NUMERICAL STUDY ON SELF-EXCITED OSCILLATION SWITCHING CURRENT IN HVDC MRTB

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ABSTRACT

This paper presents the numerical study of current self-excited oscillations during the opening of HVDC metallic return transfer breaker (MRTB). The switching arc is simulated using magneto-hydrodynamics (MHD) theory coupled with the electric circuit variation. The calculated result gives good agreement with the experiment, and shows that the arc model can accurately simulate the current oscillation and the commutation process in MRTB. The MRTB prototype in this study is designed to break about 5.2 kA of DC current. The results from both simulation and experiment show that the current oscillation starts at about 16.5 ms and the total arc time is about 24 ms when the commutation capacitor bank and inductor are 72 μF and 173 μH, respectively. This study can help improve the current interruption capability of MRTB.

1. INTRODUCTION

In recent years, ultra long distance high voltage (HV) power transmission has achieved a rapid development in China. The continuously increasing demand for electric power and the economic access to remote renewable energy sources such as off-shore wind power or solar thermal generation in deserts [1]-[2] require an electric energy transmission system that bridges very long distances with low losses.

In the HV power system, metallic return transfer breakers (MRTBs) are installed to eliminate ground faults on the neutral return line. It is extremely difficult to make the direct current dropped to zero by increasing arc voltage like the magnetic blow direct current circuit breakers (DCCBs). As mentioned in previous literatures [1]-[3], MRTB is usually employing a method that produces current zero-cross points by superimposing a self-excited oscillatory current on a direct arc current.

The previous theoretical studies of MRTB are based on the Cassive-Mayr arc model [4]-[6], assuming the arc resistivity along with the change of stored energy, and the electric arc thermal scattering from the surface. The parameters in the model, such as the arc time constant and arc conductance, have to be obtained from experiments. But in recent years, the magneto-hydrodynamics (MHD) theory has been used in researches of arc phenomenon [7]-[10], where the physical mechanism of the arc phenomenon in the real product is simulated. In this paper, the self-excited oscillatory switching current and the commutation process in a prototype of MRTB, which is designed to break about 5.2 kA of direct current, are simulated on MHD theory.

2. MRTB PRINCIPLE

According to the different structures, MRTBs can be divided into self-excited HVDC circuit breaker and separately-excited HVDC circuit breaker. This paper is focused on the self-excited CB.

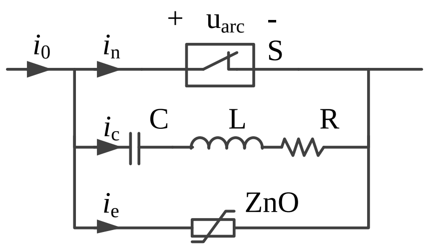


Fig. 1 Structure of Self-Excited Oscillation DC Breaker

Fig. 1 shows the structure of the MRTB. The commutation branch, a self-excited oscillation circuit consisting of a capacitor *C* and an inductor *L*, is coupled in parallel with the circuit breaker *S*. When the circuit breaker opens, a high-frequency current i_c is generated by self-excitation in the circuit breaker arc and the *LC* circuit loop. The ZnO arrester suppresses overvoltages generated following current interruptions, and absorbs the energy in the power system.

The advantage of this type of DCCB is that the SF_6 circuit breaker in normal current branch does not need to counteract the full voltage of the power system and absorb all of the stored energy in system inductance. It is only used for the current commutation. This is the reason why it can be used in ultra-high voltage transmission power system [2]. Meanwhile, there are no active elements to be controlled and the structure is relatively simple, so the reliability of this DCCB is better. However, there have to be more than 10 ms to make the increasing oscillatory current start, and the total breaking time will be even longer [6]. This disadvantage makes the application of this DCCB limited in some cases requiring very fast current interruption capability.

3. MATHEMATICAL MODELS

In Fig. 1, the circuit equations are given by

$$\frac{1}{C}i_c + L\frac{d^2 i_c}{dt^2} + R\frac{di_c}{dt} = \frac{du_{arc}}{dt} \tag{1}$$

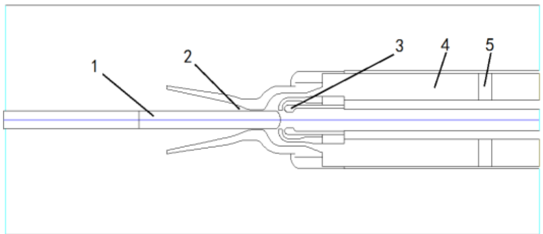
$$i_0 = i_n + i_c \tag{2}$$

where

u_{arc} arc voltage;
i_c current of commutation branch;
i_0 DC current;
i_n switching current of circuit breaker *S*;
L inductance of commutation branch;
C capacitance of commutation branch;
R circuit resistance of commutation branch.

Based on the analysis of MRTB working principle, the SF_6 arc phenomenon is the most important problem to improve the current interruption capability. An AC SF_6 circuit breaker is used as the key component of MRTB. The simplified geometric model of the SF_6 circuit breaker is shown in Fig. 2.

In this paper, we define the arc voltage as a



1- Fixed Arc Contact 2- Nozzle 3- Moving Arc Contact 4- Compression Chamber 5- Piston.

Fig. 2 Simplified Geometric Model of the SF_6 Circuit Breaker

Table 1 Terms of Governing Equations

Equation	ϕ	Γ_ϕ	S_ϕ
Mass Continuity	1	0	0
Axial Momentum	v_z	μ_e	S_{vz}
Radial Momentum	v_r	μ_e	S_{vr}
Enthalpy	h	k_e/c_P	S_h
Electron Potential	V	σ	0

scalar quantity and the arc density as a vector with axial and radial components j_z and j_r in the MHD arc model, which is coupled with the circuit equations (1) and (2) by the boundary condition.

In order to treat the problem, we make the following assumptions:
(a) The plasma flow is the two-dimensional axisymmetric and transient state.
(b) The continuum assumption is valid where the plasma is considered as a Newtonian fluid following Navier–Stokes equations.
(c) The plasma gas is assumed to be pure SF_6 in local thermodynamic equilibrium (LTE).
(d) Hall currents and gravitational effects are considered to be negligible.

Numerical analysis of the circuit breaker needs to solve both hydrodynamics and electro-magnetic field simultaneously. The behavior of the arc, its surrounding flow, and the flow in other parts connected to the nozzle interrupter are described by modified Navier-Stokes equations including the Lorentz force as the additional source of momentum and Ohmic heating and radiation loss as the sources in the energy equation. The general form of the governing equations is:

$$\frac{\partial(\rho\phi)}{\partial t} + \nabla\cdot(\rho\phi\vec{v}) - \nabla\cdot(\Gamma_\phi \nabla\phi) = S_\phi \tag{3}$$

where ϕ is the dependent variable, ρ is the gas density, and $\vec{v}$ is the velocity having axial and radial components, v_z and v_r . Γ_ϕ is the diffusion coefficient, and S_ϕ is the source term. Terms of governing equations are listed in Table 1.

In Table 1, h and V are enthalpy and electric potential, μ_e and k_e are effective viscosity and effective thermal conductivity, c_P and σ are the specific heat at constant pressure and electric conductivity, respectively. The azimuthal magnetic induction at a radius r can be calculated by Ampere's circuital law,

$$B(\mathrm{r}) = \frac{1}{\mu_0 r}\int_0^r j_z r' dr' \quad (4)$$

where μ_0 is the vacuum permeability.

The boundary conditions are set according to the theories of hydrodynamics, electromagnetic field and heat transfer. All are treated in the same way as [9]. The MHD arc model and circuit equations (1) and (2) are coupled by:

$$j_F = i_n / \pi a^2 \quad (7)$$

$$V_F = u_{arc} \quad (8)$$

where j_F and V_F are the specific flux and value of electron potential at the boundary of the fixed arc contact, respectively. And a is the radius of the fixed arc contact.

4. RESULT AND ANALYSIS

The MHD arc model coupled with circuit equations in MRTB is calculated with the FLUENT software.

Fig. 3 and Fig. 4 show the diagrams of temperature and pressure distribution during the interruption process, respectively. The velocity field distribution at 20 ms during the interruption is shown in Fig. 5. It is worth mentioning that the capacitor bank C and inductor L are 72 μF and 173 μH in this case, respectively The dynamic mesh technology is involved in our model to describe the contact and piston moving process. The detail of the interruption can be clearly seen from the results. The arc is gradually elongated with the movement of the contacts. The piston compresses the SF_6 gas in the chamber and

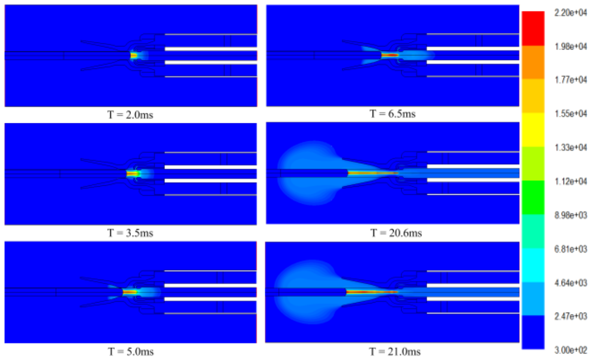


Fig. 3 Temperature Distribution during Interruption

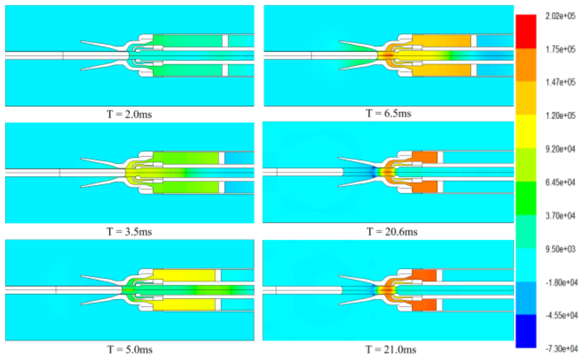


Fig. 4 Pressure Distribution during Interruption

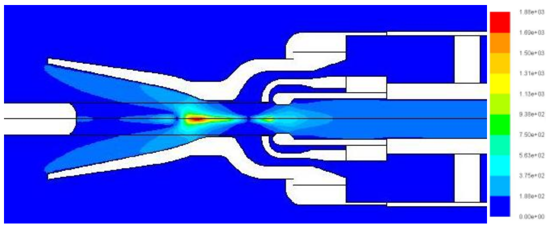
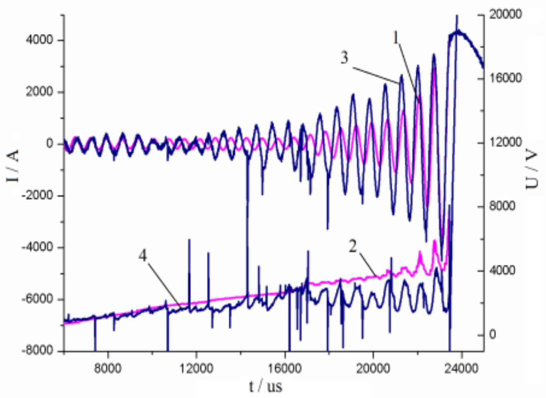


Fig. 5 Velocity Distribution during Interruption

creates a high-pressure zone at the upstream region of the nozzle. The strong gas blowing process occurred when the static contact is pulled out from the nozzle eventually is also simulated. It's found that the maximum value of the velocity is about 18800 m/s (Fig. 5) at the downstream region of the nozzle, it's mainly due to the high pressure gradient in the throat area and the arc heating of the gas.

The comparisons of current oscillations of commutation branch and arc voltage obtained in simulation and in experiments are shown in Fig. 6. Curve 1 and 2 are the calculated arc voltage and current, respectively. Curve 3 and 4 are the experimental arc voltage and current, respectively. It can be seen that the calculated curve gives good agreement with that obtained by the experiment.



1, 2- Calculated arc voltage and current oscillation of commutation branch
3, 4- Tested arc voltage and current oscillation of commutation branch
Fig. 6 Current Oscillation and Interruption

In addition, there is a notable phenomenon in the results. From the time instant of t=16.5 ms, the cold SF_6 gas in the chamber is compressed further and arc is still being elongated. The SF_6 gas blowing effect in the nozzle becomes to be more intense. As a result, the arc plasma becomes more unstable, the amplitude of arc voltage oscillation starts to increase as well as the arc current. According to the research results, the current oscillations have a strong relationship with the gas blowing process and the arc length.

5. CONCLUSION

The current oscillation in a typical MRTB is investigated by the simulation approach in this paper. The numerical model is based on the MHD theory and the calculated arc behaviors are presented by the temperature and pressure distribution sequences. The calculated oscillating current and arc voltage are validated by the experimental results.

This study will be very valuable for us to reveal the physical mechanism of the oscillation process and improve the interruption capacity of MRTB and other self-excited oscillation DCCB.

ACKNOWLEDGE

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