Seismic Finite Element Analysis of Lightning Arrester Combination by Casing and Pillar Insulator

Xiaojun Zhang and Zhenlin Liu
China Electric Power Research Institute Co., No. 33, Nanbinhe Road, Xicheng District, Beijing, China
Email: zhangxiaojun@epri.sgcc.com.cn

Abstract. The seismic performance of electrical equipment in substations has a great impact on the normal operation of the whole substation. The results of the modal analysis show that the fundamental frequency of the three devices is in the range of 0.9Hz~1.1Hz. The maximum stress of the casing for the three devices is respectively 55.43MPa, 45.39MPa, 35.26MPa, when the peak acceleration 0.4g seismic action is verified. The maximum stress of insulator is respectively 47.01MPa, 62.72MPa and 30.85MPa, and the maximum relative displacement of the top for the equipment is 617.2mm.

1. Introduction
As an important part of the lifeline project, once the power system fails or is damaged by earthquake, it will cause serious disasters and incalculable economic losses. Power interruption not only seriously affects normal production and earthquake relief work, but also may cause secondary disasters such as fire, which seriously threatens people's life and property safety.

Since the mid-1970s, with the frequent occurrence of seismic disasters, the seismic damage to electric power facilities has been reported throughout almost every strong earthquake. Among them, the 2008 Wenchuan earthquake that occurred in China, the 2011 earthquake in the Pacific Ocean in northeastern Japan, and the 2019 California earthquake in the United States all caused serious damage to electric power facilities, which directly caused serious rupture, displacement and oil leakage of electrical equipment such as lightning arresters and mutual transformers, thus it will affect the normal operation of the power system.

For the seismic safety of substation power facilities, scholars at home and abroad have conducted a lot of seismic research by using post-earthquake research, theoretical analysis and tests, and other technical means.

Ersoy S [1] et al. analyzed the coaction of high-voltage transformers and porcelain bushings during earthquakes by finite element simulation and obtained the relationship between the mutual influence of transformers and porcelain bushings; Filiatrault A [2] et al. performed finite element analysis on various types of high-voltage transformers and obtained the acceleration spectrum of porcelain bushings under the coaction with the box, which provided an analytical reference for the seismic study of transformers. Gilani A S [3] et al. conducted shaking table tests on several different sizes of high-voltage transformer bushings, and the test results showed that the bushings had better seismic performance with larger connection stiffness, and point washers were set at the bottom of the bushings, it effectively prevent leakage of transformer oil due to bushing displacement; Filiatrault A [4] et al. conducted a shaking table test on a 525 kV transformer and successfully obtained the dynamic characteristics of the transformer.
tank and bushing as well as other important components, and it provided valuable data for the seismic study of large transformers; in 2009, Knight B T [5] et al. proposed a "SVRP design method" to improve the seismic weakness of substations and gave several recommendations for the seismic design of substations. M. Fahad [6] conducted a seismic table test on electrical equipment which made of porcelain material, and the test results showed that the strength of the material is the controlling factor for the seismic performance of this type of equipment.

Chinese scholars have also studied the seismic performance of substation equipment gradually. Zhou Shiping [7] analyzed the damage to transformers in the Wenchuan earthquake, and the analysis results showed that the strong seismic resistance of the transformer body often led to the damage of accessories such as the emergence of bushings; Fan Rongquan [8] studied the mechanical properties and operation of synthetic insulators, and the results showed that the characteristics of composite insulators under dynamic loads were essentially different from those under static loads; in 2011, Zhang Jun et al [9] conducted a study on the seismic test and finite element analysis, which conducted on electric porcelain-type high-voltage electrical equipment, and the test data and simulations concluded that the bending resistance of electric porcelain-type high-voltage electrical equipment is poor, when it used as insulating sleeves or load-bearing columns. The reason is the fine and high body shape and the brittle porcelain parts.

This paper mainly uses the finite element software ANSYS to numerically analyze three kinds of composite surge arrester and insulator combination equipment, through the modal calculation and seismic calculation, the frequency, stress and displacement response of the equipment is compared and analyzed, and the seismic performance of the equipment is evaluated.

2. Finite Element Numerical Simulation

2.1. Equipment Overview

A domestic manufacturer's 750kV composite casing and insulator combination of lightning arrester electrical equipment was selected for the study, which consists of three upper sections of casing and one lower section of insulator. A total of three types of equipment are selected and represented by equipment 1, equipment 2 and equipment 3 respectively, with the structural arrangement shown in figure 1 and the specific structural parameters shown in table 1. The main difference between equipment 1 and equipment 3 is that the weight of each section for the casing, the radius of the insulator indexing circle and the size of the insulator diameter are different, but the arrangement form is the same, and the three insulators are evenly arranged on the circular plate. The main difference between equipment 2 and the other two types of equipment is that the arrangement form is not the same, i.e. equipment 2 uses single pillar insulators.

![Figure 1. Equipment structure diagram.](image-url)
Table 1. Structural parameter of equipment.

| Type of equipment | Equipment Weight (kg) | Young's modulus (x10^9 Pa) | Siméon Denis Poisson | Equipment Height (m) |
|-------------------|-----------------------|-----------------------------|----------------------|---------------------|
| Equipment 1       | 2705                  | 16/43                       |                      | 8.392               |
| Equipment 2       | 2280                  | 16/43                       | 0.3                  |                     |
| Equipment 3       | 3600                  | 20/43                       |                      |                     |

2.2. Finite Element Modeling

The simulation model of the equipment is established according to the structural scheme and related parameters. In establishing the finite element model of the structure, the beam unit (BEAM189) is usually used to simulate the electrical equipment, and the mean pressure ring and electromagnetic unit are simulated by the concentrated mass unit (MASS21). In the finite element mesh division, the cell size should be uniform and moderate to ensure sufficient calculation accuracy. The finite element models of the three types of equipment are shown in figure 2.

![Figure 2. Finite element model of equipment.](image)

2.3. Modal Analysis

Through the modal analysis of the three types of equipment, the order frequencies of the equipment structure are obtained and the dynamic characteristics of the structure are initially understood, and the modal analysis is also the basis for the seismic acceleration response spectrum analysis using the modal superposition method. Table 2 shows the calculated first 6 order frequencies of each equipment.

Table 2. The results of the first 6 modes calculation for each equipment.

| Type of equipment | Frequency/Hz |
|-------------------|--------------|
|                   | order1 | order2 | order3 | order4 | order5 | order6 |
| Equipment 1       | 1.066  | 1.090  | 6.292  | 6.362  | 11.286 | 11.380 |
| Equipment 2       | 0.903  | 5.279  | 14.400 | 16.817 | 27.461 | 37.461 |
| Equipment 3       | 1.107  | 1.114  | 7.181  | 7.195  | 12.779 | 12.796 |

From table 2, it can be seen that among the three types of equipment, the fundamental frequency of Equipment 2 is the smallest and the fundamental frequency of Equipment 3 is the largest, and the fundamental frequencies of the three types for equipment are between 0.903 Hz and 1.107 Hz.
2.4. Seismic Load Calculation
The peak seismic input acceleration is taken as 0.4g, and the standard response spectrum of acceleration input for model analysis is shown in figure 3, and the seismic calculation results of some of the schemes are shown in figure 4–6.

**Figure 3.** Input response spectrum.

| Type of equipment | Compose   | Direction of excitation | Maximum stress (MPa) | Maximum displacement (mm) |
|-------------------|-----------|-------------------------|----------------------|---------------------------|
| Equipment 1       | lightning | X                       | 55.43                | 509.2                     |
|                   | arrester  | Y                       | 54.46                | 521.1                     |
|                   | insulator | X                       | 43.23                | 509.2                     |
|                   |           | Y                       | 47.01                | 521.1                     |
|                   | lightning | X/Y                     | 45.39                | 617.2                     |
| Equipment 2       | arrester  | X/Y                     | 62.72                | 617.2                     |
|                   | insulator | X/Y                     | 35.26                | 515.6                     |
|                   | arrester  | Y                       | 35.15                | 520.5                     |
| Equipment 3       | lightning | X                       | 28.65                | 515.6                     |
|                   | insulator | Y                       | 30.85                | 520.5                     |

**Figure 4.** X-direction stress Nephogram of equipment 1.
Figure 5. Stress Nephogram of equipment 2.

Figure 6. X-direction stress Nephogram of equipment 3.

Figure 7. Maximum stress value of lightning arrester.
From Table 3 and Figure 4 to Figure 9, it can be found that the maximum stress values of the top casing for equipment 1, equipment 2 and equipment 3 are 55.43 MPa, 45.39 MPa and 35.26 MPa, and the maximum stresses of equipment 1 and equipment 2 appear at the root of the third casing section (from top to bottom). The maximum stress of the casing in equipment 3 under X-direction excitation appeared at the root of the third casing section, and the maximum stress of the casing under Y-direction excitation appeared at the root of the second casing section; the maximum stress values of the insulators in the lower part of the three devices were 47.01 MPa, 62.72 MPa and 30.85 MPa, the maximum stresses appeared at the top of the insulators, except for the maximum stress at the root of equipment 2.

In the seismic displacement response, the maximum displacement of the top of the casing for equipment 2 is 617.2 mm, and the minimum displacement at the top of the casing for equipment 1 is 509.2 mm. The difference between the maximum displacement at the top of the casing for equipment 1 and equipment 3 is very small, and the difference is less than 10 mm, i.e., the same arrangement has little effect on the displacement for the top of the equipment.

The main reason for the difference in seismic performance of each equipment is that Equipment 1 and Equipment 3 use three insulators in parallel, which increases the stiffness of the bottom of the equipment, and therefore it has better seismic performance than the structure of Equipment 2. The weight of each section of the casing for Equipment 3 is greater than the weight of the corresponding casing for Equipment 1, and Equipment 3 increases the size of the insulators, thus improving the seismic
performance of the equipment on the whole. Equipment 3 has best seismic performance from the stress aspect.

3. Conclusion
For the numerical model of 750kV lightning arrester combination by casing and pillar insulator, modal calculation and seismic calculation are carried out, and the following conclusions can be obtained by analyzing the calculation results of the three devices.

(1) Among the three devices, the fundamental frequency of equipment 1 is the smallest, and the fundamental frequency value is 0.903 Hz, the fundamental frequency of equipment 2 is 1.066 Hz, and the fundamental frequency of equipment 3 is 1.107 Hz.

(2) The maximum stress values for the casing roots of the three devices is respectively 55.43 MPa, 45.39 MPa, and 35.26 MPa for equipment 1, equipment 2, and equipment 3, The maximum stress values of insulators respectively is 47.01 MPa, 62.72 MPa, and 30.85 MPa for equipment 1, equipment 2, and equipment 3. The equipment 3 has the best seismic performance.

(3) The top displacement of the casing for equipment 2 is the largest, and the top displacement of the casing for equipment 1 is the smallest. The difference between the maximum displacement at the top of the casing for equipment 1 and equipment 3 is very small, the difference is less than 10mm, the top displacement is not greatly affected by using the same arrangement form.

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