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NUMERICAL ANALYSIS OF LOW VOLTAGE ARC MOTION PROCESS AT VARIOUS FREQUENCIES

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Abstract. A three-dimensional (3D) magneto-hydro-dynamic (MHD) model of air arc plasma is built to investigate the frequency effects on the arc motion process with different number of splitter plates. Based on this model, the arc voltage and current density are obtained. The arc motion time is normalized with the frequency and compared at different numbers of splitter plate. The result shows that the normalized time and the arc voltage peak increase with increases of the number of splitter plate.

Keywords: magneto-hydro-dynamic (MHD), eddy current, frequency, motion process.

1. Introduction

In permanent magnet wind power generation systems, the frequency of the output current may vary from several Hz to about 200 Hz. Air circuit breaker (ACB) is a crucial component for controlling and protecting the power distribution network, which requires the ACB should switch off the short-circuit current of various frequencies [1]. Therefore, it is important to study the influence of frequency on the arc motion process.

Many studies have focused on the arc motion of low voltage circuit breaking. Lindmayer et al analyzed the process of arc splitting [2, 3]. McBride et al studied the back commutation phenomena of arc by experiment [4]. Iturregi et al analyzed the influence of the number of splitter plate on arc voltage at direct current (DC) situation [5]. The formulations to calculate eddy currents in electrodes and splitter plate were developed and the eddy current effect on the arc splitting process was simulated [6]. But the influences of frequency and the number of splitter plates at higher frequency on arc motion are not clear.

In this paper, a 3-D MHD model is built to investigate the influence of frequency on air arc motion process with different number of splitter plates. The potential vector approach is adopted to calculate the time-varying electromagnetic field. The eddy current in whole calculated domains is considered. The influences of frequency and the number of splitter plate on the arc motion are analyzed by the arc voltage, the current density distribution sequences and the normalized time.

2. Numerical geometry and method

Fig.1 shows the computational domain for the fluid. A 1/2 symmetric model is adopted. The dimension of the model is $3 \times 11 \times 30$ mm in the x-y-z direction, and the origin of the coordinate is on the symmetry plane ($x = 0$). The far-away domain is built to calculate the magnetic field. The arc current is imposed on the surface "current inlet", and the value is set to $i = 600\sqrt{2}\sin(\omega t + \pi/12)$. The electrical potential is set to zero on the surface "current outlet" as shown in Fig.1. The 0.1 mm sheaths surrounding electrodes and splitter plate are applied to describe the formation of new arc roots and represent the electrode voltage drop. The electrical conductivity of sheath is calculated by nonlinear voltage-current density characteristic [5]. The distance of two electrodes is 8 mm and the materials of electrodes are copper. The splitter plate is ferromagnetic material, and the B-H curve is applied. The transport coefficients and thermodynamic properties of air plasma vary with temperature and pressure [7]. The radiation energy source term is calculated using the net emission coefficient (NEC) method [8].

The electro-magnetic equations are solved by means of ANSYS Emag. And the N-S equations of describe the arc plasma are solved by means of ANSYS Fluent. The date exchange between the two solvers is provided by the coupling server MpCCI [9].

3. Simulation results and analysis

The current density distribution and arc voltage obtained by simulation. The influence of the number of splitter plate and frequency on arc motion will be analyzed.

3.1. Influence of splitter plate number

Fig.2 shows the current density distribution sequences on the symmetry plane of 1SP and 2SP model at f=50 Hz. The negative value of current density indicates the current is along the negative direction of y-axis. We define the four typical position a, b, c, d of arc motion as shown in Fig.2 (a),(b),(c) and (d)

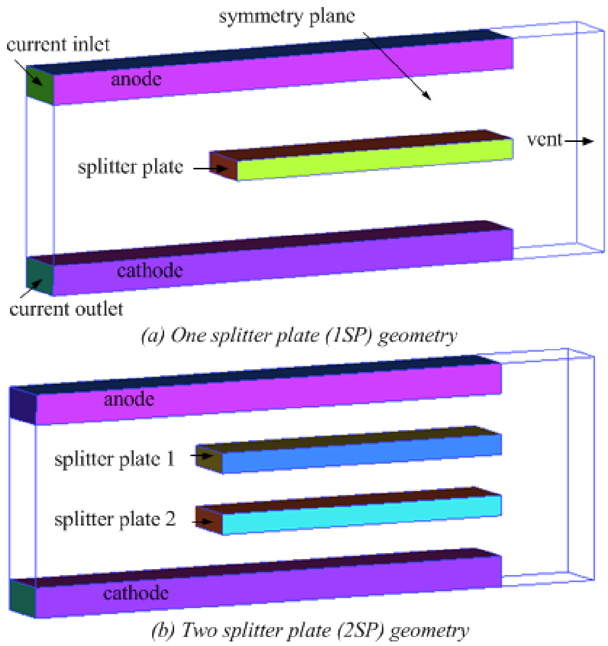

Figure 1. Numerical geometry for fluid domain.

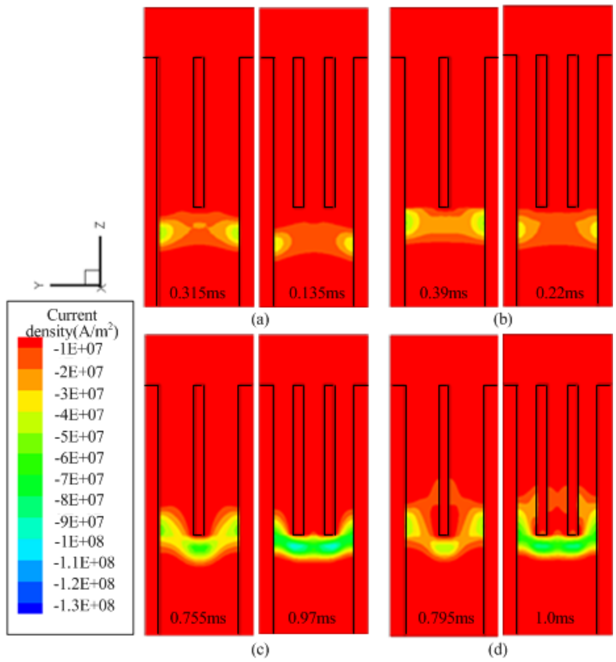

Figure 2. Current density distribution sequences on the symmetry plane at 50 Hz.

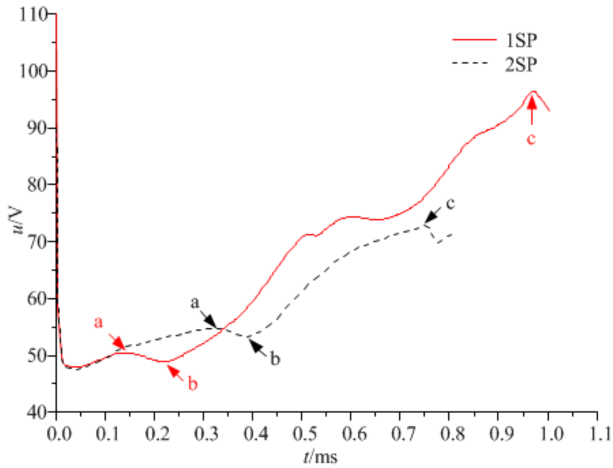

Figure 3. Arc voltage of simulation results at 50 Hz. (a,b,c represent the position a,b,c)

respectively. Fig.3 shows the arc voltages of 1SP and 2SP model. The trend of arc voltage is consistent for 1SP and 2SP model. For 1SP model, after arc ignition, the arc elongated until t=0.315 ms in Fig.2 (a). The arc voltage increases up to 54.7 V. From t=0.315 ms to t=0.39 ms in Fig.2 (b), the arc column is squeezed by splitter plate and the arc voltage decreases to 53.3 V at 0.39 ms. After 0.39 ms, the arc roots move along the electrode surfaces, and the arc column bends and stretches gradually due to the blocking effect of the relative cold splitter plate. The arc voltage achieves the peak value of 72.87 V at t=0.755 ms in Fig.2 (c). At t=0.795 ms as shown in Fig.2 (d), the new arc roots form on splitter plate surface and there are two clearly visible parallel current paths, which leads to the decreases of arc voltage.

For 2SP model, the arc column is squeezed by splitter plate from t=0.135 ms to t=0.22 ms. The arc column bends and the arc voltage increases after t=0.22 ms. At t=0.97 ms, the arc voltage reaches to its peak value of 96.46 V. The new arc roots form on the splitter plate and arc voltage decrease at t=1.0 ms. There is no obvious difference on the arc voltage between 1SP and 2SP model before 0.135 ms.

Fig.4 shows the current density distribution of 1SP and 2SP model at t=0.25 ms when f=50 Hz and f=200 Hz. It is found that the arc roots position of 2SP model are closer to the splitter plate at the same frequency, which because the attraction effect of the ferromagnetic splitter plate is enhanced in 2SP model. The cross-sectional area of arc column is larger at higher frequency due to the arc current increasing with the increase of frequency at the same time.

3.2. Influence of frequency

Fig.5 shows the simulation results of current density under various frequencies (50 Hz, 100 Hz, 200 Hz) for 1SP model. The formation of new arc roots on the splitter plate surface is the fastest at 200 Hz. This is because the Lorentz force of higher frequency is greater at the same time. Fig.6 and Fig.7 show the arc voltage of 1SP and 2SP model under various frequencies. The time of arc voltage reaching its peak will be delayed with the decrease of frequency. The arc voltage peak increase by 0.48 % and 3.6 % for 1SP model and it increase by 1.9 % and 3.8 % for 2SP model, when f increases from 50 Hz to 100 Hz and 200 Hz. The reason is that the effective resistance of arc column increases due to the higher skin effect at higher frequency.

We define the normalized time to analyze the influ-

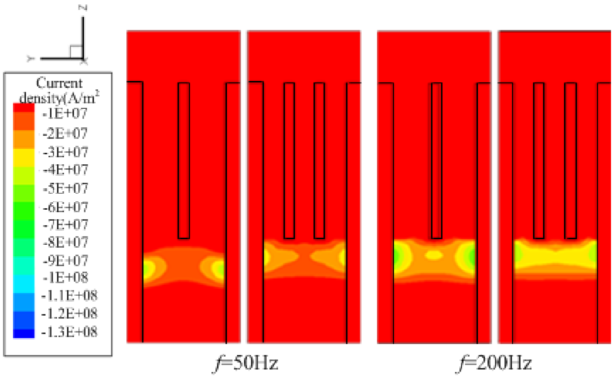

Figure 4. Current density distribution at t=0.25 ms.

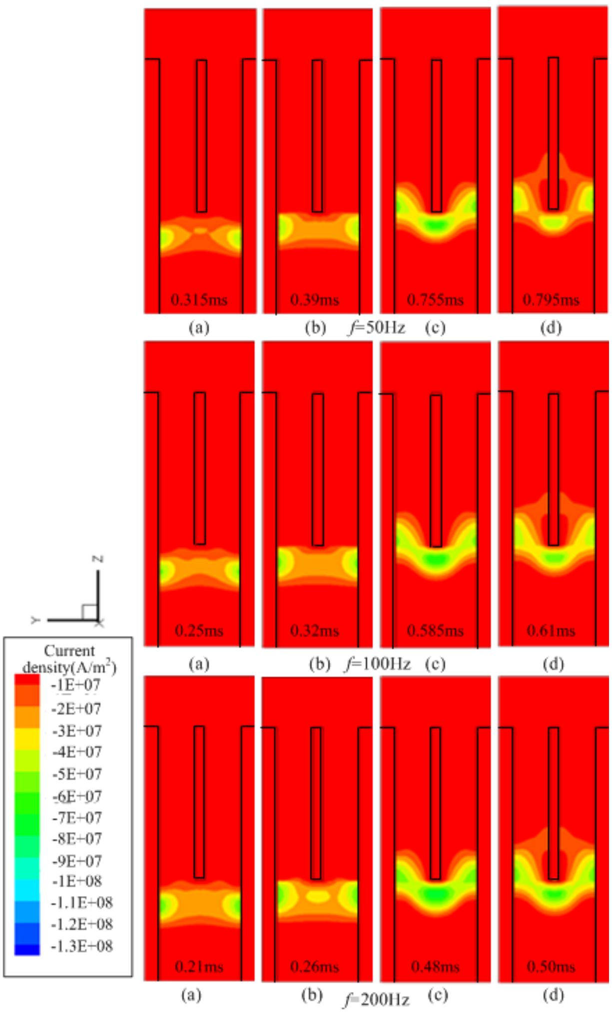

Figure 5. Current density distribution sequences on the symmetry plane under various frequencies.

ence of frequency on arc motion:

$$t_{\mathrm{n}} = \frac{t_{\mathrm{r}}}{T} \quad (1)$$

Where, t_{r} is the time when the arc moves to the same position at various frequencies (50 Hz, 100 Hz and 200 Hz), T is the current cycle of various frequencies. The t_{n} is normalized time of various frequencies in different positions are shown in Fig.8 (1SP) and Fig.9 (2SP). It is found that the normalized time t_{n}

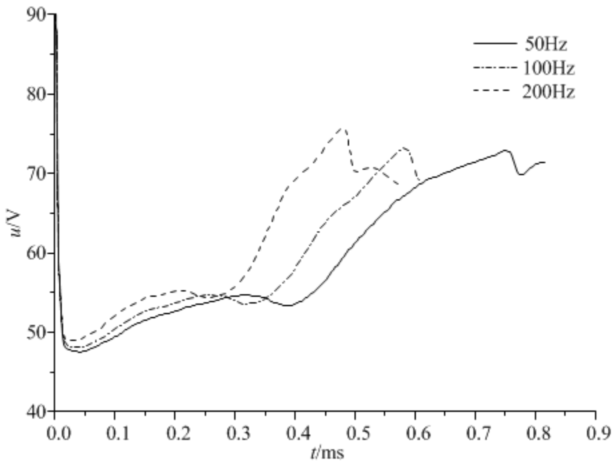

Figure 6. Comparison of the arc voltage under various frequencies 50 Hz, 100 Hz, 200 Hz(1SP).

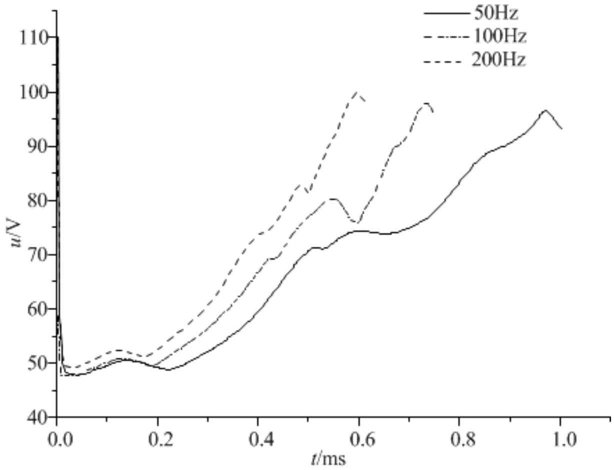

Figure 7. Comparison of the arc voltage under various frequencies 50 Hz, 100 Hz, 200 Hz(2SP).

increases with the increase of frequency because the hindering effect to arc motion by the eddy current in the splitter plate is larger for higher frequency.

In position a, the normalized time increase by 58.7 % and 167 % for 1SP model and it increase by 92.6 % and 278 % for 2SP model, when f increases from 50 Hz to 100 Hz and 200 Hz. In position b, the normalized time increase by 64.1 % and 167 % for 1SP model, and it increase by 72.7 % and 213.6 % for 2SP model, when f increases from 50 Hz to 100 Hz and 200 Hz. Therefore, the hindering effect of eddy current was enhanced with the increase of splitter plate.

4. Conclusions

A 3-D MHD model is built to investigate the influence of frequency on the air arc motion. It can be concluded that:

1. The arc motion velocity of two splitter plates model is faster than the one splitter plate model at the same frequency.

2. The new arc roots formation on splitter plate of

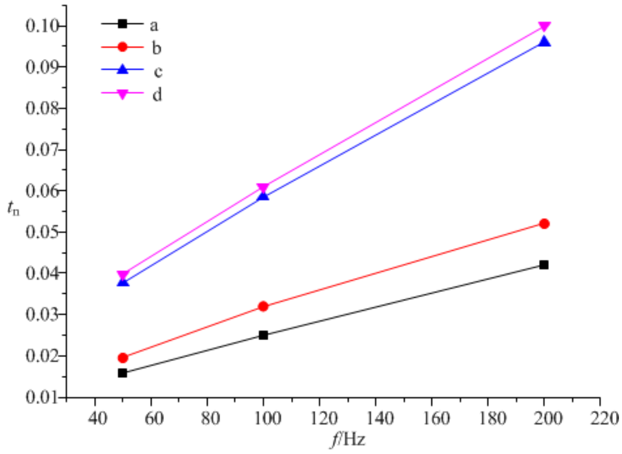

Figure 8. Normalized time of arc motion under various frequencies 50 Hz, 100 Hz, 200 Hz (1SP).

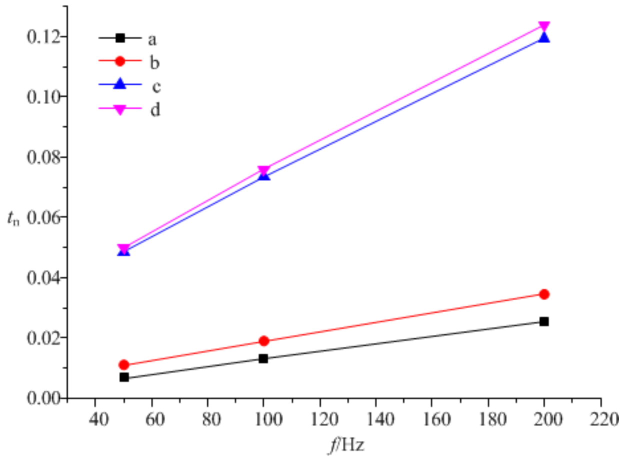

Figure 9. Normalized time of arc motion under various frequencies 50 Hz, 100 Hz, 200 Hz (2SP).

two splitter plates model is slower than one splitter plate model. And the arc voltage peak is higher in two splitter plates model.

3. The normalized time reflects the hindering effect of eddy current on arc motion, and it increases with the increase of frequency. And the growth rate is larger in two splitter plates when f increases from 50 Hz to 100 Hz and 200 Hz.

Acknowledgements

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