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ARC CHARACTERISTIC OF DIFFERENT GAS MEDIUMS IN ARC FORMATION PROCESS AND INFLUENCE OF BREAKING CURRENT

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ABSTRACT

SF_6 gas is the main arc-extinguishing medium for high-voltage circuit breakers. It has excellent characteristics such as electronegativity and high medium recovery strength. But as a kind of greenhouse gas, it has a very high greenhouse effect. Finding alternative gas for SF_6 and ensuring reliable arc-extinguishing have gradually become a hot spot in the field of high-voltage switches. Basing on the magnetohydrodynamic equations, a model of SF_6 circuit breaker nozzle is simplified in this paper. Under the condition of local thermodynamic equilibrium, the process of arc formation in air, nitrogen, argon and SF_6 under the same breaking condition are simulated in this paper. The influence of breaking current on arc characteristics is also analyzed. It provides a reference for the research work of SF_6 substitute gas.

Keywords:SF_6 substitute gas, MHD model, arc, circuit breaker

1. INTRODUCTION

SF_6 is widely used as an insulating and arc extinguishing medium in electric power equipment. But as a greenhouse gas, it has a high GWP value, and is not easily degraded[1]. Therefore, finding an environmentally friendly and excellent SF_6 substitute gas has become an urgent problem to be solved.

Argon gas, carbon dioxide and air are the common arc media at present. Researches are also carried out around these three gases. Wang Weizong and Rong Mingzhe obtained the relevant transport parameters of argon and nitrogen arc plasma under different pressure and temperature under local thermodynamic equilibrium conditions, the results provided a reference for the simulation of arc[2-3]. Y, Tanaka used a high-speed camera to observe the discharge behavior of SF_6, Ar and Ar/SF_6 arcs in IGBT. R.S. Safar studied the breakdown characteristics of SF_6 and N_2,air and CO_2 mixed gas under a non-uniform electric field of negative pulse voltage. The breakdown voltage of SF_6/CO_2 in the three mixed gases is the highest or even slightly higher than pure SF_6.N.S.Aanensen tested the breaking capacity of air on 440A, 630A and 880A, and analyzed the influence of contact and nozzle size and air flow rate on breaking capacity.

At present, some achievements and engineering practices have been achieved about the insulation performance of alternative gases. But there is no major breakthrough in arc extinguishing capability. Further exploration of the arc extinguishing performance of alternative gases is the focus of future research.

In this paper, air, nitrogen, argon and SF_6 gases are used as research objects in a simplified SF_6 circuit breaker nozzle model. By solving the Navier-Stokes equations under equilibrium, the simulation results show the arc formation process of different gases under the same breaking condition. The influence of the breaking current on the arc characteristic is also

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analyzed.

2. **SIMULATION MODEL**

2.1 Mathematical model and assumptions

A mathematical model based on the following assumptions is established in this paper: ① the arc plasma satisfies the local thermodynamic equilibrium; ② the airflow flowing into the nozzle is laminar; ③ ignores the effect of collision between ion and electrode; ④ ignores the ablation of the arc to the electrode and the nozzle; ⑤ assumes heat conduction existing in the nozzle and electrode; ⑥ ignores the influence of the self-generated magnetic field of arc.

Based on the above assumptions, the Navier-Stokes equations and the Maxwell equations are used in this paper. The equations are as follows:
Navier-Stokes:

$$\frac{\partial \rho}{\partial t}+\nabla\cdot(\rho V)=0 \qquad (2\text{-}1)$$

$$\rho(\frac{\partial V}{\partial t}+V\cdot\nabla V)=\nabla\cdot[-pI+\mu(\nabla V+(\nabla V)^T)-\frac{2}{3}\mu(\nabla\cdot V)I]+F \qquad (2\text{-}2)$$

$$\frac{\partial(ph)}{\partial t}+\nabla\cdot(puh)=\nabla\cdot(\frac{k}{C_p}\nabla h)+\frac{D_p}{D_t}+\sigma|E|^2-p_{rad} \qquad (2\text{-}3)$$

Where ρ is the arc plasma density; V is the velocity vector for the arc plasma motion; ∇ is the Laplacian operator; p is the pressure on the fluid micro-element; μ is the dynamic viscosity of the fluid; I is the unit matrix; F is the Lorentz force; p_{rad} is the radiant heat loss, $\boldsymbol{u}$ is the axial airflow velocity, h is the enthalpy change , σ is the conductivity.
Maxwell equations:

$$\nabla\cdot J=Q_{j,v} \qquad (2\text{-}4)$$

$$J=\sigma E+\frac{\partial D}{\partial t}+J_e \qquad (2\text{-}5)$$

$$E=-\nabla V \qquad (2\text{-}6)$$

J_e is current density generated by the external electric field , V is the potential.

2.2 Calculation model and parameter settings

A model as shown in Fig1 is established. The area 1 is the anode, and the area 3 is the cathode. The area 2 is respectively filled with different gases, and the area 4 represents PTFE materials. All arc models in this paper are based on the assumption that the electrode spacing is 50 mm. The gas is evenly distributed in the nozzle, assuming that the arc is symmetrical and in a local thermodynamic equilibrium.

Initial conditions are set as follows: the initial temperature is 293.15K, current on the anode side is 50 A, the cathode is grounded. According to the experimental results of Kosuke Murai, the inflation rate is 100 L/min[4], so the initial flow rate of the model is set to 1.768 m/s, and the pressure inside the nozzle is set to 0.1 MPa.

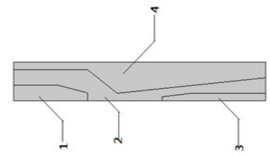

Fig 1 Simplified model of SF_6 circuit breaker

3. ANALYSIS OF SIMULATION RESULTS

3.1 Temperature field variation during arc formation process in different gas mediums

Fig 2 is the temperature distribution during argon arc formation. At the initial moment, the arc generates from the cathode. It is found that there is a strong electric field near the cathode, so that the discharge channel generated by the discharge of the cathode tip continues to develop to the center. Later, arc begins to form on the anode. When the time equals 75 μ s, the arc channels formed by the anode and cathode are connected. The high temperature range of the argon arc is large, and there is almost no low temperature area. The maximum temperature is about 1.37×10^4K.

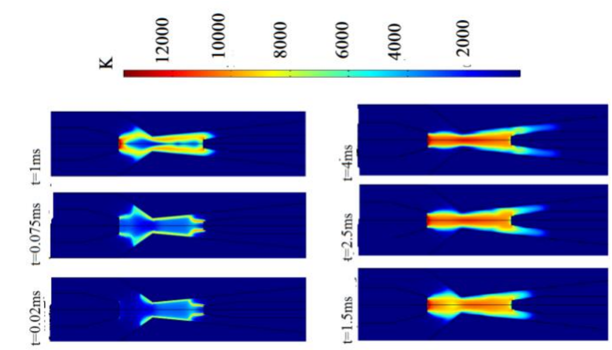

Fig 2 Temperature distribution during argon arc formation

Fig 3 is the temperature distribution during nitrogen arc formation. Compared with the process of argon arc formation, the arcing time of the nitrogen arc is longer than that of argon, and the temperature of arc is also lower. At t = 0.015ms, the anode begins to form arc. The discharge channel of nitrogen arc is wider. At t=0.21ms, the discharge channels formed by the anode and cathode are connected, and a high temperature region is formed at the center of the arc column, and the arc is developed to both ends of the arc column. At the steady state, the arc fills the entire nozzle area, the temperature distribution in the nozzle is not very uniform, and there is a long and narrow high temperature area at the position of the arc column. The maximum temperature is about 1.04×10^4K.

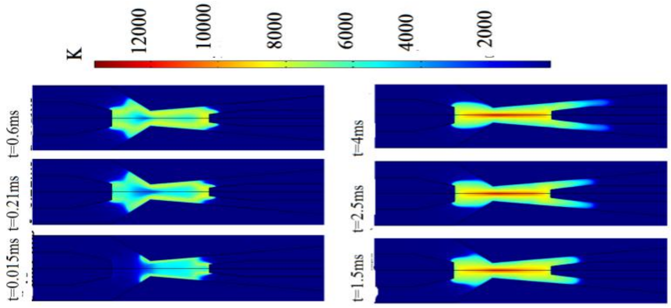

Fig 3 Temperature distribution during nitrogen arc formation

Fig 4 is the temperature distribution during air arc formation. The time of arc forming is between nitrogen and argon, but the arc develops faster. At t=0.04ms, the discharge channels that are formed by the tip discharge are connected. The formation process is similar to the nitrogen arc. The arc first contacts the arc column, so the temperature is higher here. The air arc has a triangular low temperature region near the anode and the cathode. The high temperature region of the arc column of air is slightly wider than the nitrogen arc. The arc temperature of the air arc is higher than the nitrogen arc in total. The maximum temperature isabout 1.14×10^4K.

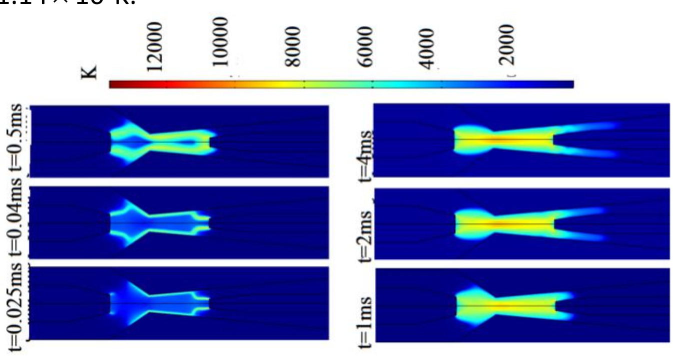

Fig 4 Temperature distribution during air arc formation

Fig 5 is the temperature distribution during SF_6 arc formation. The SF_6 gas has a longer time of arc formation and is not easy to reach the steady state than several other medias. When t = 0.1 ms, it only generates a weak arc. At about 2.09 ms, the arc first connects the anode side and continues to develop to the cathode under the action of the electric field. When t=8ms or so, the arc is basically stabilized. The maximum temperature is about 1.72×10^4K.

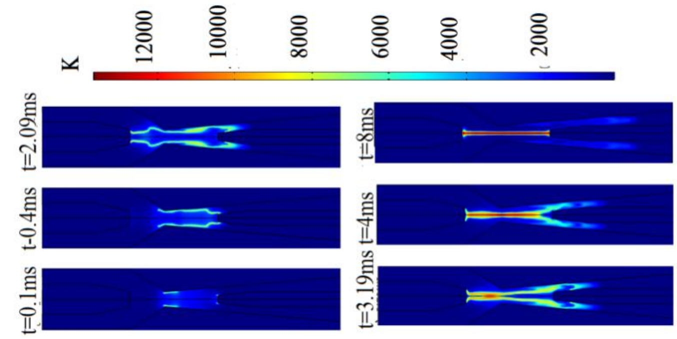

Fig 5 Temperature distribution during SF_6 arc formation

3.2. Influence of breaking current on arc characteristics

The breaking current has a great influence on the energy of the arc. So in this section the effect of different breaking currents on the gas arc voltage is simulated.

Fig 6~Fig 9 are the voltage curve of argon, air, nitrogen and SF_6 respectively in different breaking current. As shown in Fig 6 and 7, when the breaking current rises from 20A to 50A, the arc voltage decreases significantly. When the current increases to 100A, the arc voltage of the argon arc hardly changes, and the arc voltage of the air arc decreases slightly. When the current changes within a small range, the argon arc and air arc exhibit an obvious relationship of negative volt-ampere characteristic.

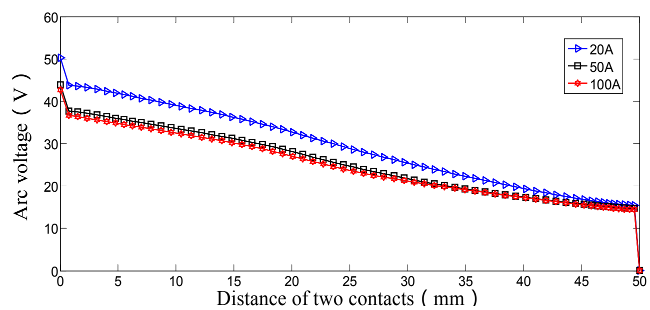

Fig 6 Voltage curve of argon arc between contacts

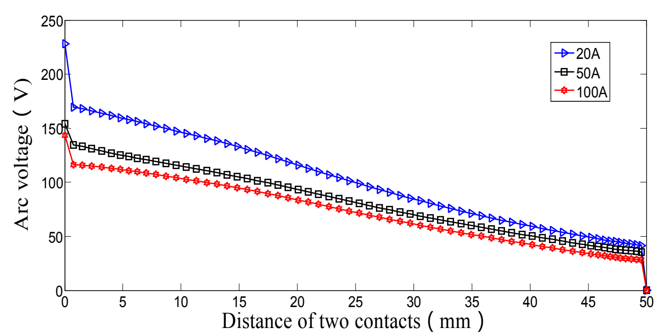

Fig 7 Voltage curve of air arc between contacts

As shown in Fig 8, when the current increases to 2 times of the initial value, the arc voltage decreases significantly. When the current value increases from 100A to 500A, although the arc voltage decreases in total, the voltage of arc column rises. This is because the magnitude of the current increasing is greater than the magnitude of the reduction of arc column resistance.

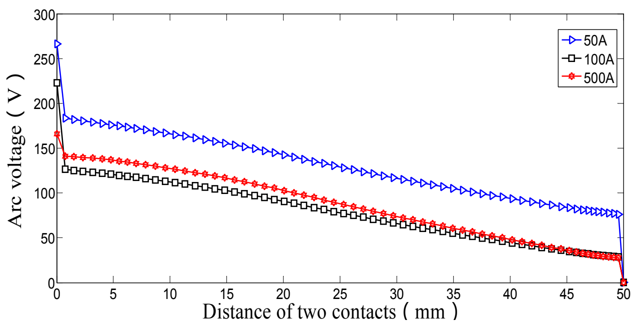

Fig 8 Voltage curve of nitrogen arc between contacts

It is found that the arc voltage shows a relatively obvious negative volt-ampere characteristic when the arc current of SF_6 changed within a large range. As shown in Fig 9, when the current is large, the arc voltage of the SF_6 arc does not change gently, however it exists a trend of curvilinear change. It indicates that the voltage is more seriously affected by the turbulence effect.

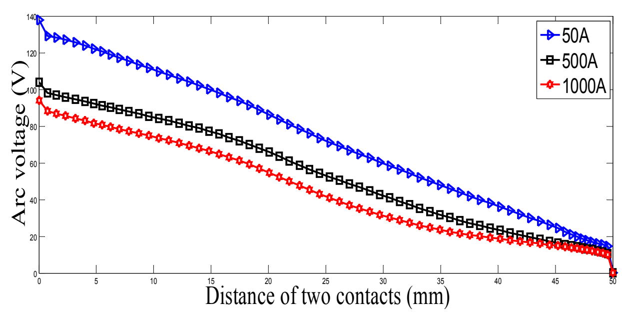

Fig 9 Voltage curve of SF_6 arc between contacts

4 CONCLUSIONS

Based on MHD model, the arc formation process of argon, air, nitrogen and SF_6 arc are simulated in the paper and the following conclusions are acquired.

(1) In the initial stage of arc generation, due to the presence of the tip a discharge phenomenon occurs first at the edge of the nozzle. And under the action of the radial electric field force, the high temperature region of the arc develops to both sides.

(2) Compared with other media, the speed of arc formation of SF_6 is slow, and it is not easy to reach steady state, the arc radius is small; N_2 is similar to the process of arc formation of air. The temperature of the arc column has a great difference. The high temperature area is thinner, the low temperature area is wider; the argon arc develops faster, and the arc temperature distribution is uniform. The arc radius of high temperature area is the largest among the four gas arcs.

(3) The arc voltage exhibits a negative volt-ampere characteristic relationship when the current increases. The argon arc and air arc have a clear trend when the currents change in a small range. The nitrogen arc and SF_6 arc have a clear trend when the currents change in a large range.

(4) In a single conventional gas, the insulating properties of nitrogen are similar to that of SF_6.There are some similar arc characteristics between them,and the mixed gas is also widely used in circuit breakers.

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