RESEARCH ON THE BREAKING CHARACTERISTICS OF NON-EQUILIBRIUM ARC WITH SMALL CURRENT FOR SF_6 HIGH VOLTAGE CIRCUIT BREAKER

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ABSTRACT

In order to meet the requirements of optimization design for SF_6 circuit breaker operating with low current and non-equilibrium-condition arc, it is necessary to study on the breaking velocity curve that makes sure of the complete extinction of SF_6 plasma arc. A simulation model of the 126kV SF_6 circuit breaker operating under rated current was built. Through the coupled calculation of electric field and fluid field, the distribution of electric field and density under different developing stages were obtained. Thus the dielectric recovery characteristics curve would be calculated. By analyzing the impact of breaking velocity on the distribution of electric field and density, the critical breakdown voltage and transient recovery voltage under different breaking velocity were compared. In the meantime, the pattern of how breaking velocity influencing the complete extinction of the non-equilibrium-condition arc was sought. A criterion curve of breaking velocity that will suffice the complete extinction of the non-equilibrium-condition arc was established.

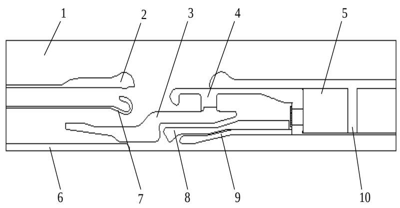
1. INTRODUCTION

The breaking velocity of high voltage circuit breaker is an important factor in the breaking characteristics. On one hand, as the breaking velocity is different, the distance between the contacts within same breaking time will be different, so the electric field distribution between the contacts will change. On the other hand, the different breaking velocity also affects the distribution of airflow in the arc-extinguishing chamber, leading to the density change between the contacts. The change of electric field distribution and density distribution will all change the dielectric recovery strength after the arc extinction [1-2]. Furthermore, in addition to interrupting fault current, circuit breaker often is needed to interrupt capacitive and inductive small current. The previous research tends to focus on interrupting equilibrium arc carrying high current in the study of the interrupting characteristic of circuit breaker; However, it has no depth in studying the interruption of the non-equilibrium arc carrying small current [3].

As to the above two kinds of problem, the flow field and electric field of 126kV SF_6 circuit breaker were calculated. Through comparing the difference between the critical breakdown voltage and transient recovery voltage under different breaking velocity, and with considering the criterion of streamer model breakdown, a velocity characteristic curve of the successful interruption of arc plasma was established.

2. THE ESTABLISHMENT OF CALCULATION MODEL

The rated breaking current of SF_6 circuit breaker in this paper is 1600A, and it is a small capacitive current. The structure diagram of arc-extinguishing chamber is shown in Figure 1.



1-SF_6; 2- Stationary main contact; 3- Large vents; 4- Movable main contact; 5-Pressure cylinder; 6- Stationary arc contact; 7- Shield; 8- Small vents; 9- Movable arc contact; 10- Piston.

Fig. 1 The Structure Diagram of Arc-extinguishing Chamber

Due to arc, arc-extinguish chamber, vents and arcing contact with axial symmetry structure, and all axis of symmetry are the axis of arc-extinguishing chamber, so the calculation model was a two-dimensional axis-symmetry.

The numerical simulation of the media recovery characteristics for SF_6 circuit breaker, includes not only the numerical calculation of the electric field also includes flow field numerical calculation. In the arc-extinguish chamber, the solution satisfies the Laplace equation [4], the mathematical expression is:

$$\begin{cases} \nabla^2\phi = 0 \\ S_1: \ \phi = \phi_0 \\ S_2: \dfrac{\partial\phi}{\partial n} = 0 \end{cases} \tag{1}$$

In the formula (1), S_1 is the Dirichlet Problem, S_2 is the Neumann Boundary Condition, φ is electric potential, the relationship between field strength E and the electric potential φ is $E = \text{-grad}\varphi$ [5],that

$$E=\sqrt{(\frac{\partial\varphi}{\partial r})^2+(\frac{\partial\varphi}{\partial z})^2} \tag{2}$$

Based on the streamer theory, dielectric strength of the entire arc gap calculated in accordance with the weakest point (E/ρ is the max), the gas breakdown criterion is:

$$(E/\rho)>k\cdot(E/\rho)^* \tag{3}$$

In the formula (3), ρ is the gas medium density, unit is kg/m^3; k is correction factor, its value is taken 0.7955[1]; assume the potential difference is U_b when $(E/\rho)>k\cdot(E/\rho)^*$, that

$$U_b=\frac{(E/N)^*}{(E/N)} \tag{4}$$

In the formula (4), U_b is the gas critical breakdown voltage. The number of particles per unit volume N and gas medium density has the following relationship:

$$N=\frac{\rho}{R_{SF_6}R_0} \tag{5}$$

In the formula (5), R_0 is Avogadro constant, its value is 6.02×10^{23}, R_{SF_6} is the molecular weight of SF_6, its value is146.07. Then we can get:

$$U_b=1.167\frac{\rho}{E} \tag{6}$$

3. NUMERICAL CALCULATION

This paper calculated the field distribution of arc-extinguish chamber at the different breaking distance by the finite element analysis. The calculation process used axis-symmetric model and smart subdivision method. The nozzle material was PTFE, its permittivity was ε_1=2.1, the permittivity of SF_6 was ε_2=1.0024. The Dirichlet Problem of moving arcing contact and the movable main contact was φ_1 =1V, The Dirichlet Problem of stationary main contact and static arcing contact was φ_2 =0V. Figure 2 was the electric field distribution of arc-extinguish chamber at different breaking distance.

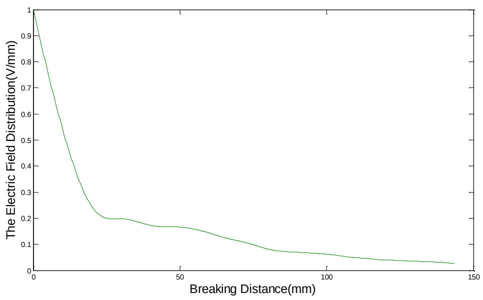


Fig. 2 The Electric Field Distribution at Different Breaking Distance.

In the numerical solution of the flow field, the finite element method combines the advantages of volume difference method and the finite element method, it still accurately meets the kinetic energy conservation and mass conservation in the discrete case, and can be applied to solve the problem of discontinuous solutions. For the complexity and specificity of flow field numerical solution of SF_6 circuit breakers, the finite element volume method is used to solve the problem and describe the dynamic process of development and extinguishing of arc. FLUENT software package of C language programming was used to realize the energy load of the electric arc area.

To reduce the complexity of the calculations, we used the method of relative motion. Assuming that moving arc contact, large nozzles and small nozzles was stationary and the piston, static arc contact were movement, this paper used dynamic grid technique and sets piston, static arc contact for the moving boundary condition, and the other for the solid wall boundary condition. SF_6 gas parameters[6] in arc-extinguish chamber as shown in Table 1, the initial temperature was T_0=300K, trip was S_k=150mm, overrun was

S_c=50mm. Subdivision adopted triangle mesh, unit area was about 4mm^2, calculated step was 0.1 mm, the grid redrawn once every 10 steps, the number of iterations for each time steps was 500.

Table 1 Parameters of SF_6

SF_6	Parameters
The molecular weight	146.05
Specific heat at constant pressure	661.42J/kg·K
Thermal conductivity	0.0133W/m·K
Dynamic viscosity coefficient	1.55×10^{-5} kg/ms
Absolute pressure	0.6Mpa

In order to meet the electrical life in the UHV project, the opening speed of the sample circuit breakers uses 11m/s. For optimization design requirements of interrupting characteristics for non-equilibrium SF_6 arc with small current, this paper simulated the interrupting process when breaking speed is 11m/s, 9m/s, 7m/s, 6m/s, 5.9m/s and 5.8m/s respectively, the corresponding arc time as shown in Table 2. The density and temperature distribution of arc time under opening speed of 6m/s respectively as shown in Figure 3 and Figure 4.

Table 2 Arc Time Under Different Breaking Speeds

Breaking speed(m/s)	Arc time(ms)
11	3.402
9	3.243
7	3.224
6	3.117
5.9	2.240
5.8	2.162

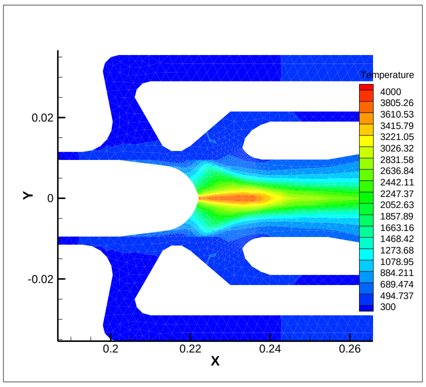
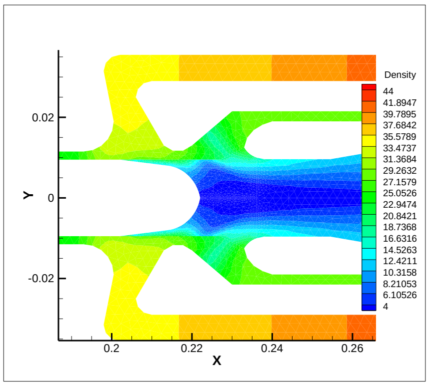


Fig. 3 The Temperature Distribution of Arc Time With Breaking Speed of 6m/s.



(c) The breaking speed is 6.0m/s

Fig. 4 The Density Distribution of Arc Time With Breaking Speed of 6m/s.

4. ANALYSIS OF RESULTS

According to Si Liebin theory[6], the extinguishing and renewed of arc depends on the comparison of voltage recovery process and the dielectric strength recovery process. It would not have happened breakdown when dielectric strength was always greater than the recovery voltage. On the contrary, arc will be renewed. Define U_p as the difference of the critical breakdown voltage and transient recovery voltage:

$$U_p = U_b - TRV \qquad (7)$$

In the formula (7), U_b is the SF_6 gas critical breakdown voltage. TRV is transient recovery voltage. The circuit breaker can successfully open circuit when U_p always greater than zero in the interrupting process, otherwise, it would be renewed.

According to the simulation results, the circuit breaker when the speed of 11m/s, 9m/s, 7m/s, 6m/s were successful in breaking. The difference between critical breakdown voltage and transient recovery voltage is shown in Figure 5. When the breaking velocity was less than 6m/s, the reignition will occur in the circuit breaker, which will lead to breaking failure. The reasons of reignition are breaking distance at the extinction moment being small, electric field intensity between the contacts being large, and the critical breakdown voltage being less than the transient recovery voltage. The difference U_p between critical breakdown voltage and transient recovery voltage is shown in Figure 6. When the breaking velocity is 6m/s, the velocity curve is shown in Figure 7.

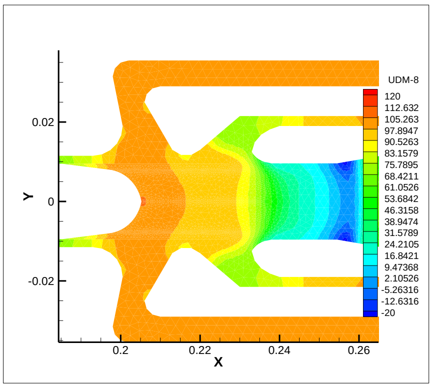


Fig. 5 The Minimum U_p *With Velocity of 6m/s*

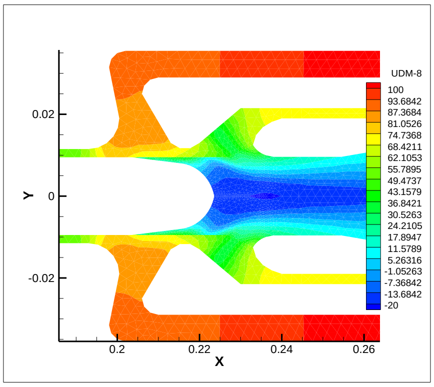


Fig. 6 The Minimum U_p *With Velocity of 5.9m/s*

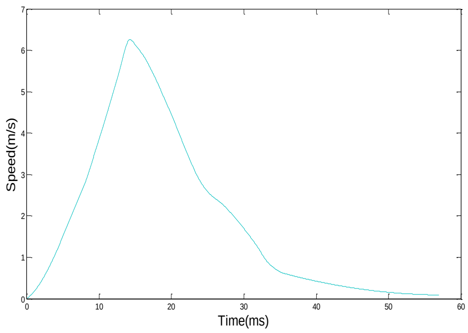


Fig. 7 The Curve When Velocity is 6m/s

5. CONCLUSION

Through the simulation calculation of the flow field and the electric field of the 126kV SF_6 circuit breaker arc-extinguishing chamber, the distribution of density, temperature and electric field intensity were obtained. According to the criterion of the streamer breakdown theory, the breakdown voltage of the arc-extinguishing chamber was obtained. On this basis, by altering the breaking velocity and analysing the influence of different breaking velocity on the breaking process, following conclusion can be drawn:

(1)When the breaking velocity of circuit breaker is comparatively low, the distance between the contacts during arc extinguishing time will be small, and the electric field intensity between the contacts will be large. Critical breakdown voltage may be less than the transient recovery voltage, therefore, the probability of reignition will increase.

(2) For the 126kV SF_6 circuit breakers, when the breaking velocity is less than 6m/s, reignition phenomenon will occur in the breaking process; when the breaking velocity is greater than 6 m/s and with no other requirements for circuit breaker performance capacity attached, the circuit breaker will operate breaking process successfully. The speed curve can provide a reference to optimization design of circuit breaker.

ACKNOLEDGMENT

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