Multiphysics Coupling Simulation and Analysis of Influencing Factors on Temperature Rise Characteristics of Tri-Post Insulator GIL

F. F. Wu, S. Y. Xie, X. Lin, M. H. Chen, and C. H. Zhang

Abstract In this paper, a 1100 kV GIL thermal–mechanical-electrical multi-physics coupling simulation model was established, the evolution characteristics of the internal temperature field of the tri-post insulator GIL with external factors were investigated. The results show that the temperature of the GIL tri-post insulator gradually decreases from the conductor to the enclosure, and the internal temperature is slightly lower than the surface; the maximum thermal stress occurs at the edge of the insulator wrapped around the conduct. Under rated conditions, the maximum stress inside the insulator can be up to 180 MPa, and the thermal expansion difference between the upper and lower surfaces of the enclosure hardly changes with temperature. This study provides an important guarantee for the safe operation of GIL.

Keywords Gas insulated transmission lines · Tri-post insulator · Temperature rise characteristics

1 Introduction

Gas insulated metal-enclosed transmission line (GIL) has the advantages of high reliability, small transmission loss, low failure rate, and is not affected by external factors such as climate change [1]. It is an advanced power transmission method with great development prospects, and has gradually become an important direction for the construction of future power transmission networks.

The temperature rise effect caused by conductor Joule heat, enclosure induced current and eddy current heat loss causes the temperature of GIL conductor, enclosure

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and insulating gas to rise [2], which leads to changes in the insulating properties, and endangers the operation safety of GIL. Therefore, the research on the temperature rise characteristics of GIL can provide a reference for the structural design of GIL equipment and provide guarantee for the safe operation of GIL equipment.

At present, numerical simulation methods are mainly used at home and abroad to study the temperature rise characteristics of GIL. Literature [3–5] established a two-dimensional model of GIL, and studied the transient temperature rise curve, the influence of different insulating gases and conductor diameters on the internal temperature distribution of GIL. Reference [2] carried out the research on the influence of external wind speed and solar radiation on the temperature field distribution of GIL in the 3D simulation model of GIL. Reference [6] carried out an experimental study on the temperature rise characteristics of GIL expansion joints, and compared with the simulation results. The temperature rise of GIL will cause the strain field and electric field of GIL to change. For multi-physics coupling, corresponding research has been carried out at home and abroad. Reference [7] used SF_6-N_2 mixed gas to carry out related research on the electric field distribution under the temperature rise of GIL. It can be seen from the research status that the temperature rise characteristics of three-post insulators are important factors affecting the safe operation of GIL. However, at present, there is still a lack of relevant studies on the influence of GIL temperature rise on the internal stress of three-post insulators and the thermal expansion characteristics of the envelope.

Therefore, this paper builds a three-dimensional simulation model of GIL, and studies the factors affecting the temperature rise of GIL for the tri-post insulator GIL, as well as the effect of temperature rise on the strain field of GIL. The goal of clarifying the temperature rise characteristics of GIL and clarifying the factors affecting the local temperature rise of GIL has been achieved.

2 GIL Multiphysics Simulation Model

This research uses the COMSOL finite element simulation software to create a three-dimensional GIL model, and conducts simulation research on the internal temperature field, strain field and electric field of the GIL.

2.1 Geometric Model

The research object of this paper is the 1100 kV tri-post insulator GIL. Its basic structure is shown in Fig. 1, which can be divided into a central conductor (1), a connecting cylinder (2), an epoxy resin insulator (3), and an aluminum alloy enclosure (4).

In order to prevent the asymmetry of the simulation results caused by meshing, the 3D geometric model of the GIL is simplified, as shown in Fig. 2.

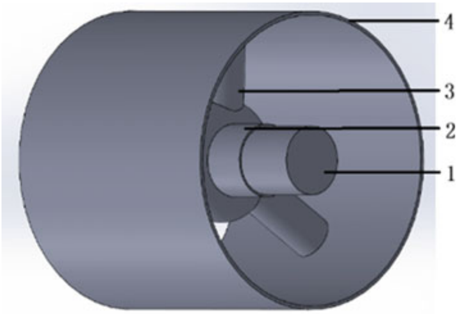


Fig. 1 Schematic diagram of tri-post insulator GIL, central conductor (1), connecting cylinder (2), an epoxy resin insulator (3), aluminum alloy enclosure (4)

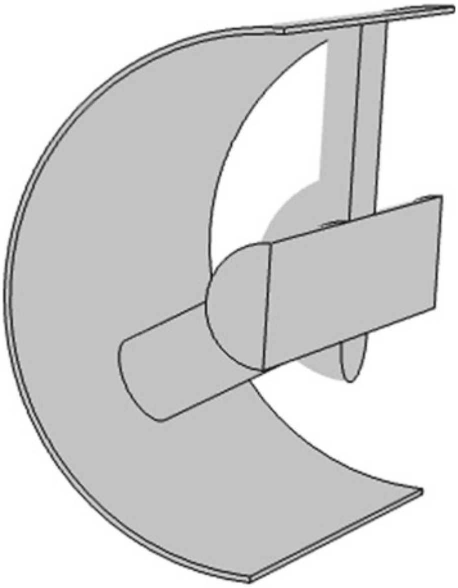


Fig. 2 GIL tri-post insulator simulation model

2.2 Flow Field-Temperature Field Mathematical Model

At the initial ambient temperature of 20 °C, the physical parameters of insulating gas, enclosure and insulator are shown in Table 1.

Under the set rated working conditions, the rated current is 6000 A, the ambient temperature is 20 °C, and the insulating gas pressure is 0.4 MPa. The insulating gas inside the GIL is set to SF_6. The parameters of the influencing factors of the temperature rise characteristics used in the simulation are shown in Table 2.

Table 1 Physical parameters of insulating gas, enclosure and insulator

	Destiny/(kg/m^3)	Thermal Conductivity/[W/(m K)]	Dynamic viscosity/(Pa s)	Constant pressure heat capacity/[J/(kg K)]	Specific heat rate
SF_6	6.52	0.01206	1.42e−5	665.18	1.09
Aluminum alloy	2680	156	/	942	/
Epoxy resin	1200	0.35	/	550	/

Table 2 GIL external influence factor settings

Parameter	Selected value
Load current/A	4000, 5000, 6000, 7000, 8000
Ambient temperature/°C	0, 10, 20, 30, 40
Insulating gas pressure/MPa	0.1, 0.2, 0.3, 0.4, 0.5, 0.6, 0.7

2.3 Temperature-Strain Field Mathematical Model

On the basis of inputting the thermal physical properties of the material in the coupled flow-heat analysis, in the thermal stress analysis, the mechanical properties of the material should also be input. The mechanical properties of the material required for the simulation are shown in Table 3.

First, fixing the two ends of the enclosure and the conductor, and the thermal–mechanical coupling analysis of the GIL is carried out. Then, fixing one end of the enclosure, and symmetrical boundaries are imposed on the inner and outer sides of the enclosure to explore the axial thermal expansion characteristics of the GIL enclosure.

Table 3 Mechanical parameters of enclosure and insulator materials

	Elastic modulus/Pa	Poisson's ratio	Thermal expansion coefficient/(1/K)
Aluminum alloy	7e10	0.33	2.3e−5
Epoxy resin	2.5e10	0.38	6.24e−5

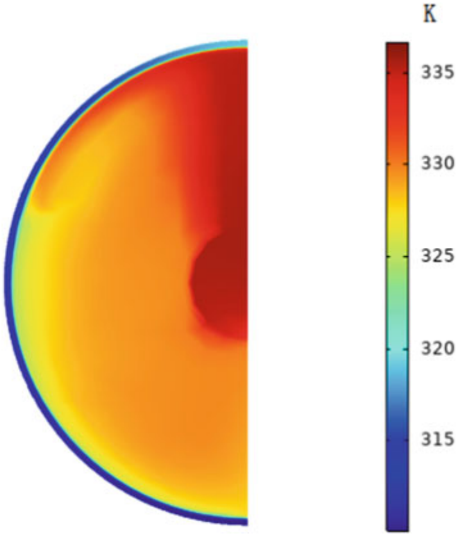


Fig. 3 GIL temperature distribution

3 Results and Analysis

3.1 GIL Temperature Field

The temperature distribution is shown in Fig. 3, and the gas flow rate distribution is shown in Fig. 4. It can be seen from the figure that the temperature of the insulating gas inside the GIL presents a distribution law of high above and low below. The maximum gas velocity is about 0.09 m/s.

The temperature distribution of the GIL tri-post insulator is shown in Fig. 5. It can be seen from the figure that the temperature of the insulator gradually decreases from the conductor to the enclosure. The internal temperature of the insulator is slightly lower than the surface temperature.

The temperature distribution of the GIL enclosure is shown in Fig. 6. The temperature of the upper surface of the enclosure is the highest and the temperature of the lower surface is the lowest. The temperature on both sides of the upper surface of the enclosure is higher than that of the middle part.

3.2 Effect of Different Factor on GIL Temperature Field

Figure 7a–c are GIL temperature rise curves obtained by changing load current, ambient temperature or gas pressure.

It can be seen from Fig. 7a that the relationship between the temperature of the GIL conductor and the enclosure is a nonlinear positive correlation. Figure 7b shows

Fig. 4 GIL gas flow velocity distribution

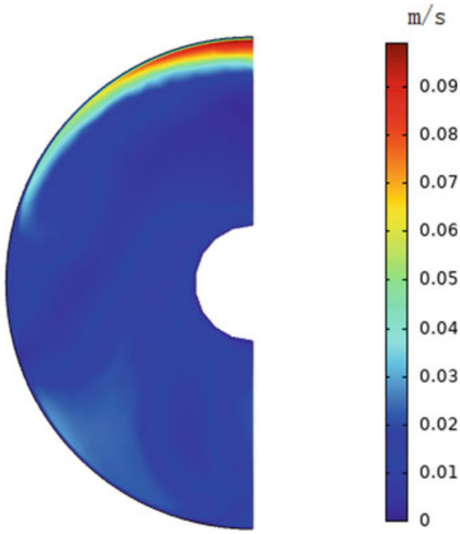


Fig. 5 Temperature distribution of GIL insulator

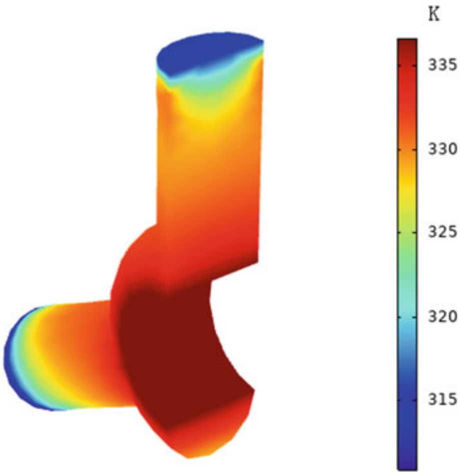


Fig. 6 Temperature distribution of GIL enclosure

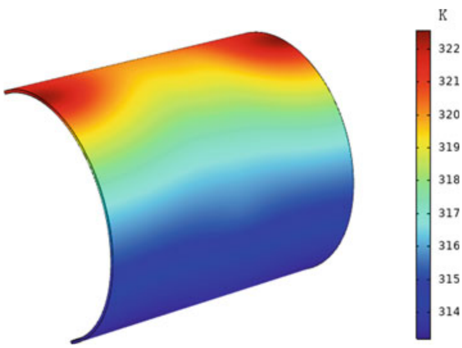
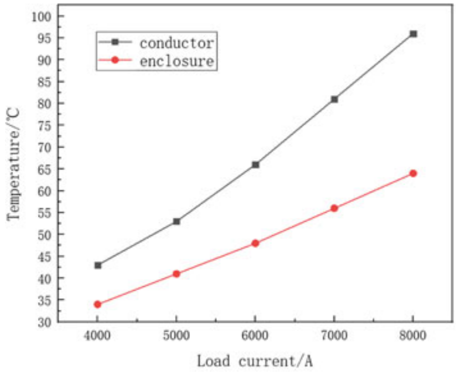
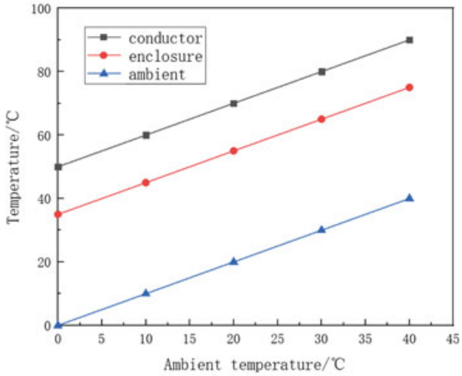


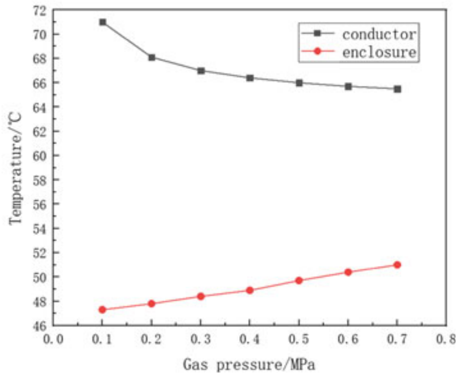
Fig. 7 Influence of load current **a**, ambient temperature **b**, and gas pressure on GIL temperature distribution



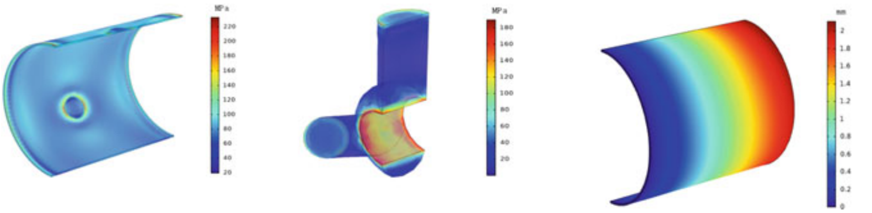
(a)



(b)



(c)



(a)GIL enclosure stress (b)Thermal stress inside the insulator (c) GIL enclosure thermal expansion

Fig. 8 GIL thermal strain simulation results

that the GIL conductor and enclosure temperature are positively correlated with the ambient temperature. The temperature difference between the enclosure and the ambient temperature does not change with the change of the ambient temperature. Figure 7c shows that the GIL conductor temperature is more sensitive to the change of insulating gas pressure at lower air pressure, but remains basically unchanged when the air pressure reaches about 0.4 MPa.

3.3 Effect of Different Factor on GIL Thermal Strain

The simulation results of GIL enclosure stress (a), insulator stress (b) and GIL enclosure thermal expansion (c) are shown in Fig. 8. It can be seen from the figure that the thermal stress of the GIL enclosure is axisymmetric. The thermal stress at both ends is the largest and decreases in the middle of the pipeline. The maximum stress inside the insulator occurs at the junction of the conductor and the insulator, because the temperature of the insulator part close to the conductor is the highest. There is also a large stress distribution at the junction between the two ends and the enclosure.

Under rated conditions, the GIL enclosure with a length of 1 m thermally expands axially, with an upper surface of 2.11 mm and a lower surface of 1.83 mm.

4 Conclusion

In this paper, the temperature rise of the tri-post insulator GIL is calculated by the method of finite element simulation, and some related factors affecting the temperature rise and the strain field of tri-post insulator GIL are quantitatively analyzed. Based on the temperature rise results, the conclusions are as follows:

(1) The temperature of the insulating gas inside the GIL presents a distribution law of high above and low below, and the temperature above the enclosure is higher than the temperature below the enclosure. The relationship between the

influencing factors and the temperature rise effect of GIL was quantitatively analyzed.

(2) The thermal stress of the GIL enclosure is axisymmetric, and the maximum stress of the insulator occurs at the junction of the conductor and the insulator. The maximum stress of the insulator increases with increasing temperature. The thermal expansion of the enclosure increases linearly with temperature, and the difference between the upper and lower surfaces is basically unchanged.

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