J. Basic. Appl. Sci. Res., 2(5)4377-4381, 2012

ISSN 2090-4304
Journal of Basic and Applied Scientific Research
www.textroad.com

Dynamic Arc Modelling Based on MHD Equations for SF_6Circuit Breaker Using FEM

***DiakoAzizi[1], SajadSadr[2], Ahmad Gholami[3], Dear Azizi[4]**

[1]Department of Electrical Engineering, West Tehran Branch, Islamic Azad University, Tehran, Iran
[2,3]Department of Electrical Engineering, Iran University of Science and Technology, Tehran, Iran
[4]Department of Mechanical Engineering, Science and Research Branch, Islamic Azad University, Tehran, Iran

ABSTRACT

In this paper, a dynamic arc model based on MHD (Magneto Hydro Dynamic) equations for a high voltage(HV) SF6 interrupter has been investigated and analyzed. Moreover,for simulating the insulating performance and interruptingcharacteristics of the SF6 interrupter, dynamic variation of thearc, such as arcmoving in the presence of Lorentz force have been established,and the compressibility and viscosity of SF6 gas in the whole interruptingcourse has been taken into consideration.The mass-fraction equation is introducedto the model on the basis of traditional mass, momentum, andenergy-balance equations.The distributions of temperature field,pressure field, and mass fraction in the arc chamber are calculated.
Keywords: Arc, dynamic, electromagnetic, mass, simulation.

1. INTRODUCTION

SF6 gas is widely used as an insulation and arc-quenching medium in electric apparatus because of its excellent insulating performance in uniform electric field and extended in HV, extra HV, and ultra HV circuit breakers (CBs). The kernel problem to be investigated is dielectric recovery characteristic and interrupting performance, which mainly depend on the combined effects of the electric field and gas flow state in the arc quenching chamber during the interrupting process and the arc energy dynamic simulation. The interrupting process in a CB involves different phases, and considerable knowledge has been covered in the understanding of the physical processes, which bring great difficulties for investigating the opening property [1]. Moreover, flow field computation within the SF6 interrupting is extremely difficult due to the complex flow path with stride sonic flow, active, viscous, compressible, variable boundary, and some intricate physical phenomena, such as shock waves and vortices during interrupting. Recently, inherent weakness has been reported lying in the simplifications of computing structure and arc modeling. The aim of this paper is to solve the numerical problem with complex flow path and space-time processing synchronously, a coupled field mathematical model of electric field and flow field has been established.

2. Model description

The simple model presented in this paper assumes 2-D axisymmetric lamp geometry. The discharge is assumed to be in local thermodynamic equilibrium (LTE). The difference reported between the LTE and non-LTE electrical conductivities were in the cathode-sheath [2], where the electrical conductivity is generally very low. Therefore, a non-LTE situation in such lamps would be very local and its effect on total lamp characteristics may not be significant. In this paper the model that presented in [3], has been used.

The following are the set of equations that are solved in the steady-state system:

1) Mass continuity

$$\frac{\partial}{\partial z}(\rho u)+\frac{1}{r}\frac{\partial}{\partial r}(r\rho v)=0 \qquad (1)$$

2) Momentum conservation

$$\frac{1}{r}\frac{\partial}{\partial z}(r\rho uu)+\frac{1}{r}\frac{\partial}{\partial r}(r\rho uv)=-\frac{\partial\rho}{\partial z}+F_z-\rho g+\frac{\partial}{\partial z}\left(2\mu\frac{\partial u}{\partial z}\right)+\frac{1}{r}\frac{\partial}{\partial r}\left[r\mu\left(\frac{\partial u}{\partial r}+\frac{\partial v}{\partial z}\right)\right] \qquad (2)$$

$$\frac{1}{r}\frac{\partial}{\partial z}(r\rho uv)+\frac{1}{r}\frac{\partial}{\partial r}(r\rho vv)=-\frac{\partial\rho}{\partial r}+F_r+\frac{1}{r}\frac{\partial}{\partial r}\left(2r\mu\frac{\partial v}{\partial r}\right)+\frac{\partial}{\partial z}\left[\mu\left(\frac{\partial u}{\partial r}+\frac{\partial v}{\partial z}\right)\right]-\frac{2\mu v}{r^2} \qquad (3)$$

3) Energy conservation

$$\frac{\partial}{\partial z}(u\rho H)+\frac{1}{r}\frac{\partial}{\partial r}(rv\rho H)=\frac{\partial}{\partial z}\left(\frac{k}{C_p}\frac{\partial H}{\partial z}\right)+\frac{1}{r}\frac{\partial}{\partial r}\left(\frac{k}{C_p}\frac{\partial}{\partial}(rH)\right)+\frac{5k}{2e}\left(\frac{J_z}{C_p}\frac{\partial H}{\partial z}+\frac{J_r}{C_p}\frac{\partial H}{\partial r}\right)+\sigma E^2-R-div\left[h_{H_g}\vec{j}_{\ \ H_g}+h_{Ar}\vec{j}_{Ar}\right] \qquad (4)$$

***Corresponding Author:** DiakoAzizi, Department of Electrical Engineering, West Tehran Branch, Islamic Azad University, Tehran, Iran. Tel:+989128195358 Email: azizi@iust.ac.ir

4) Chemical species conservation for Ar

$$\frac{\partial}{\partial z}(u\rho m_{Ar}) + \frac{1}{r}\frac{\partial}{\partial r}(v\rho m_{Ar}) = -\frac{\partial}{\partial z}\left(\rho D_{Ar.m}\frac{\partial m_{ar}}{\partial z}\right) - \frac{1}{r}\frac{\partial}{\partial r}\left[\rho D_{Ar.m}\frac{\partial}{\partial r}(rm_{Ar})\right] \quad (5)$$

The solution of argon-mass concentration helps to calculate the mercury-mass concentration automatically since the total mass concentration of Ar and Hg is 1.

5) Curl of Ampere's law for magnetic field

$$\frac{\partial}{\partial z}\left(\frac{\partial B_\theta}{\partial z}\right) + \frac{1}{r}\frac{\partial}{\partial r}\left(r\frac{\partial B_\theta}{\partial r}\right) = \frac{B_\theta}{r^2} + \mu_0\frac{J_z}{\sigma}\frac{\partial\sigma}{\partial z} \quad (6)$$

6) Laplace's equation for electrostatic potential

$$\frac{\partial}{\partial z}\left(\sigma\frac{\partial V}{\partial z}\right) + \frac{1}{r}\frac{\partial}{\partial r}\left(r\sigma\frac{\partial V}{\partial r}\right) = 0 \quad (7)$$

Where, σ and k are the electrical and thermal conductivities; ρ, μ, C_p, and H are the mass density, viscosity, heat capacity and enthalpy, respectively; h_{Hg} and h_{Ar} are the enthalpies of Hg and Ar, respectively; $\vec{J}_{Hg}$ and $\vec{J}_{Ar}$ are the diffusion fluxes of Hg and Ar respectively; m_{Ar} and $D_{Ar,m}$ are the local mass concentration and diffusion coefficient of Ar, respectively; u and v are the axial and radial velocities, respectively; B_θ is the azimuthal component of the magnetic field intensity; F_z and F_r are the axial and radial Lorentz forces, respectively; V is the electrostatic potential; J_z and J_r are the axial and radial current densities, respectively; and g, e, E and μ_0 are the gravitational acceleration, electronic charge, electric field intensity and permeability of free space, respectively. R on the right-hand side of the energy equation represents the volumetric radiated loss and it is included into the calculation scheme using either the net emission coefficient or mean absorption coefficient

$$R = 4\pi\varepsilon_N = \alpha(4\pi B - G) \quad (8)$$

Whereε_N, α, B, and G are the net emission coefficient, absorption coefficient, Plank's function, and incident radiation (or integrated incident radiation over all solid angles), respectively. The P-1 radiation model is employed when the mean absorption coefficient is used to calculate the mean incident radiation and, thus, the radiation loss. Note that the mean absorption coefficient and the mean incident radiation are the averaged absorption coefficient and incident radiation over a band. A Helmoltz- type equation of the following form is solved for the mean incident radiation G_i of the band i when the P-1 model is used:

$$\frac{\partial}{\partial z}\left(\frac{1}{3\alpha_i}\frac{\partial G_i}{\partial z}\right) + \frac{1}{r}\frac{\partial}{\partial r}\left(r\frac{1}{3\alpha_i}\frac{\partial G_i}{\partial r}\right) = -\alpha_i(4\pi B_i - G_i) \quad (9)$$

3. Case study

The following assumptions were made to reduce the complexity of the simulation because ithas been interested in the motion of the arc column rather than the chemical processesof the arc.

1) The plasma studied was assumed to satisfy the conditions for local thermodynamic equilibrium, and the flow was laminar [4]–[6].

2) The arc–electrode interaction was not modeled.

3) The plasma was considered to be high-temperature air with the thermodynamic and transport properties obtained from the literature [7-11]. The physical properties, including thermal conductivity, viscosity, density, specific heat, and electrical conductivity, were functions of the plasma temperature and pressure.

4) The plasma was assumed to be electrically neutral. This condition was nearly exactly fulfilled with the arc column. However, this so-called sheath region, i.e., space charge region close to the electrode with violated quasineutrality, was ignored since the behavior of the plasma in the arc column was the focus of this paper, and its interaction with the surroundings was of primary importance in switching applications.

5) The arc-plasma flow can be regarded as a moving conductor in a magnetic field, and then, it was assumed that the induced current given by the transient terms inMaxwell's equations was small compared to the injected current from the circuit. It was therefore neglected.

6) No ferromagnetic materials in the domain were presented, thus, justifying the use of a constant permeability for the gaseous medium in order to simplify the calculation of the magnetic field.

The arc plasma can then be modeled by the Navier–Stokes equations to describe the mass, momentum, and energyconservation processes, and Maxwell's equations to describe the electromagnetic processes. In addition, in accordance with the physical process of the arc column, to reflect the ohmic heating and radiative cooling, together with the Lorentz force on the plasma due to self-induced and external magnetic fields, it is necessary for the simulation of the arc to include source terms in the energy and momentum equations.

Figure1 shows the calculation model.The calculation plane ABCD was parallel to the electrodesor perpendicular to the arc column. The region geometry was80 × 14 mm, which was just the same as the experimentalmodel. The grid size was 0.2 × 0.2 mm.The boundary conditions are as follows.

1) To boundaries AB, CD, and AD, the adiabatic conditionswere assumed for thermal conditions, and no-slip conditionswere specified for velocity.
2) To full open venting BC, the static pressure was equalto zero, and the temperature was set to environmenttemperature of 300 K.

It was assumed that arc current flowed out from the paperplane, and with the action of external magnetic field of*y*-direction, which was consistent with the experimental conditionsand set to 5 mT, together with the gas flow, the arc maymove toward the venting.

Due to the peak values of current and the ignition current ofthe aforementioned experimental results were all almost equalto 200 and 100 A, respectively, the simulation current could beexpressed by $i = 200 \sin(100\pi t + \pi/6)$.

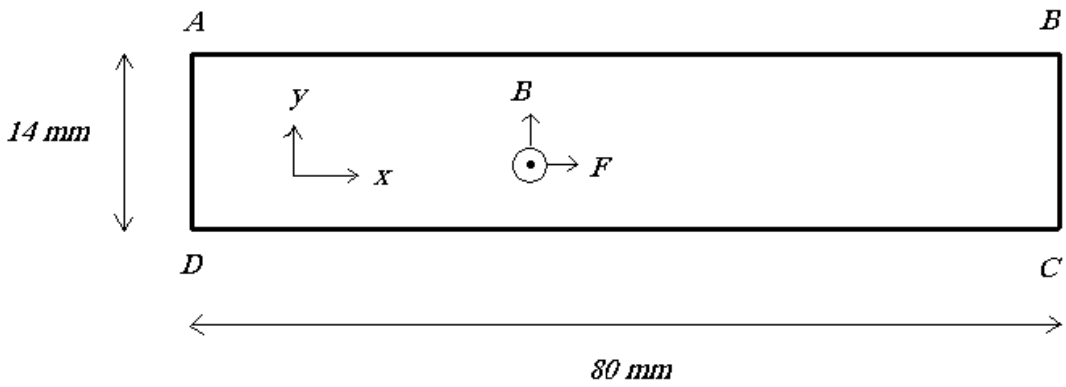

Figure 1: Selected model of arc chamber

5. Simulation and results

Figure 2 shows the temperature distribution of the arc at 1 ms.The arc has been formed in the central part of chamber. It has several layers, very hot, hot, cool and etc. Conductivity of these layers is a function of their temperature. Figure 3 shows temperature distribution of the arc at 10 ms.It can be seen that during less than 10 ms, the arc temperature increases very fast. Significant part of current flows from central part of arc. Following the development of the study, temperature distribution of the arc at 10 ms with the presence of electromagnetic force has been simulated (Figure 4).

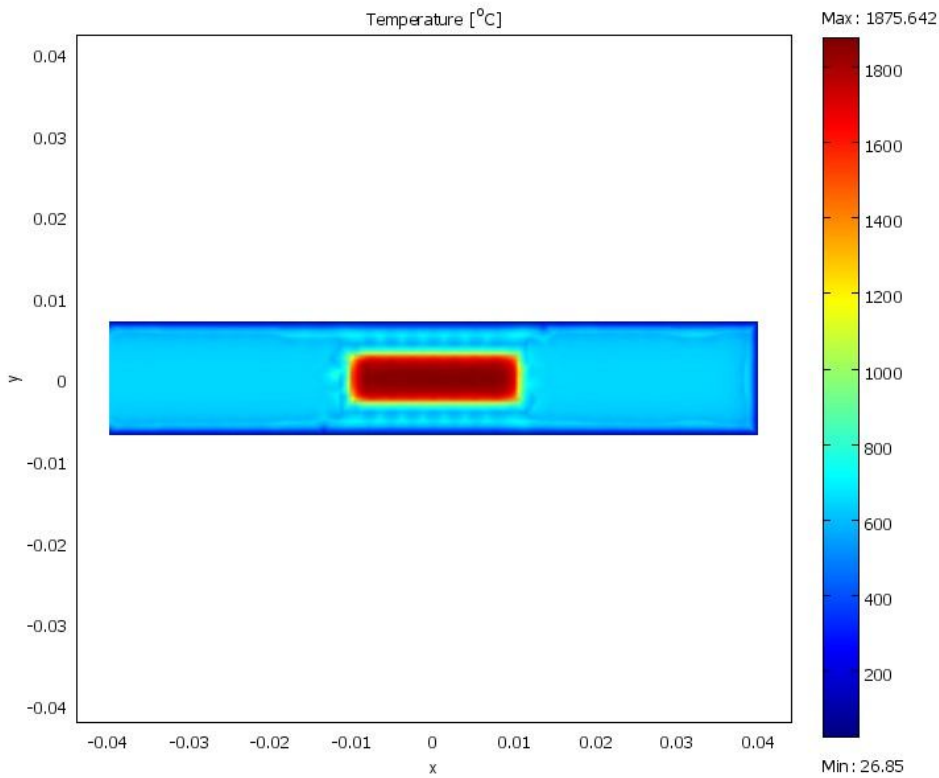

Figure 2: Temperature distribution of the arc at 1 ms

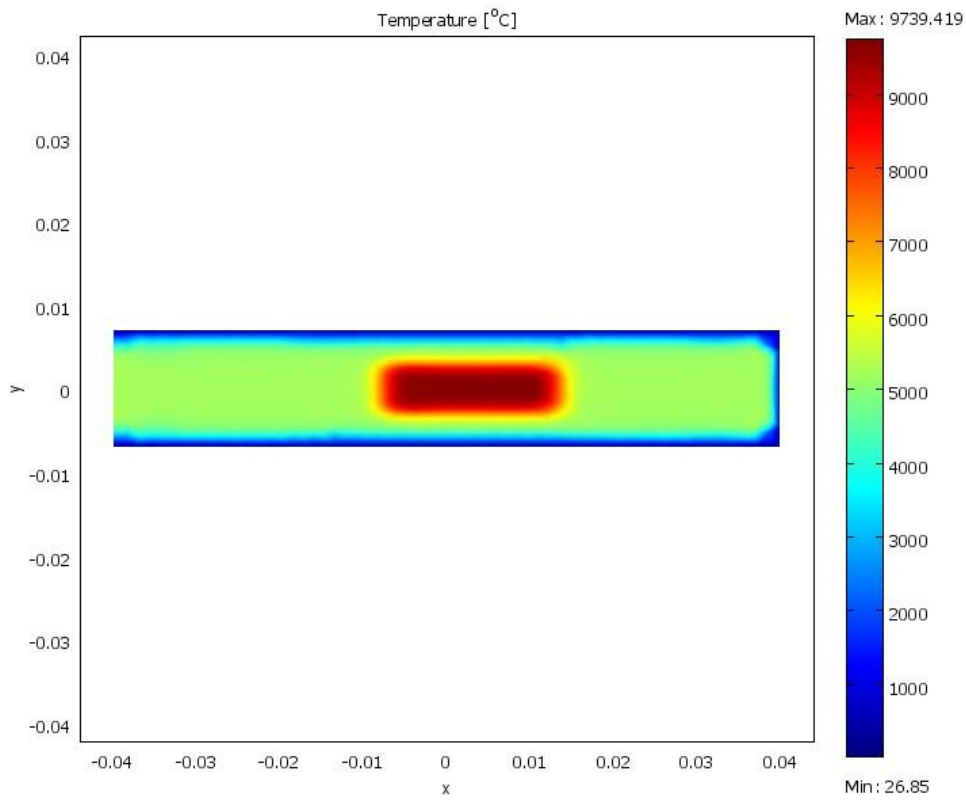

Figure 3: Temperature distribution of the arc at 10ms

Using Navier-Stokes equations, the mobility of arc due to Lorentz force can be simulated. This mechanism is used for better cooling and interrupting of arc in its chamber. This method is widely used in gas circuit breakers.

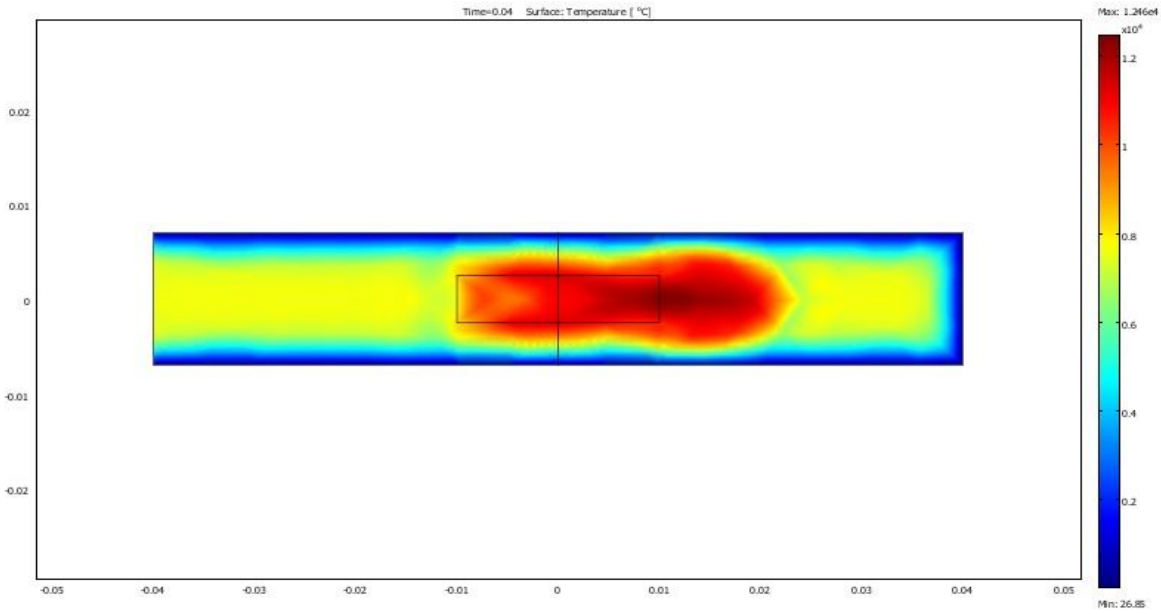

Figure 4: Temperature distribution of the arc at 10 ms with the presence of electromagnetic force

6. Conclusion

This paper presents results for MHD simulation that can be used for studying a SF6 circuit breaker. The P-1 radiation method applied in this work is used to predict the radiation output from the arc. Although this method tends to over predict radiation flux density in optically thin walls, it is computationally efficient and gives reasonably good quantitative information about the temperature profile and radiative flux. Parametric studies using such a model should help reduce the development times for new CB designs. In the example presented in this paper, it has been provided results for a CB with a medium consisting of SF6 gas. The maximum temperature within CB operating at a pressure of 1.1 atm and a current of 200 A is 12000 K. From the study of this paper, the following conclusions couldbe drawn.

1) The arc ignition position has an important effect on thearc-motion process. The less volume behind the arc is,the faster the arc-motion velocity will be.

2) If the back venting is open fully, i.e., the volume behindthe arc is large enough; the arc almost does not moveforward.

3) The arc-motion velocity could be improved significantlywith the action of the gassing material, which also benefitsto improve the interruption performance to someextent.

7. Acknowledgment

The authors gratefully thank West Tehran Branch, Islamic Azad University for supporting this research project.

REFERENCES

[1] Liu Xiaoming, Wang Erzhi, and Cao Yundong, 'Dynamic Arc Modeling Based on Computationof Couple Electric Field and Flow Fieldfor High Voltage SF6 Interrupter', *IEEE Trans. Magn.*, Vol. 40, No. 2, pp. 601–604, March. 2004.

[2] ——, "Numerical simulation of a dc high-pressure discharge lamps including electrodes," J. Phys D, Appl. Phys., vol. 35, pp. 1681–1694, 2002.

[3] K. C. Paul, T. Takemura, H. Matsuno, T. Hiramoto, F. Dawson, J. J. Gonzalez, A. Gleizes, G. Zissis, A. Erraki, and J. D. Lavers, "Predicted results of a HID DC current lamp considering a P-1 radiation model," IEEE Trans. Plasma Sci., vol. 32, no. 1, pp. 118–126, Feb. 2004.

[4] F. Karetta and M. Lindmayer, "Simulation of the gasdynamic and electromagneticprocesses in low voltage switching arcs," *IEEE Trans. Compon.,Packag., Manuf. Technol.*, vol. 21, no. 1, pp. 96–103, Mar. 1998.

[5] H. Rachard, P. Chevrier, D. Henry, and D. Jeandel, "Numerical study of coupled electromagnetic and aerothermodynamic phenomena in a circuit breaker electric arc," Int. J. Heat Mass Transf., vol. 42, no. 10, pp. 1723– 1734, 1999.

[6] A B. Swierczynski, J. J. Gonzalea, P. Teulet, P. Freton, and A. Gleizes, "Advance in low voltage circuit breaker modeling," J. Phys. D, Appl. Phys., vol. 37, no. 4, pp. 595–609, 2004.

[7] J. Yos, Revised Transport Properties for High Temperature Air and Its Components, 1967, Wilmington, MA: Avco Space Systems Division. Technical Release.

[8] B. Halliop, F. P. Dawson, M. C. Pugh, 'A Dynamic Model of a High-Temperature Arc Lamp', *IEEE Trans on Industry applications,* vol. 46, no. 6, 2010.

[9] J. Ribas, J. M. Alonso, A. J. Calleja, E. Lopez, J. Cardesin, J. Garcia, M. Rico, 'Arc Dynamic Stabilization in Low-Frequency Square-Wave Electronic Ballast for Metal Halide Lamps', *IEEE Trans on Power Electronics'*, vol. 2, no. 5, 2007.

[10] Tu. Xin, H. J. Gallon, J. C. Whitehead, 'Dynamic Behavior of an Atmospheric Argon Gliding Arc Plasma', *IEEE Trans on Plasma Science*, vol. 39, no. 11, 2011.

[11] W. Hartmann, A. Lawall, R. Renz, M. Romheld, N. Wenzel, W. Wietzorek, 'Cathode Spot Dynamics and Arc Structure in a Dense Axial Magnetic-Field-Stabilized Vacuum Arc', *IEEE Trans on Plasma Science*, vol. 39, no. 6, 2011.