Research on vibration characteristic simulation of the 220 kV gas insulated metal enclosed switchgear equipment

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Abstract. GIS equipment (gas insulated switchgear) is more and more popular in power system, and people often pay more attention to its discharge fault than other mechanical faults. But in the operation of GIS, besides discharge faults, mechanical faults are also a major cause of accidents. Therefore, we should give more research to abnormal mechanical vibration. At the same time, compared with discharge signal, mechanical vibration fault is more difficult to study. In this article, based on the size of real GIS equipment, we first built a three-dimensional model through COMSOL software to study the propagation characteristics of vibration signals. Simply considered, the bus air chamber is two-dimensional axisymmetric. Firstly, the natural vibration frequency of the equipment is calculated by finite element method, and the vibration propagation characteristics of GIS shield cover loose of the GIS equipment are calculated and analyzed. The simulation calculation shows that the longer the shell is, the lower the natural vibration frequency is. Therefore, we should pay more attention to the natural vibration frequency far away from 100 Hz, when designing and manufacturing GIS equipment, so as to avoid serious consequences caused by resonance. Because the basic vibration frequency caused by the loosening of shield cover is twice as high as the power frequency of 50 Hz. Then the 100 Hz simulation source is added to COMSOL model as the vibration source of loosening fault, and the propagation rule and characteristics of vibration fault about GIS are received. After the vibration fault occurs, the loosening vibration signal at the connection between the GIS shell and the basin insulator is the strongest. These conclusions by simulation also conform to objective rules and facts. Meanwhile it can guide us to arrange sensors reasonably and improve the signal-to-noise ratio of vibration detection signals.

1. Introduction
GIS equipment has many advantages, such as compact structure, reliable operation, less impact on the environment and less maintenance workload. It is an important manifestation of technological progress in power equipment manufacturing. In recent years, with the development of high voltage power transmission and the need of urbanization construction, GIS has been more and more widely used [1-3].

Although GIS has high reliability and low failure rate, with the extensive application of GIS, the failure of GIS has become a problem that can not be ignored. Existing research methods at home and abroad are mainly aimed at GIS discharge fault, but in fact, the phenomenon of mechanical fault is
increasing. Therefore, it is necessary to systematically study the mechanical vibration fault of GIS [4,5]. At present, in most literatures, the research on vibration of GIS equipment is mainly carried out by experiments. Undoubtedly, the test data are quite real, but it is time-consuming and laborious to carry out the test, and it also needs a more expensive test platform. Therefore, more and more researchers begin to carry out the corresponding simulation research. Through the simulation research, we can quickly understand the generation and transmission characteristics of GIS vibration signal, and then guide the development of the experiment. Through the combination of simulation and experiment, the abnormal sound fault of GIS equipment can be studied efficiently.

In this paper, the finite element simulation software COMSOL is used to model and simulate 220 kV GIS real equipment. Firstly, the natural vibration frequency of the equipment is obtained, and then the vibration propagation characteristics are obtained by adding the excitation source to simulate the vibration. The simulation results are used to guide the follow-up experimental research, which is of great significance to the safe operation of GIS equipment.

2. Calculation and simulation of natural frequency of GIS equipment

The study of the vibration frequency of GIS is generally divided into the natural vibration of GIS conductor and shell. The main vibration frequency of this type of GIS buses is close to the first-order natural frequency \( f \) of a single span. If the span length of the bus is changed, the natural frequency \( f \) will also change.

The theoretical formula for natural frequencies of bus is as follows [6]:

\[
\frac{1}{f_0^2} = \frac{\pi^2}{4L_{ks}^2} \left( \frac{EJ}{\rho s} \right) \quad (\text{Hz})
\]

Among them, \( E \) is the elastic modulus of conductor material; \( J \) is the moment of inertia of a conductor; \( s \) is the cross-sectional area of the conductor; \( \rho \) is the mass density of conductor materials; \( L_{ks} \) is the pot insulator spacing (span).

The ratio of expected thickness radius of GIS shell is very small, generally less than 2.5%. For the structure of GIS, flanges are often clamped on both sides of the pot insulator and the shell is reinforced. A real conductor - shell system can be regarded as a beam to approximate the natural frequency of the shell.

The natural frequencies of the shell can be calculated according to the following formula [6]:

\[
\frac{1}{f_{ks}^2} = \frac{k_s}{2\pi^2} \left( \frac{2EC_2}{(1-\mu)^2 \times (0.5D_2)^2} \right) \quad (\text{Hz})
\]

Among them, \( k_s \) is related to \( C_2, D_2 \) and \( L_{ks} \); \( C_2 \) is the thickness of the shell; \( D_2 \) is the diameter of the shell; \( \mu \) is the Poisson's ratio of the shell material; \( E \) is the elastic modulus of the shell material.

However, real GIS equipment is often not such a simple geometry, so it is not simple and accurate to calculate the natural frequency in engineering. In this paper, a simple GIS model is built by COMSOL, and the natural frequency simulation is carried out [1].

As shown in figure 1, the GIS bus model in COMSOL consists of a 2.5-meter-long GIS shell, two basin-shaped insulators and a central conductor. The outer diameter and wall thickness of GIS shell are 620 mm and 20 mm respectively. The two ends are sealed with a 20 mm thick cover plate, and the radius of the central conductor of GIS is 50 mm. By simplifying the processing, a three-dimensional model of GIS structure is established.

In this model, GIS shell is made of steel. Copper is used as the central conductor. The material of the basin insulator is polypropylene composite material. The parameters of SF\(_6\) are set at 0.4 MPa pressure. The shield is made of aluminium. The material properties are shown in table 1.
In order to get the characteristics and changing rules of natural vibration frequency, we calculated the following data by changing the length of bus air chamber in GIS. It is worth mentioning that there are many natural frequencies, here only five lower natural frequencies are listed, as shown in Table 2.

Table 2. Five natural frequencies of the low frequency section.

| Length | Natural vibration frequency (Hz) |
|--------|----------------------------------|
| 2 m    | 143.33 190.89 210.43 238.24 270.63 |
| 2.5 m  | 135.70 136.37 143.34 190.68 238.21 |
| 3 m    | 91.76  95.56  143.32 181.02 190.86 |

From the above data, we can find that the natural vibration frequency of GIS bus air chamber is closely related to its length. The simulation results show that in a certain range, the longer the bus air chamber is, the lower its natural vibration frequency is, the shorter the bus air chamber is, and the higher its natural vibration frequency is. This is in line with our sensory perception. At the same time, we know that the common mechanical fault vibration of GIS equipment is caused by electric force, and the frequency of electric force caused by poor contact is twice the working frequency, that is 100 Hz. Therefore, we should pay attention to the natural vibration frequency of GIS equipment and keep it away from the common fault frequency of 100 Hz, so as to avoid causing more serious problems of resonance. Figure 2 shows the vibration displacement distribution for 238.21 Hz, which is a typical example through simulation.
3. Simulation of vibration propagation characteristics

Based on the above model, in order to simplify the simulation and calculation, a 100 Hz vibration source is added to the simulation model to simulate the fault signal. The propagation characteristics of the vibration signal in the gas chamber of GIS bus are obtained by simulation[7-10]. Taking 2.5 m bus air chamber length as an example, vibration sources are added to the central conductor, shield cover and basin insulator to simulate the mechanical fault. Through simulation calculation, the surface pressure distribution of GIS equipment shell can be obtained, as shown in figures 3 to 5.

![Figure 3](image1.png)

Figure 3. Vibration excitation is applied to the connection between the basin insulator and the central conductor. (a) R directional vibration excitation is applied to the connection between the basin insulator and the central conductor and (b) Z directional vibration excitation is applied to the connection between the basin insulator and the central conductor.

![Figure 4](image2.png)

Figure 4. Vibration excitation is applied to the shield. (a) R directional vibration excitation is applied to the shield and (b) Z directional vibration excitation is applied to the shield.

![Figure 5](image3.png)

Figure 5. Vibration excitation is applied to the central conductor. (a) R directional vibration excitation is applied to the central conductor and (b) Z directional vibration excitation is applied to the central conductor.

As shown in the six figures, it could be clearly seen that the vibration signal is strongest at the connection between the GIS shell and the basin insulator when the fault occurs inside the GIS equipment and produces the vibration signal. Because the central conductor is directly connected to the insulator, the vibration signal propagates along the solid to the surface of the GIS shell. The vibration of the central conductor causes pressure changes in the gas chamber, and then transmits to
the GIS shell through gas pressure or acoustic vibration. Obviously, the resistance of this propagation path is huge, and the signal will be attenuated to a large extent. Therefore, when measuring the mechanical fault signal, the vibration sensor should be as close as possible to the basin insulator to get a higher signal-to-noise ratio signal, improve the effectiveness of the detection signal and test sensitivity.

In addition, the analysis of the above six graphs shows that the vibration in R direction is more intense than that in Z direction. This is because the gas chamber of GIS bus is similar to a cylinder, with smaller diameter in the R direction and longer size in the Z direction. Therefore, for the same degree of vibration, the R direction will be more sensitive and the vibration will be more intense.

Finally, we can also find that loosening of the connection between the basin insulator and the central conductor can lead to more serious vibration. This is also evident, because the basin insulator is directly installed at the joints of the GIS shell, the loose signal of the basin insulator itself is transmitted to the shell and captured by the sensor almost without attenuation.

4. Conclusion

The natural vibration frequency of GIS bus air chamber is negatively correlated with its length. Therefore, when designing the size of GIS equipment, the common frequency of mechanical fault should be avoided at 100 Hz to avoid causing more serious consequences of resonance.

Mechanical fault signal is the largest in the area where the basin insulator is connected with the GIS shell. Vibration sensors should be arranged as close as possible to the insulator to improve the signal-to-noise ratio and obtain more effective data. In addition, special attention should be paid to the loosen fault along the radius direction and the loosen signal of the basin insulator itself.

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