

Arc Interruption Performance of SF₆/N₂ Gas and Dielectric Recovery in Disconnecter



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Abstract SF₆ as a gas medium for power switchgear, has outstanding performance on arc suppression and insulation. However, because of the strong greenhouse effect, it is limited to use recently. SF₆/N₂ mixture is an effective alternative in high voltage power switchgear, which not only reduce the emission of SF₆ but also lower the gas liquefaction temperature. Based on a 220 kV disconnecter, this paper built a magneto-hydro-dynamic (MHD) model to simulate the arc burning process. The electric field distribution and the critical breakdown voltage within 100 us after current zero (CZ) were calculated to evaluate the arc interruption performance of the SF₆/N₂ mixture. The model established in this paper is effective and referable in arc simulation and dielectric recovery assessment. The research results in this thesis are significant to the application of SF₆/N₂ mixture in disconnecters.

Keywords SF₆/N₂ mixture · Disconnecter · Critical breakdown voltage · Dielectric recovery

1 Introduction

SF₆ as a gas medium for power switchgear, has outstanding performance on arc suppression and insulation [1]. But for its strong greenhouse effect, the electrical industry urgently needs to find an environmentally friendly substitute gas. Researchers have conducted extensive and in-depth research in the field of SF₆ alternative gases over the years. At present, the widely studied and applied SF₆ alternative gases can be divided into four categories. The first is natural conventional gases [2], which are cheap and do little harm to the environment. But their arc interruption

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and insulation performance are insufficient. The other two are new environmentally friendly gases such as fluorocarbons and new fluoride, which are still being explored [3–5]. And the last category is the SF₆ mixture [6]. This category of gas can solve the problem of SF₆ liquefaction that can occur in cold regions and also helps reduce SF₆ use, which has great important engineering significance. One of the most studied gases is the mixture of SF₆ and N₂ [7, 8].

Researchers have done a lot of research on the breakdown characteristics of the SF₆/N₂ mixture. Christophorou et al. [9, 10] studied the breakdown characteristics of SF₆/N₂ mixture under different electrode structures and found an excellent synergistic effect of them. Lu et al. [11] conducted frequency breakdown tests and lightning impulse tests to 30% SF₆/N₂ mixture at a temperature range from –30 to 20 °C based on a 126 kV GIS partial discharge test platform. The results showed that in low temperatures about –30––10 °C, the frequency breakdown voltage was significantly influenced by the mixing ratio of SF₆; as in the higher temperature of 0–20 °C, the influence became inconspicuous. Dmitry and Laxminarayan [12] built a two-dimensional axisymmetric fluid model and coupled it with the comprehensive mechanism of plasma chemical reactions, to figure out the influence of the SF₆ fraction in the SF₆/N₂ mixture on the breakdown voltage. It was observed that the breakdown voltage increased by 7–43% when adding only 1% SF₆ to N₂ depending on the voltage rise time. All the studies mentioned above were carried out on the single electrode structure or simplified electrode model. Therefore, studying the arc-suppressing performance of SF₆/N₂ mixed gas on specific electric high voltage power switchgear is essential and has great engineering practical research significance.

This thesis aims to evaluate the arc suppressing property of SF₆/N₂ mixture. Firstly, a magneto-hydro-dynamic (MHD) model of a 220 kV disconnecter structure was built up to simulate the arc burning process. Secondly, the electric breakdown in the arc extinguishing room after arc was evaluated. The probability of electrical breakdown in each region of the arc extinguishing room was predicted through the temperature, pressure, and the actual electric field distribution of the mixture, meanwhile, the critical breakdown voltage of the SF₆/N₂ mixture was calculated. The results revealed the breakdown probability and arc reigniting after current zero (CZ), and effectively evaluate the arc interruption performance of the SF₆/N₂ mixture. The model established in this paper is effective and referable in arc simulation and dielectric recovery assessment. The research results in this thesis are significant to the application of SF₆/N₂ mixture in disconnectors.

2 Simulation Model and Calculation Method

In this section, a two-dimension MHD model is built based on ANSYS FLUENT, which is software to simulate the interaction of multiple physical fields during arc burning process [13]. Then the method to calculate the critical breakdown field strength of the mixture and the method of evaluating the electric breakdown in the arc extinguishing room after arc is presented.

2.1 MHD Model

In the process of current interrupting simulation, the arc is regarded as a special fluid, and the arc plasma is considered to be electrically neutral, which is in the state of Local Thermodynamic Equilibrium (LTE) and Local Chemical Equilibrium (LCE). The effect of a thin sheath near the electrode is ignored. The dynamic development of arc and surrounding airflow field is described using the Navier–Stokes equations that reflect the conservation of mass, momentum, and energy, electromagnetic field equations, radiation model, and turbulence model [14].

2.2 The Geometric Model of Disconnecter

The geometric model is based on a 220 kV disconnecter. It is axisymmetric including half of the disconnecter structure, so as to simplify the calculation. Figure 1 shows the disconnecter model as the moving contact has moved for 9 ms. Along the axis, there is an evaluation line L1, which is used to calculate the critical breakdown voltage.

The boundary and initial conditions of the model are set as follows:

1. The IRMS and frequency of current is 1.6 kA, 50 Hz. The maximum value of the transient recovery voltage (TRV) is 73 kV.
2. The inflation pressure is 0.6 MPa, the upper part of the chamber is set as the pressure outlet, and the ambient temperature is 300 K. And the separation speed of contact is 5 m/s.
3. There are three proportions of mixture filled in the switch: pure SF₆, 28%SF₆ + 72%N₂, and 40%SF₆ + 60%N₂.

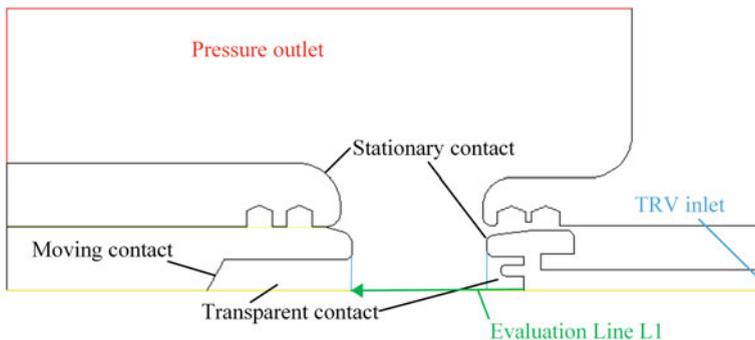


Fig. 1 Geometric model of the disconnecter

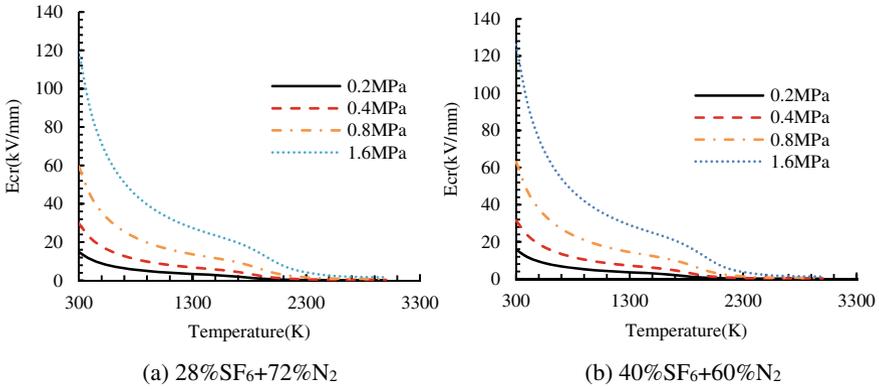


Fig. 2 The E_{cr} of SF₆/N₂ gas at different temperatures and pressure

2.3 Calculation of Critical Breakdown Field Strength

During the arc burning process, the gas will decompose and change its properties because of the high temperature and fluctuating pressure. To assess the dielectric strength recovery after arc, the critical breakdown electric field strength E_{cr} at high temperatures is calculated. For the mixture, the collision cross sections are acquired using the semi-classical Deutsch-Märk (DM) method. Then, the collision cross sections and gas components are used to calculate E_{cr} at different temperatures and pressures by solving the Boltzmann equation [15]. Figure 2 shows the E_{cr} of two proportions of mixture. The E_{cr} is the function of temperature and pressure, inversely correlated with temperature and positively correlated with pressure.

2.4 Evaluation of the Dielectric Strength Performance of Gas Mixture

To estimate the electrical breakdown of the gas mixture in the arc extinguishing room, the real electrical field distribution and the airflow field are considered. Figure 3 shows that the electrical field E_a is determined by the transient recovery voltage (TRV) after arc. The distribution of temperature and pressure field in the chamber influences the critical breakdown field E_{cr} . It is supposed that the gas gap is likely to break down when the critical breakdown field is smaller than the background field. Therefore, the ratio of E_a to E_{cr} represents the probability of electric breakdown in this area.

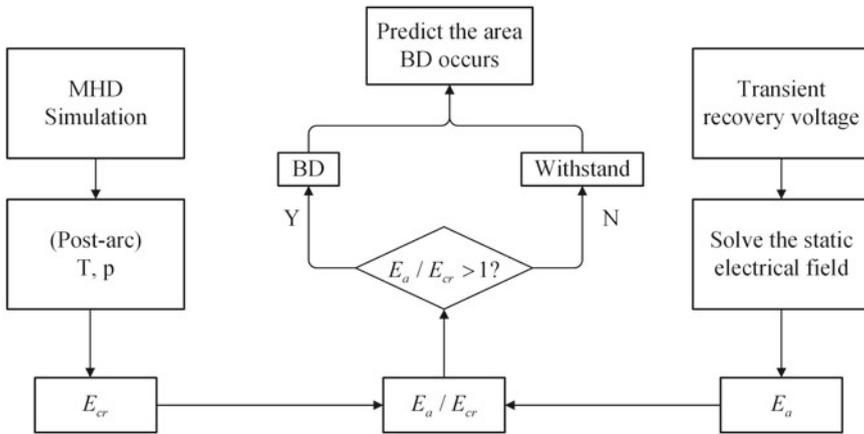


Fig. 3 The evaluation method of electrical breakdown

3 Simulation Results and Analysis

In this section, the post-arc electrical breakdown simulation of the disconnector is carried out after the CZ. After that, the distribution of the physical field and the critical breakdown voltage for three proportions of SF₆/N₂ mixture are analyzed.

3.1 The Distribution of the Physical Field

Figure 4 shows the temperature contour and E_a/E_{cr} contour of the disconnector in three proportions of SF₆/N₂ mixture at 100 us after arc. It can be found that the temperature of gas is low at this time, as the highest temperature of the three gases is within 3000 K. Therefore, it is helpful for the recovery of dielectric insulation strength. When analyzing the distribution of the E_a/E_{cr} , it is similar in all three cases. The maximum value of E_a/E_{cr} appears at the edge of the contact, because of the large electric field caused by the unsmooth structure. For 28% SF₆/N₂, the maximum value of it is 0.7, which is less than 1, so the arc is less likely to be re-struck. Although the highest temperature appears at the bottom of the static contact which can lead to the lowest E_{cr} , as E_a is much lower, the E_a/E_{cr} value is small. At last, it can be concluded that in the same position, the higher the SF₆ concentration is, the smaller the E_a/E_{cr} value is.

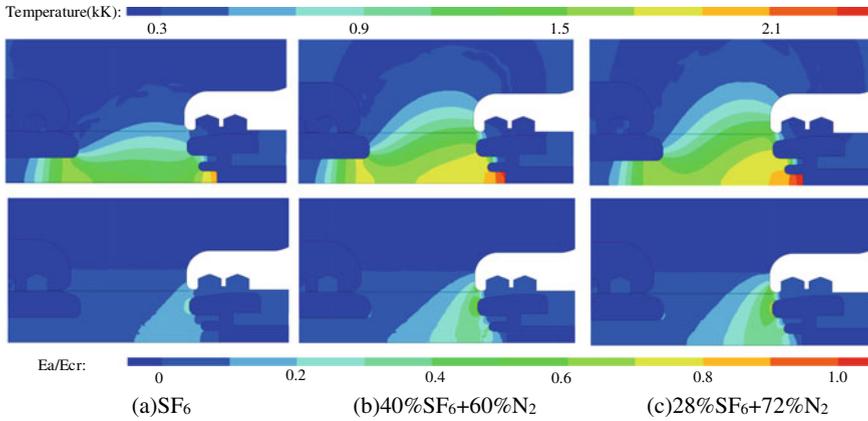


Fig. 4 Temperature and E_a/E_{cr} distribution at 100 μ s after CZ

3.2 The Calculation of Critical Breakdown Voltage

The critical breakdown voltage along the selected path (shown in Fig. 1) is calculated and shown in Fig. 5. With the decrease of the temperature and the fluctuation of the pressure in the arc extinguishing room, the critical BD voltages all fluctuate in a small amplitude, and show an upward trend overall time. The initial critical BD voltages of 28% SF₆/N₂ and 40% SF₆/N₂ mixture are 275.5 and 300 kV, about 56.0 and 61.0% compared to SF₆, but still higher than the TRV, the maximum value of which is set as 73 kV. Meanwhile, the presence of N₂ in the mixed gas also increases the fluctuation of the critical BD voltages and affects the recovery of dielectric strength. It is indicated that in the first 30 μ s, the critical breakdown voltage of the two SF₆/N₂ mixtures fluctuated sharply, and the value was very close. After 30 μ s, the critical breakdown voltage began to stabilize and because of the effect of SF₆, the critical breakdown voltage of 40% SF₆/N₂ was slightly higher than 28% SF₆/N₂.

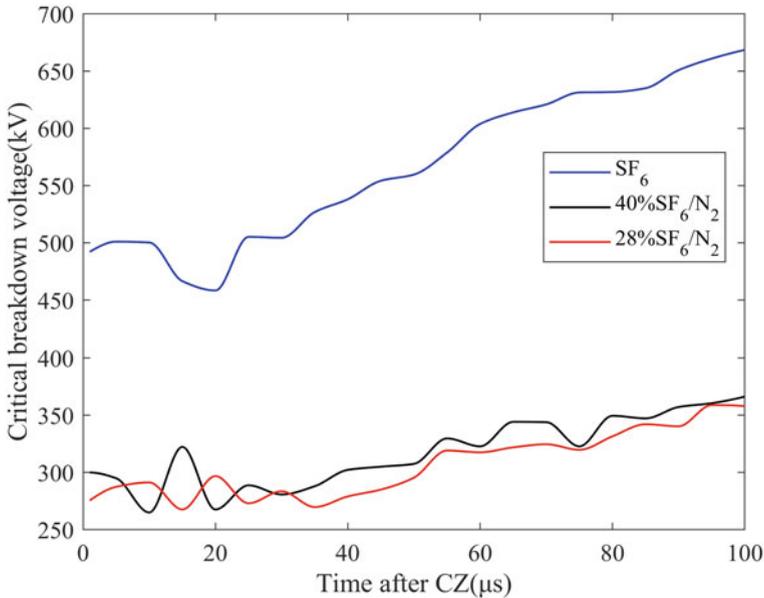


Fig. 5 The critical breakdown voltage along the selected path

4 Conclusion

To evaluate the arc suppressing property of SF₆/N₂ mixture, the MHD model was built based on the 220 kV disconnector. The arcing process of SF₆ gas and SF₆/N₂ mixture is simulated and the critical breakdown field strength is calculated as the precondition to evaluate the dielectric recovery performance of SF₆ and SF₆/N₂ mixture. The following conclusions were drawn:

1. The critical breakdown field strength of SF₆/N₂ mixture is calculated, which decreases when temperature increases and pressure decreases. At the same time, the rise of SF₆ ratio in the mixture increases the critical breakdown field strength.
2. The critical breakdown voltage of 28%SF₆/N₂ and 40%SF₆/N₂ mixture under 0.6 MPa after current zero is predicted and compared to pure SF₆. The calculated critical breakdown voltage is lower than SF₆, but it is much higher than the maximum of TRV, without the risk of breakdown.

Therefore, SF₆/N₂ mixture has perfect arc suppressing performance and can be used as the substitution for SF₆ in the power switchgear. The simulation results in this thesis are helpful to the application of SF₆/N₂ mixture in disconnectors and have high engineering significance.

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