction

High-voltage gasinsulated switchgear (GIS) is a key equipement in high-voltage transmission system which provides controlling and protectingfuncions under normal operation and fault conditions. It seals high-voltage components, such as circuit breakers, disconnectors, grounding switches, in a metal pipe, uses SF_6 as insulating medium[1]. SF_6 has a strong adsorption ability of electrons, the strong electronegative indicates its excellent properties of insulation and arc extinguishing[2,3], another feature of the SF_6 gas is having a high thermal conductivity[4]. Till now, SF_6 gas is the best insulation and arc extinguishing medium. Base on its excellent properties of insulation and arc extinguishing, there excists a widespread use of SF_6 in power industry including gas-insulated transformers (GIT), transformers, cables (GIC), line (GIL) and combination units (GIS). According to statistics, 80% of SF_6 gas is used in power industry, but during practical application of SF_6, there are also some problems, mainly in the following aspects[6]:

1)SF_6 gas is very serious greenhouse gas, which is about 25,000 times that of CO_2; the degradation of SF_6 under atmosphere condition is very slow, takes about 3200 years [7];

2)SF_6 gas is sensitive to non-uniform field, in engineering applications, tiny conductive particles and roughness of electrode surface cause the non-uniformity, result in reduction of SF_6 insulating properties[8];

3)In alpine region, SF_6 in GIS has a problem of liquefaction and density reduction;

4)Due to the normal operation of the circuit breaker or an internal short, occurrence of arc causes SF_6 decomposes, the reaction produces toxic gases for instance SF_4, SOF_2;

5)When the SF_6 gas contains water, condensation will produce in the insulation material surface, leads to significantly decrease of insulating properties, SF_4 and other decomposition products hydrolysis into HF and SO_2 and other acidic substance, internal members are corrosived, result in operation failure[9];

6) SF_6 gas is in higher cost, there exists no natural SF_6 gas, SF_6 gas in industry is synthetic so far[10].

When reducing the use and emissions of SF_6 gas, the selection of alternative gas of SF_6, 3 main indicatiors are considered: the electric strength (E/N)tbm, greenhouse index (GWP) and liquefaction temperature（℃）. Since no gas could completely replace SF_6 gas, many studies tend to use a mixture of SF_6 and other gases. The SF_6 gas mixture can solve the liquefaction in alpine region, hybrid gas-insulated manner can also spare expensive SF_6 gas, and mixed gas is less sensitive to small defects in the electrode surface. All these properties show a good prospect. Therefore, research of insulating properties of SF_6 gas mixture under low temperature circumstance has great significance to development of grid and environmental protection.

2 Researching methods of insulation properties of SF_6/N_2 mixed gas

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SF_6/N_2 mixed gas insulation theoretical foundation and main research methods includes: breakdown characteristics experiment, studies of discharge mechanism of electron avalanche stage, in which including Steady State Townsend (SST) and Pulse Townsend (PT), simulation methods, Boltzmann equation analysis and Monte Carlo method.

Breakdown experiment applies under certain experimental conditions: different electric field distribution and different voltage waveforms to directly obtain experimental electric strength of the insulating gas, but this method cannot access to the discharge mechanism of mixed insulating gas, it is difficult to propose effective method of inhibiting the breakdown. studies of discharge mechanism of electron avalanche stage, serve as methods complement to the experimental studies, could predict and control the gas insulation breakdown, theorically analyse the breakdown process. Simulation gas electron avalanche development process, mainly describe the relationship between collision cross-sectional and electron energy distribution in gas discharge. Boltzmann equation analysis is under the condition of known various cross sections, solving the microscopic parameters of the gas discharge. It obtains various cross sections and other appropriate data by experiment, by solving the Boltzmann equation, describes the gas electron avalanche development process with a series of elastic collision and inelastic collision, eventually derives electron energy distribution ionization coefficient, adhesion coefficient, drift velocity and diffusion coefficient and other parameters. The basic idea of Monte Carlo method is based on the probabilistic model on the basis of physical phenomena, and according to the unknown number of random variation, a random sample test is applied to calculate the approximate probability of occurrence of an event, uses the probabilistic models to obtain its estimated parameters. During the study of the mechanism of gas discharge, Monte Carlo method can simulate the behavior of particle dynamics and transport properties in a gas discharge process, simulate the occurence and development of electronic avalanche.

Currently discharge theories such as Townsend streamer discharge theory are incomplete. The breakdown of specific structure can not be accurately calculated. Engineering design and improvement of insulation structure often rely on experimental methods or variety of typical test data, discharge theory has important reference value of analysis and prediction of the insulating structure, and is helpful for analyse the problems of insulated structural. Combining the method of experimental and theoretical analysis to calculate the variety of insulation in different ratio of the mixed gas, supersede SF_6 gas with gas mixture of high electrical resistance performance, low greenhouse effect, low-temperature liquefied. Solves practical application problems of SF_6 alternative gases.

2.1 Frequencydielectric strength of SF_6 and SF_6/N_2 gas mixture

According to the experimental research literature and research institutions[2-4]. In frequency AC voltage, SF_6 gas gap electric strength (peak) can be represented by the following empirical formula:

$$Eb_{(SF6)} = 65(10p)0.73 \quad (1)$$

SF_6 gap breakdown voltage can be approximatelyestimate:

$$Ub_{(SF6)} = 65\eta d(10p)0.73 \quad (2)$$

Where: $Eb_{(SF6)}$as SF_6 gas gap frequency Dielectric strength, kV/cm; $Ub_{(SF6)}$as SF_6 gas gap frequency breakdown voltage, kV; *P*as gas absolute pressure, MPa; ηas utilization factor of insulation, calculated, $\eta = 0.9$; *d*as the electrode spacing (cm).

For SF_6/N_2 gas mixture with SF_6 gas percentage of x%, $x \geq 10$, empirical formula of SF_6/N_2 gas mixture gap breakdown voltage present as:

$$Ub_{(SF6/N2)} = 65\eta d(10p)0.73x/100 \quad (3)$$

Where: $Ub_{(SF6/N2)}$as frequency gap breakdown voltage of SF_6/N_2 mixed gas,kV; *x*as the volume fraction of SF_6 gas in the mixed gas required $x \geq 10\%$.

2.2 Impactdielectric strength of SF_6 and SF_6/N_2 mixed gas

In the condition of operational negative impact voltage, the empirical formula of SF_6 gas gap $Eb_{(SF6)}$ (lower limit) is:

$$Eb_{(SF6)} = 68(10p)0.73 \quad (4)$$

By equation (2), (3), (4) Export gap electric strength (lower limit) $Eb_{(SF6/N2)}$ of SF_6/N_2 mixed gas is empirical formula (5) and gap breakdown voltage (lower limit) of SF_6/N_2 mixed gas (6)

$$E_{b(SF6/N2)} = 68(10p)0.73x0.18 \quad (5)$$

$$Ub_{(SF6/N2)} = 68\eta d\,(10p)0.73(x/100)0.18 \quad (6)$$

Where: $Eb_{(SF6/N2)}$ gap impact resistance of SF_6/N_2 mixed gas, dielectric strength, kV/cm; $Ub_{(SF6/N2)}$ gap impulse voltage of SF_6/N_2 mixed gas, kV; *P*is gas absolute pressure, MPa;*x* is the volume fraction of SF_6 gas in the mixed gas required $x \geq 10\%$.

3Experimental study of power frequency withstand voltage and lightning impulse test of SF_6/N_2gas mixture under low temperature environment

3.1 Test Platform

Based on the structure and characteristics of switch-type device under condition of low temperature. Established a mixed gas test platform with 126kV GIS equipment carried out SF_6 gas mixture withstand voltage test at different temperatures. tested SF_6 gas mixture variety of mixing ratio, pressure and temperature and other factors along with frequency withstand voltage. 126kVGIS simulation test device is shown in Figure 3-1, there is an air chamber, including cables joints, can be set to a variety of types of electrodes, the discharge gap can be adjusted.

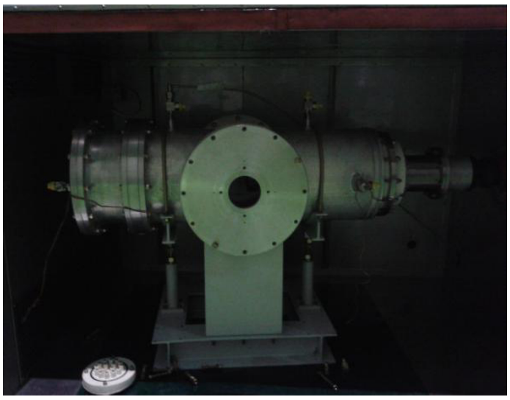

Figure 1.126kV GIS discharge test platform

Figure 2. 126kV GIS discharge device structure diagram

3.2 Electrode size designand gap arrangement

According to experimental pre-discharge results of gaps in the air and SF_6 gas, set a bar-plate discharge gap in GIS simulation device. Objects are made of copper, plate electrode radius R = 21.5mm, the rod-shaped electrode radius R = 6mm, hemispherical electrode radius 21.5 mm, the discharge gap distance is adjustable between 1.0--15mm.

3.3 Temperature control

To realize temperature control, used low temperature test chamber, temperature, control range from -60℃ to room temperature, room size is 2500×1200×1500mm, temperature fluctuation ≤ ±0.5℃, temperature uniformity ≤±2℃. Cooling rate 0.7~1℃/min, heating rate of 2~3℃ / min.

3.4 Voltage Control

Frequency breakdown test used 70% step-up mode, i.e. First constantly increase voltage to 70% of estimated breakdown voltage, then increase voltage by 5% of starting voltage, at a speed of 4kV/s slowly rise until breakdown. Interval between 2 tests was 10 min, to ensure that the gas insulation strenthrecovered[11-17]. with a digital oscilloscope for recording and storing the voltage waveform, 50% of the breakdown voltage measured by lifting method to calculate the average of 50% probability breakdown voltage values.

Lightning impulse characteristic test, according to the requirements of GB/T16927.1 "High VoltageTestTechnology", test voltage started from 50% of estimated breakdown voltage, increased 5% in amplitude until the breakdown, detected full-wave lightning waves with the hatox of 1.2μs, and wave tail of 50μs. At the breakdown voltage, applied tests of both positive and negative full-wave, each ≥30 times the full-wave.

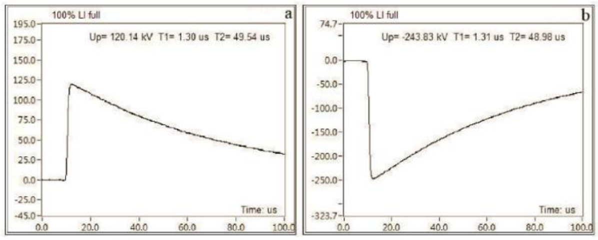

Figure 3. Standard lightning impulse voltage waveform

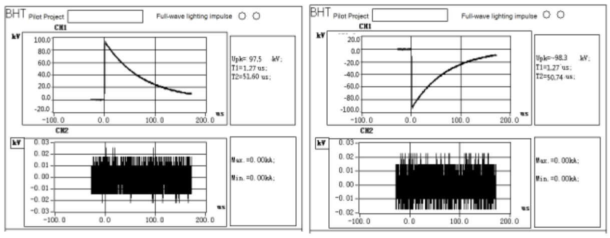

Figure 4. Positive and negative lightning impulse test waveform diagram

4 Test results and analysis

4.1 Impact of mixing ratio of SF_6 gas in the mixed gas to the frequency breakdown voltage

Test results of SF_6/N_2 mixed gas under different temperature conditions and slightly non-uniform electric field configuration showed that, in the temperature range of -30℃~20℃, the frequency breakdown voltage of mixed gas decline linearly as the temprature decreased. When the mixing ratio of SF_6 in the SF_6/N_2 mixed gas raised, its frequency breakdown voltage significantly increased.

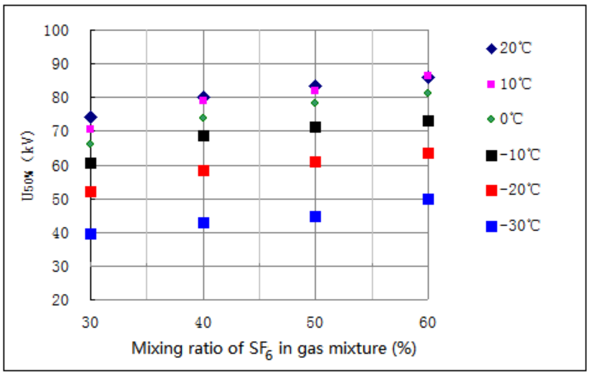

Figure 5. Variation of frequency breakdown voltage in SF_6/N_2 mixed gas at different temperatures under circumstance of slightly uneven frequency voltage

In the temperature range of -30℃ to -10℃, the frequency breakdown voltage of mixed gas increased as the the mixing ratio of SF_6 in the SF_6/N_2 mixed gas raised;

in the temperature range of 0℃ to 20℃, frequency breakdown voltage increase as the increase in the mixing ratio of SF_6 is not obvious, there existed a saturation trend. Frequency breakdown voltage and the mixing ratio of SF_6 showed positive correlation with saturation tendency in the normal temperature range, especially when the temperature is above 0℃, the saturation trend was particularly evident.

4.2 Impact of ambient temperature to the frequency breakdown voltage of mixed gas

The temprature of mixed gas decreased along with the ambient temperature, the frequency breakdown voltage declined. In the temperature range of -30℃ to -10℃, frequency breakdown voltage declined as the temperature decreased significantly; in the temperature range of -10℃ to 20℃, frequency breakdown voltage with decreasing temperature drop is not obvious; A positive correlation existed between frequency breakdown voltage and ambient temperature, in the normal temperature range trend slowed, especially at temperatures above 0 ℃ area, its decline is not obvious; In the temperature range of -30℃ to -10℃, mixed gas Power frequency withstand voltage greatly influenced by the ambient temperature decreased significantly.

4.3 Impact of mixing ratio of SF_6 gas in the mixed gas to 50% probability of lightning impulse breakdown voltage

The variation of 50% probability of lightning impulse breakdown voltage in mixed gas in different ambient temperature, the mixing ratio of SF_6 gas in the mixed gas varied within 30%~60%, showed in Figures 6 and 7, in the positive and negative lightning impulse, 50% probability of lightning impulse breakdown voltage of SF_6/N_2 mixed gas shows a downward trend at -30℃ to -10℃ range. As the mixing ratio of SF_6 gas in the mixed gas decreased, drop trend of 50% probability of lightning negative impulse breakdown voltage was not obvious, drop trend of 50% probability of lightning positive impulse breakdown voltage had a significant effect. When the mixing ratio of SF_6 gas was within 40%~60%, the impact of the mixing ratio of SF_6 gas to 50% probability of negative lightning impulse breakdown voltage was not clear. When the mixing ratio of SF_6 gas was under 40%, the impact of the mixing ratio of SF_6 gas to 50% probability of negative lightning impulse breakdown voltage was quite obvious.

4.4Impact of ambient temperature to the lightning impulse characteristics in the SF_6/N_2 gas mixture

Analysed Figures 6 and 7, As Ambient temperature went down, the 50% probability of lightning impulse breakdown voltage showed a decrease trend. The 50% probability of positive lightning impulse breakdown voltage decreased more distinct.

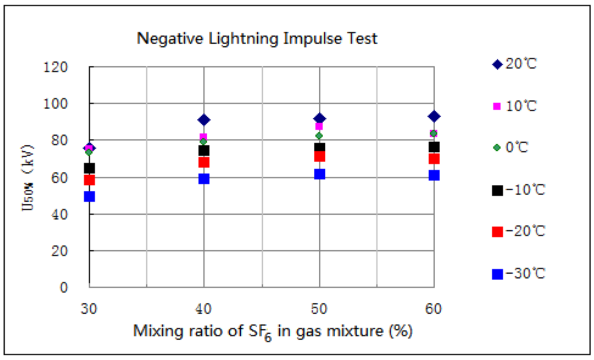

Figure 6. Variation of 50% probability of negative lightning impulse breakdown voltage in different mixing ratio of SF_6

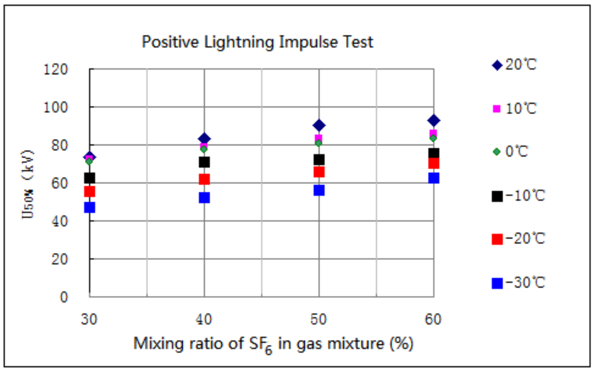

Figure 7. Variation of 50% probability of positive lightning impulse breakdown voltage in different mixing ratio of SF_6

In condition of same mixing ratio of SF_6, in the range of ambient temperature as -30~-10℃, positive impulse breakdown voltagewas lower than that in negative; in the range of ambient temperature was 0~20℃, negative impulse breakdown voltage was lower than that in positive. Under normal circumstances in pure SF_6 gas, since the test perfomed in a slightly nonuniform electric field, the breakdown voltage of negative polarity lightning impulse was sure to be lower than which of positive polarity lightning impulse at low temperature environment. Experimental results showed that the breakdown voltage of negative polarity lightning impulse was increased, its polar effect was different with pure SF_6 gas, polarity inversion occured at low temperature, the temperature range was about -30~-10℃.

5 Conclusion

This paper designed and constructed a 126kV GIS partial discharge test platform, performed frequency breakdown tests and lighting impulse tests at temperature of -30~20 ℃ to SF_6/N_2 gas mixture. By analysed the experimental results, received following conclusions:

In low temperature and slightly nonuniform electric field enviroment, the frequency breakdown voltage had a significant increase along with the augment of mixing ratio of SF_6, in the temperature range of -30℃ to -10℃; as in the temperature range of 0℃ to 20℃, the increase trend was unconspicuous. Frequency breakdown voltage and the mixing ratio of SF_6 showed positive correlation with saturation tendency in the normal temperature range, especially when the temperature was above 0℃, the saturation trend was particularly evident.

In the temperature range of -30℃ to -10℃, frequency breakdown voltage declined as the temperature decreases significantly; in the temperature range of -10℃ to 20℃, frequency breakdown voltage with decreasing temperature drop was not obvious. Mixed gas Power frequency withstand voltage greatly was influenced by the ambient temperature decreased significantly.

50% probability of breakdown voltage showed a decrease trend as the ambient temperature decreases under the positive or negative impulse. When the mixing ratio of $SF_6$was high, the decrease trend was obvious; when the mixing ratio of $SF_6$was low, the decrease trend was unconspicuous.

In the temperature range of -30℃ to -10℃, 50% probability of negative lightning impulse breakdown voltage decreased slowly, while probability of positive lightning impulse breakdown voltage decreased observably. In the condition of same mixing ratio of SF_6, polarity inversion occurs.

SF_6/N_2 mixed gas with 30% SF_6 supersede pure SF_6 gas was feasible in engineering applications. This replacement can effectively reduce the consume of SF_6, the greenhouse gas emissions and the insulating gas in GIS.

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