Electrical field simulation and analysis of 1200kV gas insulated test reactors

Tengfei Li¹, Yuhang Jiang², Lei Zhao¹ and Yifei Wang*²
¹ EPRI of State Grid Shanghai Municipal Electric Power Company, Shanghai, 200437, China
² Key Laboratory of Control of Power Transmission and Conversion, Shanghai Jiao Tong University, Shanghai, 200030, China
*Corresponding author’s e-mail: yifei701@163.com

Abstract. The size of high voltage test equipment is strictly limited in field test in substations. Test reactors, as an important kind of experimental equipment for field application, have to meet the capacity requirements and space limitation in such situations. SF₆ gas insulated test reactor is one of the best solutions. In this paper, the model of a 1200kV gas insulated test reactor is set up and simulated to analyse the electrical field distribution inside the equipment using the finite element analysis software INFOLYTICA. According to the simulation results, it is verified that the designed gas insulated test reactor meets the insulation requirements and size limit for 500kV underground substation application. The work of this paper helped the design and development of SF₆ gas insulated test reactors.

1. Introduction
In order to meet the power needs of urban area, HV and EHV underground substations are recognized as an effective way to solve the land shortage problem [1]. Partial discharge free test reactor [2], as an important device for high voltage field tests, needs to improve its capacity and reduces its size for underground substation applications. For this purpose, development of SF₆ gas insulated high voltage test reactors has been proposed. SF₆ has excellent electrical performances in homogenous electric fields [3], and thus the electric field distribution inside such reactor becomes a key factor affecting its design and operation.

Electric field control and design optimization are important process in the development of new high voltage test reactors. Many simulation studies of high voltage test equipment had been carried out in existing literature [4-6], but there is little research addressed on the testing reactors. The electric field distribution in a newly designed 1200kV gas insulated test reactor is numerically simulated in this paper. The characteristics of electric field distribution inside the reactor are analysed. According to the simulation results, local structure design optimization is provided to avoid electric field concentration and potential discharge or partial discharge risk inside the reactor.

2. Numerical modelling
As shown in Figure 1, the 1200kV gas insulated test reactor is mainly composed of five parts, the low voltage segment of the reactor (0~400kV), the middle voltage segment of the reactor (400~800kV), the high voltage segment of the reactor (800~1200kV), the output protective resistor and the capacitive divider.
Figure 1. Structure of the gas insulated test reactor.

The FEM based simulation software Infolytica is adopted for modelling and the electric field simulation. For the main object of the simulation analysis is to investigate the influence of each part of the gas test reactor on the electric field distribution. Each part of the complete set of equipment is modelled and simulated respectively, in order to understand the distribution of electric field in each part more intuitively. According to the preliminary design of the test reactor, a three-dimensional simulation model is set up as shown in Figure 2.

Figure 2. 3D-models of the main parts of the gas insulated test reactor.

Considering the high symmetry structure of the five main parts of the test reactor, the cross sectional view is used to display the electric field distribution inside the reactor, as shown in Figure 3, which can directly reflect the electric field distribution inside the object.
In order to ensure the accuracy of calculation and to save the computing time, auto division and manual division combined method is adopted in the mesh generation of the model. As shown in Figure 4, the mesh of each part of the test reactor is presented.

In the employed Infolytica software, the potential and electric field equations are solved by using the Newton-Rapson method to calculate the node potential. In the simulation, the error range is set to 1%, the potential function is approximated by two order polynomial, and the convergence gradient is 10-8.

3. Simulation and analysis

3.1 Potential distribution in the 1200kV gas insulated test reactor
For the three-stage series gas insulated test reactor, the voltage source of 400kV, 800kV and 1200kV is applied as the excitation on the three coil segment, respectively. The potential distribution (peak value) in the three-stage reactor is shown in Figure 5.
For the protective resistor, the potential at both ends of the nickel chromium wire is almost the same, 1200kVrms in practice. Hence, when a voltage source with an effective value of 1200kV is applied at both ends as excitation, the potential distribution is shown in Figure 6 (a) (peak value). For the capacitive divider, its high voltage terminal is connected with the protective resistor, and the other end is earthed through the shell. At the high voltage end, a voltage source with an effective value of 1200kV is used as the excitation. When the excitation voltage reaches its peak, the potential distribution is shown in Figure 6(b).
3.2 Electric field distribution in the 1200kV gas insulated test reactor

For the gas insulated test reactor, the highest electric field occurs at the peak voltage, and therefore the main concern is the electric field distribution under peak voltage. If the maximum field strength meets the insulation requirements at this time, no insulation breakdown or partial discharge will occur at other times. If the insulation size does not meet the requirements, then the structure and size of the test reactor need to be redesigned until all the requirements have been met.

The three-stage series test reactor, the protective resistor and the capacitive divider of the gas insulated test reactor are excited respectively. When the excitation voltage reaches its peak, the corresponding electric field strength distribution is shown in Figure 7.

As the simulation results shown in the figures, the maximum electric field strength inside the 1200kV gas insulated test reactor is 6.97kV/mm, far less than the breakdown field strength of SF6. The high electric field only concentrates in some small regions. Local optimization of the electric field distribution is needed only in the concentrated area.
4. Conclusions

In this paper, the finite element method based on software INFOLYTICA is employed to model the main components of the designed 1200kV gas insulated test reactor and simulate the electric field distribution. The simulation results show that the preliminary designed size of 1200kV test reactor meets the insulation requirements. There are certain hidden dangers in areas where the radius of curvature is small. In order to eliminate the hidden dangers and ensure the working stability of the reactor, further local optimization of the part component is necessary to make the electric field more uniform in the concentrated area by increasing the radius of curvature. The simulation work can help the design and development of the gas insulated test reactor.

References

[1] Chen, Z., Ding, B. (1999) Summary for SF$_6$ Gas-Insulated Transformer. Transformer, 36(8):24-28.
[2] Liu, Y., Ye, H., Shan, H., et al. (2013) Study on Spot Test of Partial Discharge for 500kV Shunt Reactor. High Voltage Apparatus, 49(2): 80-84.
[3] Li, Z., Guo, Z. (1990) The electrical performance of SF$_6$ in transformer applications. Transformer, 27(10): 28-32.
[4] Khaligh, A., Vakilian, M. (2008) Power Transformers Internal Insulation Design Improvements Using Electric Field Analysis Through Finite-Element Methods. IEEE Transactions on Magnetics, 44(2):273-278.
[5] Liu, Y., Cao, Y., Li, Y., et al. (2008) Design for new type of main insulation of 35kV electric power transformer based on electric field analysis. Automation Congress, Wac. IEEE, 2008:1-4.
[6] Zhou, F., Zhen, H., Lei, M., et al. (2007) FEA and Optimization Design of High Voltage Isolation Transformer in UHV Series TV. High Voltage Engineering, 33(12):5-8.
[7] Yan, N., Fu, Z., Wang, G., et al. (2012) Electric Field Simulate Calculation and Experimental Layout Optimization of Ultra High Voltage Power Frequency Test Transformer without Partial Discharge. High Voltage Engineering, 38(2):368-375.