Application of Isolation Technology in High-voltage Electrical Equipments

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ABSTRACT :

The isolation layer made of laminated rubber bearing is set under electric reactors. A new type model principal simulating electrical equipments has been built up successfully to solve the problem. The authors presented calculation method and analysis process in a real isolated electric engineering and compared the results with non-isolated engineering. It's shown from the results that isolation technology can decrease the seismic reaction of high-voltage reactors obviously and it's the effective way to enhance seismic ability of electrical equipments.

KEYWORDS: High-voltage reactor, Base isolation, Time history analysis, Spectrum

1. INTRODUCTION

As the important component of lifeline system, electric power system no doubt takes great role in modern society. With social modernization improving, the seismic capacity and safety evaluation of electrical equipments had become an important research subject at home and abroad in recent years. It not only affects the power system of its own security work, but also affects other industries, regional economy and national economic development. Therefore, the function of the power facilities is very necessary and very important research topic.

Since the damage caused by earthquake on the power installations was mainly inspired by the ground movement and strong vibration, that is, destruction energy came from the ground to upper structure. The limited horizontal moving can significantly reduce the upper structure destructiveness when earthquake happened. With the establishment of isolation theory, development of materials and using of isolation technology, changing the dynamic characteristics of the structure and reducing the structure earthquake response had become the hot issue in earthquake engineering.

2. BASIC THEORY

The basic isolation principle of electricity equipments based on seismic response is as following. High-voltage power facilities have some traits such as great rigidity, short natural period and small displacement and so on. Only extending period can decrease earthquake wave acceleration. The aim of using isolation equipment is reducing input accelerate to ensure security of upper structure and electric equipments. Lower rigid isolation layer set between upper structure and the foundation may extend period of entire structure and accumulate energy on isolation layer. Compared to previous ways of electrical equipments with strong stiffness and low distortion to absorb seismic energy, there has great difference between isolation structure and non-isolation structure because the latter avoided predominant period earthquake and absorbed energy by itself.

2.1. Isolator Mechanical Properties and Calculation Model

Isolator is a kind of installations set between foundation and building, its main role is to prevent earthquake action and high frequency from base to upper structure, support gravity of buildings in vertical direction, on the other hand, give horizontal stiffness to extend natural period of building, which can effectively reduce the building's earthquake response. In addition, isolator also has good capacity of large deformation which makes it restore the original position after earthquake happened.

Lead Rubber Bearing (LRB) has great vertical rigidity so elastic model can be used in vertical direction and bilinear Coulomb damper and viscous dampers are considered in horizontal direction. Combination process of bilinear spring is shown in figure 1.

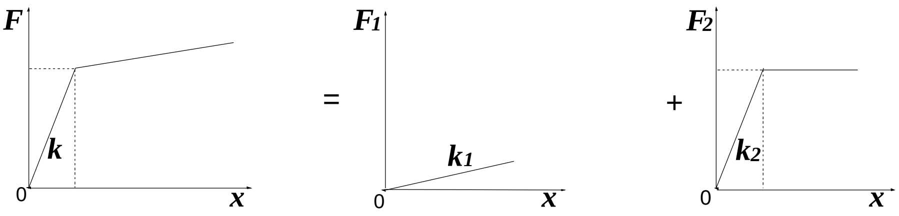


Figure 1 bilinear spring combination

In Figure 1, k is combined by elastic stiffness k_1 and elastoplastic stiffness k_2. That is $k=k_1+k_2$, $k_1=pk$, $k_2=qk$ and $p+q=1$.
In this paper, a lot of work is calculated by SAP2000 program, and Wen model is mainly used in non-linear analysis. Hysteretic restoring force and viscous restoring force are adopted in restoring force model. The general horizontal restoring force F of bearings can be expressed as follows.

$$F = F_{bh} + F_{bx} \tag{2.1}$$

F_{bh} is bilinear hysteretic restoring force with Coulomb damper shown in Figure 2.
$F_{b\xi}$ is viscous restoring force using velocity viscous dampers model shown in Figure 3.

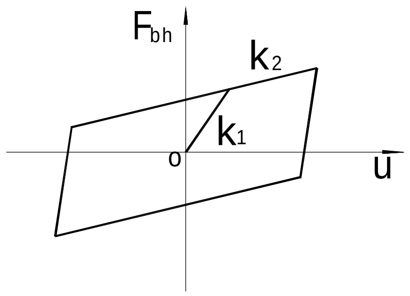


Figure 2 Bilinear restoring force model

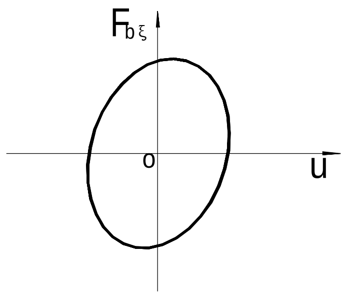


Figure 3 Velocity-viscous liquid damper model

2.2. Analysis Method

As the isolator device is nonlinear system and the structure is changeable, the classic mode superposition method is no longer applicable, thus time-history analysis method is adopted in this paper. Time-history analysis method is a dynamic analysis method to solve vibration differential equations by the gradual integration, while the changing displacement, velocity and acceleration reaction can be get from this method.
Based on the above analysis, in this paper, the isolation structure of the system is simulated by bar model; LRB is simulated by Wen model.

3. EXAMPLE ANALYSIS

This paper uses BKK-20000/35W parallel reactor as an example (the picture is shown in Figure 4), analyzes its dynamic model by finite element method shown in Figure 5. Some mechanical characteristics such as mechanical strength and stiffness can be obtained from the mechanics calculation. The main purpose of dynamic analysis and calculation of the structure is to determine natural frequency and vibration mode, and use time-history analysis method to calculate the seismic response of buildings.

Figure 4 Picture of High-voltage reactor

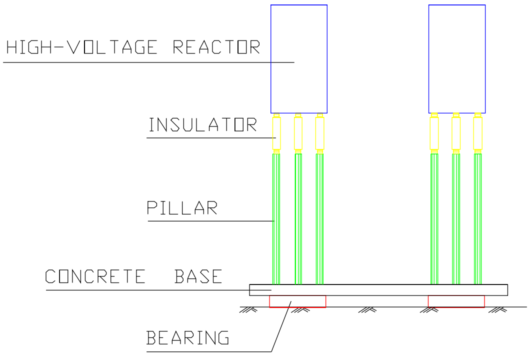


Figure 5 High-voltage reactor model

3.1. Basic Parameters

In this paper, El-centro wave and Taft wave are selected as natural waves and two artificial waves LARGE and SMALL are selected as the strong earthquake and small earthquake wave input. Seismic intensity is 8. The acceleration peak of natural waves is adjusted to 4.0 m/s^2 in strong earthquakes and 0.07 m/s^2 in small earthquakes.

As one group reactors are composed by three-phase, which are fixed on one platform and linked together in isolation design. Bearings are installed between base and concrete platform under reactor. The type of bearing is LRB-80, that is, each reactor phase center axis has one bearing. Isolated model is shown in Figure 5.

In accordance with their different materials, the BKK-20000/35W parallel reactor materials can be divided from up to bottom in glass steel materials, insulator materials, reactor materials, whose properties are shown in table 3.1.

Table 3.1 Material characteristic

Material	Elastic modulus (kN/m^2)	Poisson ratio	Mass density	Allowable stress (MPa)	Thermal expansion coefficient
Fiber reinforced plastics (FRP) pole	1.500E+07	0.30	18.0	42	1.800E-06
Insulator	5.500E+11	0.15	60.0	18	1.170E-05
Reactor	1.900E+08	0.30	75.0	120	2.2000E-05

3.2. Vibration Mode Analysis

Table 3.2 Natural frequency in two difference structures (Hz)

Vibration mode	Non-isolation structure	Isolation structure
1	1.743983	0.862292
2	1.743983	0.862292
3	19.41748	0.923191
4	19.41748	1.731072
5	68.96552	1.731072
6	94.33962	17.31224
7	94.33962	25.6128
8	555.5556	25.6128
9	769.2308	74.8252
10	769.2308	136.612

The natural frequency of structure changing with the rigidity is described in Table 3.2. It can be seen from the table that the natural frequency has reduced significantly and the period has been extended after setting the platform bearing isolation. Also, the vibration modes of isolation structure is equivalent to adding 3 first modes on the base of non-isolation structure, which 3 modes are x direction vibration, y direction vibration and distortion vibration of isolation platform. By the knowledge of response spectrum we know that only several former modes play major role in structure vibration, therefore, isolation structure changes the order of the first three modes and seismic performance of original system.

3.3. Maximum Deformation Value and Stress

Under strong earthquake action, maximum deformation value and stress in isolation structure and non-isolation structure are shown in Table 3.3.

Table 3.3 Maximum horizontal displacement value and stress under strong earthquake action

		Layer displacement(cm)			Average value	Story drift（cm）	maximum stress（MPa）
		El-centro	Taft	LARGE			
Non-isolation structure	reactor	13.99	17.64	16.76	16.13	7.36	40
	insulator	7.48	9.41	8.95	8.77	4.63	17
	FRP pole	3.60	4.51	4.32	4.14		105
Isolation structure	reactor	16.48	18.40	22.29	19.06	3.69	25
	insulator	12.59	15.43	18.09	15.37	2.14	10
	FRP pole	10.33	13.67	15.69	13.23	1.47	56
	LRB	8.35	11.97	14.96	11.76		

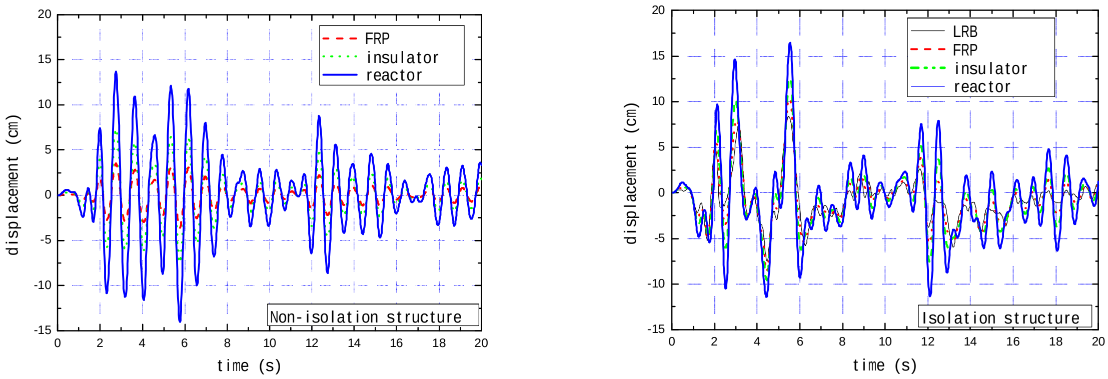


Figure 6 Maximum displacement time-history curves under strong earthquake action

It can be seen from the results in table 3.3 that the displacement values in non-isolation structure are greatly different in each floor and increase from bottom to upper structure. The upper structure shows swing form typically. However, in isolation structure, the difference displacement in each floor is so small that the main displacement concentrated in the isolation layer and the upper structure is shown synchronous motion. The maximum displacement time-history curve is shown in Figure 6.

The maximum stress of reactor, insulator and FRP pole support are 40 MPa, 17MPa and 105 MPa separately, which are very close to their allowable materials stress value with low safety ability. After using Isolation technology, the maximum stress values of them have reduced significantly and safety performance greatly improve. So it can be used lower strength materials to meet the requirements of materials optimization.

3.4. Horizontal Acceleration

The horizontal acceleration value under strong earthquake action is shown in table 3.4. It can be learned that the horizontal acceleration values are very different in isolation structure and non-isolation structure. The average ratio of them reaches 0.58. Clearly, LRB filter out nearly half of the level of ground importation acceleration values, so that acceleration of the upper structure greatly reduced and ensure the reactor safe using.

Table 3.4 Horizontal acceleration value under strong earthquake action (m/s^2)

Earthquake wave	Non-isolation structure	Isolation structure	ratio of isolation and non-isolation structure
El-centro	4.00	2.11	0.53
Taft	4.00	2.65	0.66
LARGE	3.28	1.81	0.55
average value	3.76	2.19	0.58

3.5. Horizontal Seismic Decrease Coefficient

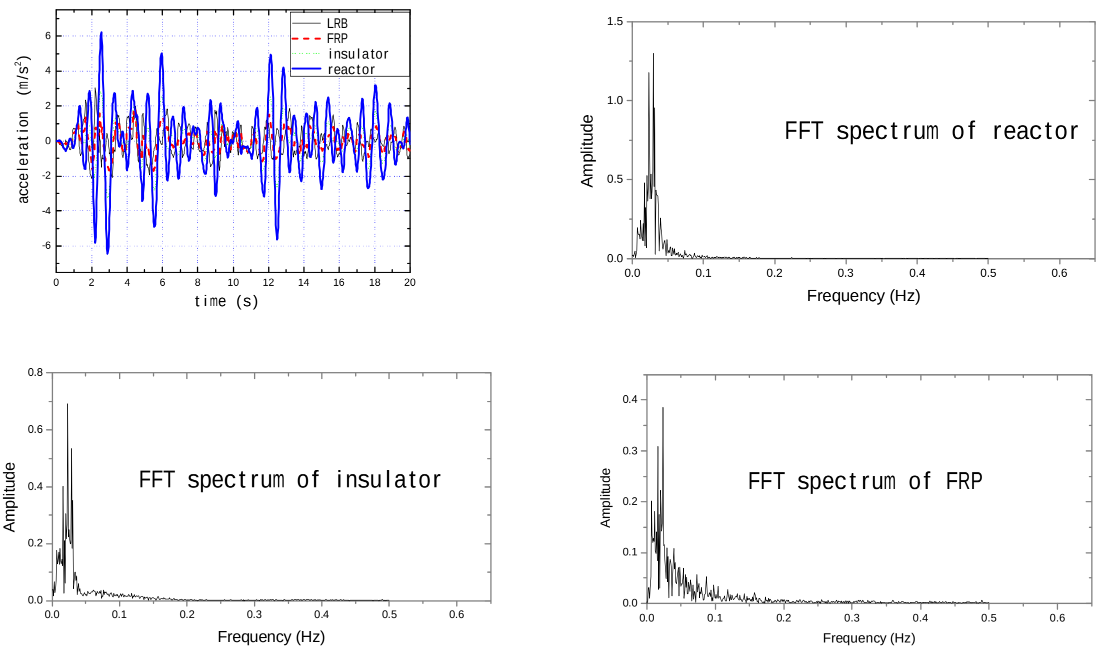
According to *Code for seismic design of buildings* (GB50011-2001), the horizontal seismic decrease coefficient should be decided by the largest layer shear force ratio of isolation structure and non-isolation structure in small earthquake action. The shear force value of reactor system using isolation technology and non-isolation technology in small earthquake action and time-history curve are shown in table 3.5.
The horizontal seismic decrease coefficient in table3.5 is 0.42/0.7=0.60. from it, we learn that the fortification intensity can decrease one degree which means the fortification intensity is 7 in isolation design.

Table 3.5 layer shear force and ratio of isolation and non-isolation structure in small earthquake action

wave	Non-isolation (kN)	Isolation (kN)	ratio of isolation and non-isolation structure
El-centro	17.85	8.29	0.46
Taft	20.43	7.82	0.38
SMALL	17.04	7.45	0.43
Average value	18.44	7.85	0.42

3.6. Spectrum Analysis of Acceleration in Isolation Structure

The time-history curve and amplitude spectrum of each part of isolation structure are showing in figure 7.



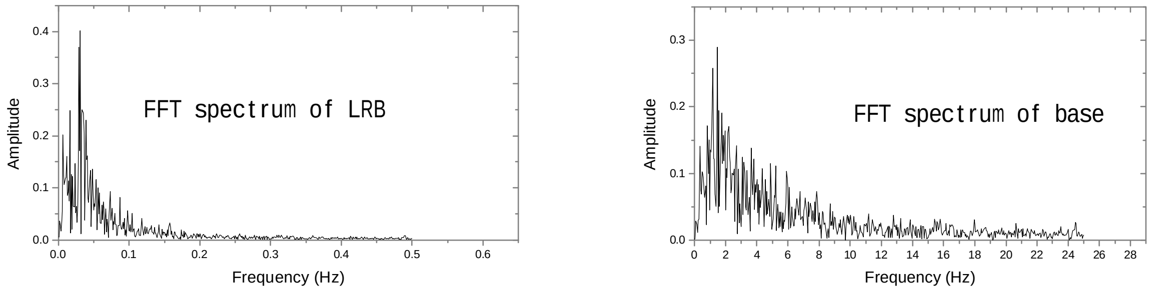


Figure 7 Acceleration time-history curve and Fourier amplitude spectrum of isolation structure

From Figure 7 it can be seen that there is a wide vibration band on the top of base, while high-frequency has been effectively filtrated out through the isolation layer. The main vibration frequency range of FRP pole is from 0 to 0.1 Hz and the main vibration frequency range of roof is from 0 to 0.05Hz, which explains isolation layer has successfully avoided peak value of earthquake action to the upper structure and expresses the superiority of isolation system.

4. CONCLUTION

High-voltage reactor is so important in electric power system that it is necessary to ensure its seismic ability. In this paper, nonlinear time-history analysis method is used to consider different materials of the isolation structure. According to reactor features, the group isolation method is presented. In order to judge the performance of this new structure, it is compared using isolation technology with no using isolation technology in BKK-20000/35W parallel reactor.

The results show that the group isolation methods and calculation model presented in this paper is feasible. After using isolation measures, the natural period of whole structure greatly extends and earthquake action reduces significantly. The horizontal displacement of upper structure accumulates to isolation layer, the shear force of base and accelerates decrease largely. The motion style of whole structure is translational. The internal force and material stress of isolation structure are reduced obviously which make the material design optimized. The results from the analysis also show that isolation technology in electric power system has following advantages: (1) It can improve seismic safety of electrical equipments and ensure them in large scope function. (2) The structure design can be more freedom. (3) It has a high economic applicability.

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