Temperature Rise Prediction of the Novel Fast Vacuum Circuit Breaker Bus Bar Using a 2-D Coupled Model

Xiao Yu[1], Fan Yang[1], Shaogui Ai [2], Wei Du [3], Xing Li[1], Bing Gao[1]

[1]State Key Laboratory of Power Transmission Equipment & System Security and New Technology, School of Electrical Engineering, Chongqing University, Chongqing, 400044, China, yuxiao@cqu.edu.cn

[2]State Grid Ningxia Power Company, Yinchuan, 750001, China, Aishaogui@yeah.net

[3]Wuhan NARI Limited Company of State Grid Electric Power Research Institute, Wuhan, 430074, China, duweinr@sina.com

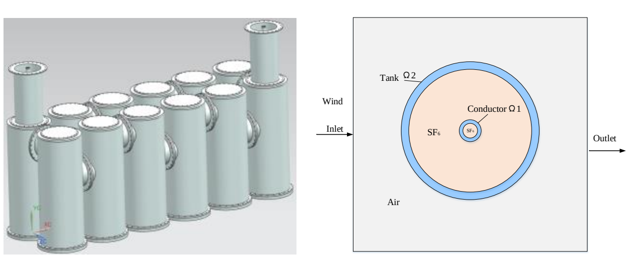
This paper presents a 2-D coupled mathematical model to analyze the temperature rise process of the bus bar of a novel fast vacuum circuit breaker (FVCB). The model couples the electromagnetic, thermal and laminar flow field and takes the impacts of wind, load current and environment temperature into consideration. The complex process of the above multi physical field is simulated, and results for both the steady-state temperature distribution and transient response have been obtained and compared to those predicted by IEC standards. Based on the presented model, the impacts of load current, ambient temperature and wind velocity on the temperature of conductor and tank are analyzed. As a result of the study, an empirical formula to calculate the conductor temperature is obtained to guide the first step of the FVCB design and performance evaluation.

***Index Terms*— Coupled model, Temperature rise, Fast vacuum circuit breaker, Bus bar**

I. Introduction

WITH the rapid development of power system, the general vacuum circuit breakers (VCB) or SF_6 breakers sometimes fail to interrupt the high short circuit current immediately. A 363kV/63kA novel faster vacuum circuit breaker (FVCB) is put forward to interrupt the high current in extremely short time. Its opening time is 5ms. It consists of six VCBs in series and six VCBs in parallel. SF_6 is adopted as the external insulation. For the first step design of FVCB, temperature rise is one of the key indexes of its reliability and performance. Many researches have been carried out on the numerical calculation of similar gas insualted swithgear such as GIB, GIS and bus bar [1-3]. 2-D and 3-D coupled models based on FEM were used to calculate the gas flow field. In these papers, convective heat transfer coefficient and external wind effects are hard to determine. In this paper, we focus on the connector between each tank of the FVCB. The aim of this paper is to develop a model for the effective temperature prediction of the bus bar of FVCB. The problem is described by an electric–magnetic–thermal-laminar coupled model and solved by the COMSOL Multiphysics software.

The structure of the FCVB and the scheme of the bus bar are shown in Fig.1.



(a) Structure of FVCB (b) Scheme of the bus bar

Fig.1 Structure of FVCB

II. Model Description

According to the Maxwell's equation, electromagnetic field governing equation is as follow [4],

$$\nabla \times (\nu \nabla \times \boldsymbol{A}) - \nabla \cdot (\nu \nabla \cdot \boldsymbol{A}) = \boldsymbol{J}_e \qquad \text{in } \Omega_1 \quad (1)$$

$$\nabla \cdot (-\boldsymbol{J}_e \omega \sigma \boldsymbol{A} - \sigma \nabla \varphi) = 0 \qquad \text{in } \Omega_2 \quad (2)$$

Power loss is calculated by following equations,

$$\boldsymbol{J}_t = -j\omega\sigma\boldsymbol{A} + \boldsymbol{J}_e \quad (3)$$

$$Q = \frac{1}{2}\int_s \frac{\left|J_t^2\right|}{\sigma} ds \quad (4)$$

Where $\boldsymbol{A}$ is the magnetic vector potential, the ν is the reluctivity, σ is electrical conductivity, $\boldsymbol{J}_e$ is the source current density, $\boldsymbol{J}_t$ is the total current density, Q is the power loss.

There are three heat transfer modes: heat conduct, convection and radiation. These complex process are governed by a series of equations.

$$\rho C_p \boldsymbol{u} \cdot \nabla T + \nabla \cdot (-k \nabla T) = Q_v \quad (5)$$

$$\nabla \cdot \rho(\boldsymbol{u}) = 0 \quad (6)$$

$$\rho(\boldsymbol{u} \cdot \nabla)\boldsymbol{u} = \nabla \cdot [-p\boldsymbol{I} + \mu(\nabla \boldsymbol{u} + (\nabla \boldsymbol{u})^T) - \frac{2}{3}\mu(\nabla \boldsymbol{u})\boldsymbol{I}] + g\Delta\rho \quad (7)$$

Where ρ, k and μ are, respectively the density, thermal conductivity, and dynamic viscosity, $\boldsymbol{u}$ is the gas velocity, p is the gas pressure, $\boldsymbol{I}$ is the identity matrix, $\boldsymbol{g}$ is the gravity constant, $\boldsymbol{F}$ is the volume force, T is the temperature. Q_v is the volumetric heat source.

Surface radiation boundary of tank and conductor is

$$-k \left.\frac{\partial T}{\partial n}\right|_{\Gamma} = \varepsilon\sigma(T^4 - T_{amb}^4) \quad (8)$$

Constant temperature condition is applied on the air boundary

$$\left.T\right|_{\Gamma} = T_{amb} \quad (9)$$

Where the T_{amb} is the ambient temperature, σ is the Stefan–Boltzmann constant, ε is the emissivity.

The inlet and outlet boundary conditions of wind is stated as

$$\boldsymbol{u}\big|_{inlet} = -v_0 \boldsymbol{n} \tag{10}$$

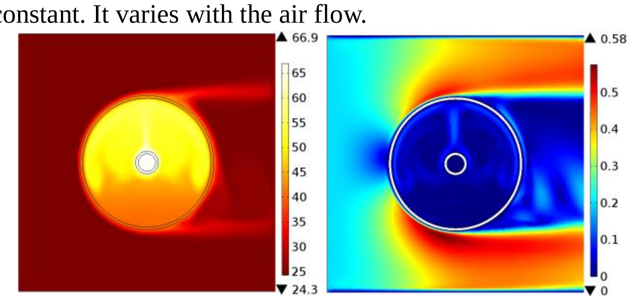
$$p\big|_{outlet} = p_0 \tag{11}$$

Where v_0 and p_0 is the inlet initial velocity and outlet static pressure respectively. $\boldsymbol{n}$ is the normal direction.

III. Simulation Results and Discussion

A. Steady temperature rise at rated current

The wind velocity is 0.2m/s and the applied current is 2kA. Fig.2 shows the simulation results. The temperature of conductor is 66.9℃. Compared with the method of reference [4-5], temperature distribution of the tank is uneven because of SF_6 gas flow. The temperature of tank top surface is 3.5℃ higher than the bottom surface. Moreover, the convection of air and wind will cool the temperature distribution of the tank. Convective heat transfer coefficient of the tank surface is not a constant. It varies with the air flow.

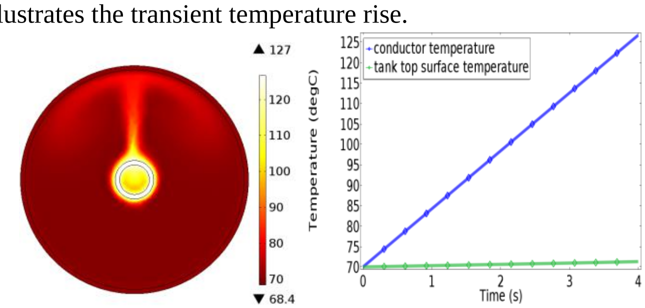


(a) Temperature distribution (b) velocity distribution

Fig.2 Temperature and velocity distribution at rated current

B. Transient temperature rise at short-cut current

The conductor power loss increases dramatically under high short current. The applied short current is 31kA lasting for 4 seconds. Simulation is based on the steady temperature. Fig. 3 illustrates the transient temperature rise.



(a) Temperature distribution (b) temperature rise

Fig.3 Transient temperature rise.

The conductor temperature rises almost linearly while the temperature of the tank remains stable during the short time. It reaches 127℃ at the end of the short cut. Material and dimension of the bus bar should be well designed.

C. Effect of load current, wind, and ambient temperature

The external environment factors are significant because the FVCB may operate under harsh environment. Based on the presented model, the influences of load current, wind and ambient temperature are analyzed. Fig. 4 shows the effect of load current. With the increasing of load current, temperature of the conductor and tank increase at different rate. The top and bottom temperature difference of the tank is 3.3℃. The effect of wind velocity and ambient temperature are also studied. As the ambient temperature increases, both conductor and tank temperature increase rapidly. Meanwhile, with the increase of wind the conductor and tank temperature decrease obviously. Their temperature will be saturated with wind growing because the convective heat transfer coefficient of tank surface will be saturated.

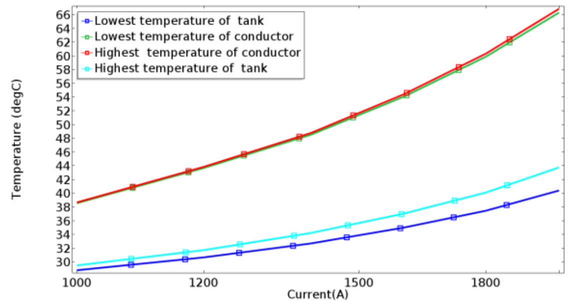


Fig .4 Temperature change of conductor and tank with the load current

D. Temperature prediction of the FVCB's bus bar

Load current makes great contribution to the temperature of conductor and tank. The ambient temperature and wind mainly change the temperature of tank. But their impacts are limited. Based on the simulation results, an empirical formula is derived.

$$T_{con} = 5.08I^2 + 12.96I + T_{amb} - 4.34 \tag{12}$$

Where T_{con} (℃) is conductor temperature, I (kA) is the load current, T_{amb} (℃)is the ambient temperature. The simulation results and the experiment results in reference [4] are a good validation of this model and empirical formula.

IV. Conclusion

To design the FVCB accurately, an electromagnetic-thermal-laminar coupled model has been performed to determine the temperature distribution of the bus bar. In this approach, the steady temperature rise at rated current and temperature rise at short current were specified. Further, the effect of load current, ambient temperature and wind velocity were investigated. The temperature of tank and conductor were obtained under different operation environment. Finally, an empirical formula to calculate the conductor temperature was obtained. This formula could predict the conductor steady temperature and guide the design of FVCB.

V. Acknowledgement

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References

[1] J. Paulke, H., et al. "Thermal simulation of switchgear," *IEEE Trans. Compon. Packag. Technol.*, vol. 25, no.3, pp. 434–439, Sep. 2002.

[2] Guan, X., et al. "Multiphysics Analysis of Plug-In Connector under steady and short circuit conditions." I*EEE Trans. Compon. Packag. Technol*., vol.5, no.3, pp. 320-327, 2015
[3] J. K. Kim, et al. “Temperature rise prediction of EHV GIS bus bar by coupled magnetothermal finite element method,” *IEEE Trans. Magn.*, vol. 41, no. 5, pp. 1636–1639, May 2005.
[4] Wu, Xiao Wen, et al. "Contact Temperature Prediction in Three-Phase Gas-Insulated Bus Bars With the Finite-Element Method." *IEEE Trans. Magn.*, vol.50, no.2, pp: 277-280, 2014.
[5] IEC 62271-1, Edition 1.1, “High-voltage switchgear and control gear – Part 1: Common specifications,” International standard, 2011.