Simulation Analysis of Earthquake Resistance and Isolation of 220kV GIS Equipment in Tianjin

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Abstract: The anti-seismic and isolation simulation analysis of a 220 kV GIS equipment is carried out using finite element software. The response spectroscopy method is used to simulate the displacement and acceleration dynamic response of the whole structure under the two working conditions before and after the isolation device is installed, and to analyze the change of the natural frequency of the structure. The results show that the relative deformation of 220 kV GIS equipment is smaller than before isolation, and the vibration characteristics of the overall structure are close to the single-particle model, and the structure’s seismic performance is significantly enhanced for the maximum acceleration of the overall structure is reduced by 90%.

1. Introduction
As an important infrastructure, the power grid system, if has any damage caused by earthquake, will bring serious economic losses and affect the earthquake relief and the recovery of working and living. In recent years, earthquakes have occurred in China and caused the outage of substations, bringing inconvenience to the earthquake relief and the reconstruction projects after earthquake [1]. GIS (gas insulated enclosed combination switch) equipment has better seismic performance than other switchgear. The Code for Seismic Design of Electrical Installations (GB 50260-2013) [2] and other relevant codes provide detailed reference and calculation methods for seismic design of high-voltage electrical products.

At present, similar studies of seismic simulation of electrical equipment shaking table tests have been carried out in China [3-4], but due to the large weight of GIS equipment, the test is only selected part of the GIS (casing and connecting part), and only part of the equipment’s seismic performance can be assessed, and also due to the high test cost, such similar studies are less used in actual design.

In this paper, the response spectra of a typical 220 kV GIS equipment under seismic response are analyzed by finite element method, and some suggestions for structural optimization design are provided.

2. A Typical 220 KV GIS Equipment Structure and Finite Element Modeling
The overall dimensions of a typical GIS device structure studied in this paper is 55063 mm×19024 mm×4005 mm. GIS device modeling is such an important step in the finite element analysis that directly related to the efficiency of subsequent calculations and the accuracy of the results.

This paper uses ANSYS software for modeling and analysis. The numerical model of the equipment is composed of beam unit, mass unit and combin unit. As shown in figure 1 is the theoretical diagram of the support model in ANSYS, and the isolation device is built by combin40 unit. In the numerical model, X direction represents the length, and the Y direction represents the width, and
the Z direction represents the height. It is much closer to the actual product, and the connection between the flanges is rigid connections. The final GIS finite element model is shown in figure 2.

![Theoretical model diagram of COMBIN40 unit.](image1)

![Typical 220 kV GIS numerical model diagram.](image2)

**Figure 1.** Theoretical model diagram of COMBIN40 unit.  
**Figure 2.** Typical 220 kV GIS numerical model diagram.

### 3. A Typical 220 kV GIS Seismic Calculation Method

The response spectrum method firstly defines the ground motion parameters according to the site conditions, then figure out the response spectrum curve for calculation, then calculates the maximum response of the structure in each order of vibration mode according to the response spectrum, and finally calculates the total maximum response through the modal merging algorithm [5-7]. In this paper, the peak acceleration of the earthquake is 0.4 g, and the characteristic period of the site is 0.45 s [8]. The response spectrum curve can be identified by referring to the provisions in “Code for Seismic Design of Buildings” (GB50011-2010), as shown in figure 3.

![Earthquake response spectrum curve.](image3)

**Figure 3.** Earthquake response spectrum curve.

### 4. Seismic Effects Analysis

The modal analysis of the 220 kV GIS numerical model is carried out, and the first 4-order modes of the model are shown in table 1, the seismic structure is fully confined at the bottom, and the first 4-orders modes are shown in figure 4. From the vibration mode diagrams of the seismic structure and the seismic isolation structure, it can be seen that the vibration modes corresponding to the first 4-order frequencies of the seismic structure are all partial [9-10].
Figure 4. The vibration modes of the main mode of the Typical 220kV GIS.

Table 1. The natural frequency and vibration mode of typical 220kV GIS.

| Order (math.) | Frequency (Hz) | Amplitude of vibration                  |
|---------------|----------------|-----------------------------------------|
| 1             | 7.7            | Partially bent vibration pattern        |
| 2             | 7.7            | Partially bent vibration pattern        |
| 3             | 7.88           | Partially bent vibration pattern        |
| 4             | 9.33           | Partially bent vibration pattern        |

The X-directional seismic effect is applied to the 220 kV GIS model, and the model is fully confined at the bottom, that is, the whole GIS equipment is not equipped with a seismic isolation device model. The response spectrum analysis is generated with reference to GB 50260-2013 “Code for Seismic Design of Electrical Installations”.

Response spectrum will be analyzed according to the rule that the fortification design should be stronger than the actual condition, the corresponding acceleration is 0.4 g and the characteristic period is 0.45 s. The model will be applied the seismic effect in the solution module of ANSYS software. The analysis results are as follows shown in figures 5-6.

Figure 5. Overall displacement cloud map (unit: m).

Figure 6. Overall acceleration cloud map (the structure maximum acceleration 105.30 m/s²).
The Y-directional seismic effect is applied to the model and the analysis result is shown in figures 7-8 below.

Figure 7. Overall displacement cloud map (m).  
Figure 8. Overall acceleration cloud map (structure maximum acceleration 138.11 m/s²).

5. Seismic Isolation Analysis

The seismic isolation structure is fully confined indoor support and the outdoor support on the bottom, and the parameters of the seismic isolation support adopt the equivalent stiffness and damping corresponding to 250% deformation.

The modal analysis of the 220 kV GIS numerical model after the installation of the seismic isolation device is carried out. The first 3 orders modes of the model are shown in table 2, the seismic structure is fully confined at the bottom, and the first 4 order vibration modes are shown in figure 9, the vibration mode corresponding to the first three order frequencies of the seismic isolation structure is overall flat and overall torsional vibration modes.

![Modal Analysis](image)

(a) First order  
(b) 2nd Order  
(c) 3rd Order  
(d) 4th Order

**Figure 9.** The main modes of the Typical 220kV GIS.

**Table 2.** The natural frequency and vibration mode of typical 220kV GIS.

| Order (math.) | Frequency (Hz) | Amplitude of vibration     |
|---------------|----------------|---------------------------|
| 1             | 1.55           | Integral Y-axis parallelism|
| 2             | 1.58           | Integral X-axis parallelism|
| 3             | 1.67           | Twist along the Z axis     |

The 220 kV GIS model is fitted with a seismic isolation device model at the bottom, and the bottom support is fully confined, the indoor seismic isolation device is placed on the bottom of the structure, while the outdoor seismic isolation device is placed on the bottom of the support, and the bottom of the support is fully confined. The X-directional earthquake action is applied to the overall model, and when the response spectrum analysis is performed with the seismic analysis, the corresponding acceleration is 0.4 g and the properties period is 0.45 s, and the analysis results are shown below (figures 10-12).

The maximum displacement relative to the floor of the seismic resistant structure under the action of the X-directional earthquake action is 34.67 mm, while that number of the seismic isolation...
structure is 115.18 mm and the maximum displacement relative to the upper part of the seismic isolation device is 2.4 mm (The difference between the overall displacement cloud map in figure 10 and the displacement of the support figure 12).

The maximum acceleration in the seismic structure is 105.30 m/s², and this number after isolation is 11.41 m/s², which decreased the maximum acceleration of the overall GIS structure by 89% after isolation versus before isolation.

Y-directional earthquake action is applied to the overall model of the isolated structure and the results are shown below (figures 13-15).

The maximum displacement relative to the floor of the seismic resistant structure under the action of the Y-directional earthquake action is 32.35 mm, while that number of the seismic isolation structure is 125.78 mm and the maximum displacement relative to the upper part of the seismic isolation device is 9.34 mm (The difference between the overall displacement cloud map in figure 13 and the displacement of the support figure 15).
The maximum acceleration in the seismic structure is 138.11 m/s², and this number after isolation is 13.24 m/s², which decreased the maximum acceleration of the overall GIS structure by 90% after isolation versus before isolation.

6. Conclusion
In this report, the seismic response of a typical 220 kV GIS equipment under seismic and isolation conditions is studied separately through finite element simulation analysis, and the main conclusions are as follows:

(1) The 220 kV GIS modal analysis showed that the first three modes of the structure vibrated as a whole after isolation, and the fundamental frequency before isolation was 7.70 Hz, and the fundamental frequency after isolation is significantly reduced to 1.55 Hz;

(2) The results of the model analysis under earthquake action show that the maximum displacement of the equipment before isolation is 34.67 mm, the maximum displacement of the equipment after isolation is 115.18 mm, and the displacement of the upper part of the isolation device is 2.4 mm. The relative deformation of the equipment after isolation is smaller, and the overall structure is close to a single particle point, and the seismic resistance is significantly enhanced, which changes from 138.11 m/s² to 13.24 m/s², under the same working conditions. The decrease of the acceleration after the relative isolation down to 90%;

(3) After the installation of vibration isolation devices, the displacement of the equipment will increase significantly, it is recommended to leave enough space around the equipment for movement.

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