A 220KV Transformer Equipment Vibration Damping Calculation

Xiangyang Fang, Shiyong Li, Zihe Zhang, Guangbin Ji and Mengxuan Liu
State Grid Tianjin Electric Power Company, Tianjin 300143 China
Email: 18222202109@163.com

Abstract. Considering the current poor seismic performance of pillar equipment in substations, for pillar equipment transformers, the ANSYS software is used to establish the corresponding finite element model, and the analysis of the finite element model without and with the shock-absorbing device is carried out under the effect of earthquake through the time course analysis method. The results show that the overall seismic performance of the transformer equipment is significantly improved by installing the vibration damping device, and after evaluation by the safety factor method, the equipment without vibration damping device does not meet the safety factor requirements of the code but the equipment installed vibration damping dose.

1. Introduction
Earthquake is a kind of common physical phenomenon that greatly affects and threatens human work and life. China is an earthquake-prone country [1-3]. Surveys have shown that electrical equipment as an important part of lifeline engineering, if damage occurs in the earthquake process, it will not only cause huge economic losses and endanger the safe operation of the power grid, but also produce serious secondary disasters [4-5]. Therefore, improving the seismic performance of electrical equipment and the damping control of electrical equipment has become an important advance subject that urgently to be solved.

Vibration damping control of engineering structures includes vibration isolation, energy damping and various kinds passive control, active control and hybrid control. This paper uses the principle of energy dissipation damping to conduct vibration damping research on 220 kV transformer to improve its seismic performance [6-7]. The principle of energy dissipation and shock absorption is: to install energy dissipation damping device in some parts of electrical equipment, so that in the normal working condition or when small scale earthquake occurs, the energy dissipation device has sufficient initial rigidity and in the elastic state and the equipment has sufficient lateral stiffness to meet the requirements of use [8]. When a moderate or large scale earthquake occurs, the energy dissipation device enters the inelastic state as the lateral deformation of the structure increases, producing greater damping and absorbing a large amount of seismic energy pressed into the structure, so that the main structure could avoid entering into obvious inelastic state, and quickly attenuate the seismic response of the structure, thereby protecting electrical equipment and its components from damage in a strong earthquake, and ensuring the safety of the main structure.

To ensure the safety of the 220 kV transformer equipment used in the substation project in earthquakes, it is necessary to analyze its seismic and damping performance under the action of earthquakes, and to make reasonable judgments on the strength of the structure. The analysis of 220 kV transformer in this paper mainly includes two parts: (1) seismic performance analysis of the
transformer structure and (2) vibration damping analysis of the transformer structure after installation of vibration dampers [9].

2. Equipment Parameters

The structure of the 220kV transformer is shown in figure 1, the transformer is composed of 3 elements and a base, the equipment parameters are shown in table 1.

| Equipment                        | Transformer |
|----------------------------------|-------------|
| Modulus of elasticity (MPa)      | 1.0×10^5    |
| Breaking Bending Moment (kN·m)   | 35.6        |
| Breaking stress (MPa)            | 47.72       |
| Height (m)                       | 6.55        |
| Weight (kg)                      | 1070        |

3. Numerical Modelling of Structures

3.1. Introduction to Computing Software

As one of the most common and effective commercial finite element software, ANSYS plays a pivotal role in scientific research and practical engineering applications of building structures. When the actual building structure model tests are not available due to various reasons, numerical simulation analysis becomes an indispensable and necessary process to check the mechanical behavior and predict the general damage of the structure. Because of its large and abundant unit library, models and solvers, it can efficiently solve static problems, modal analysis, harmonic response analysis, transient dynamics analysis, spectrum analysis and other dynamic problems of various structures and the steady-state and transient thermal analysis and thermal-structure coupling problems, compressible and incompressible fluid problems.

According to the structural characteristics of electrical equipment, ANSYS is selected to establish a structural numerical model, and a reasonable unit type simulation equipment is selected to make the established numerical model as close to the real situation as possible. The specific analysis process is: establishing the model, checking the model, dividing the grid, and finally performing modal analysis, transient dynamics analysis and various load condition combination analysis on the established finite element model, and showing the data in the diagram.

3.2. Numerical Models

According to the parameters of the transformer equipment structure and referring to the flange bending stiffness formula in the code, the numerical model of the structure is established and shown in figure 2. The seismic damping model is the seismic damping devices that set at the bottom of seismic model. For the foreign project this paper referred, there are four damping device with the yield force of 20kN, and the damping ratio of 30%.

![Figure 1. 220kV Transformer device.](image1)

![Figure 2. Numerical model of the transformer.](image2)
On the left of the figure 3 is the numerical model that has been installed vibration damping device, the bottom is four vibration damping device units. The equipment structure is simulated by software beam189 and mass21 units. The vibration damping unit using combin40 to simulate, figure 4 is the schematic diagram of combin40.

**Figure 3.** Vibration damping and seismic modeling. **Figure 4.** Schematic diagram of combin40 unit.

### 4. Reference Codes, Load Combination and Evaluation Methods

In the process of calculation, a dynamic amplification factor of 1.2 was taken for the stent, and the load calculation and safety evaluation of the structure were carried out, and the load combinations and evaluation basis are shown in table 2.

The time history calculation method is used for calculation of the Earthquake action, the time duration wave is generated according to the response spectrum of 0.5g, 2% damping ratio in IEEE specification and shown in figure 5, and the peak seismic acceleration of the input structure is 0.6g after considering the dynamic amplification factor of the stent.

#### Table 2. Load combination and basis of evaluation.

| Working condition | Load combination | Safety |
|-------------------|------------------|--------|
| Seismic           | 1.0×Gravitation load+1.0×seismic action(1.0 times X direction+0.8 times Z direction) | 2 (Short duration of load) |

**Figure 5.** Input time duration wave and the response spectrum.
5. Modal Analysis

5.1. Model Analysis of Seismic

The modal analysis of the structure, can be used to obtain the frequencies and shapes of the first three orders of the structure and to get a preliminary understanding of the dynamic characteristic of the structure. The modal analysis is also the basis for the seismic acceleration response spectrum analysis which using the modal superposition method. Table 3 shows the calculated frequencies of the first 3 orders of the transformer. Figure 6 is a representative first three-order mode diagram of the transformer structure.

| Order of | 1    | 2    | 3    |
|----------|------|------|------|
| Frequency (Hz) | 4.60 | 27.49| 71.20|

(a) First-order modes of vibration | (b) 2nd order modes of vibration | (c) Third-order modes of vibration

**Figure 6.** Transformer structure first 3rd order modes of vibration diagram.

5.2. Modal Analysis of Vibration Damping Structures

The frequency and shape of each order of the damping structure can be obtained by installing four damping devices and conducting modal analysis of the whole structure. Table 4 shows the calculated first 3 order frequencies of the structure. Figure 7 is a representative first three-order mode vibration diagram of the damping structure.

| Order of | 1    | 2    | 3    |
|----------|------|------|------|
| Frequency (Hz) | 3.81 | 21.87| 57.59|

(a) First order modes of vibration | (b) 2nd Order modes of vibration | (c) Third-order modes of vibration

**Figure 7.** Diagram of the first 3 orders of vibration modes of the 4 damping device scheme structure.
6. Seismic Calculations
Firstly, the structure is calculated under normal operating conditions, that is, 1.0 times the gravitational load in the load combination formula, and the gravitational acceleration is applied to calculate the gravitational load effect, and the maximum stress of the equipment is 0.37 MPa.

The structure is calculated for 1.0 times earthquake action, input 1.0 times X direction and 0.8 times Z direction earthquake action, the calculation result is as follows (figures 8-9), the maximum stress is 35.64 MPa, and the maximum stress after the combined gravity calculation result is 36.01 MPa.

![Figure 8. Maximum Stress Curve for Transformer Seismic Calculation Equipment.](image)

![Figure 9. Top Displacement Curve for Transformer Seismic Calculation Equipment.](image)

Since the destructive stress of the equipment is 47.7 MPa, the seismic analysis of the results resulted in a safety factor of 1.32, which does not meet the IEEE code specification of safety factor of 2.0 times.

7. Seismic Damping Calculations
The structure is calculated for 1.0 times earthquake action, input 1.0 times X direction and 0.8 times Z direction earthquake action, the damping calculation results are shown in the following curve, the maximum stress of the equipment is 18.06 MPa, and after combined gravity load of 0.37 MPa, the equipment stress is 18.43 MPa, the safety factor is 2.59 when the destructive stress is 47.72 MPa, and figure 10 is the time history curve of stress of the equipment, and figure 11 is the displacement time history curve of the top of the equipment. The maximum top displacement is 49.31 mm.

![Figure 10. Maximum Stress Curve for Transformer Seismic Calculation Equipment.](image)

![Figure 11. Top Displacement Curve for Transformer Seismic Calculation Equipment.](image)
8. Conclusion
In this paper’s analysis, the finite element analysis software ANSYS is used to establish the numerical model of the transformer seismic structure and damping structure, and conducted a modal analysis, the dynamic time course analysis of the seismic structure and the damping structure, and according to the IEEE specification requirements and the analysis results in this paper, obtained following conclusions:

(1) The seismic analysis shows that the maximum stress of the equipment is 36.01 MPa and the safety factor is 1.32 (calculated based on the 35.6 kNm breaking moment) under the seismic load combination 1.0 times the gravity + 1.0 times X-directional seismic effect+ 0.8 times Z-directional seismic effect, the breaking stress of the equipment is 47.72 MPa), the safety factor of the equipment under the seismic effect does not meet the requirement of greater than 2 specified in the code.

(2) The damping analysis shows that the maximum stress of the equipment is 18.34 MPa and the safety factor is 2.59 (according to the 35.6kNm breaking moment convert 47.72 MPa breaking stress to the equipment) under the seismic load combination 1.0 times the gravity + 1.0 times X-directional seismic effect+ 0.8 times Z-directional seismic effect, and the safety factor of the equipment after the shock absorption device is installed under the seismic effect meets the requirement of greater than 2 specified in the code.

Acknowledgments
Project Name: (KJ20-1-36) Research and application of seismic isolation and damping technology for electrical equipment of 220 kV Junction substation in 8-degree seismic precautionary intensity area of Tianjin.

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