

Study on Earthquake Response of High Voltage Electrical Equipment Coupling System with Flexible Busbar

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Abstract. With the rapid development of technology and society, all walks of life in China are becoming more and more dependent on power systems. When earthquake occurs, the electrical equipment of substation is prone to damage because of its own structural features, top-heavy, and brittleness of main body. At the same time, due to the complex coupling of the soft electrical connection of substation electrical equipment, the negative impact can not be estimated. In this paper, the finite element model of the coupling system of the single unit of high voltage electrical equipment with the connecting soft bus is established and the seismic response is analysed. The results showed that there is a significant difference between the simple analysis for the seismic response of electrical equipment monomer and the analytical results of electrical equipment systems, and the impact on different electrical equipment is different. It lays a foundation for the future development of seismic performance analysis of extra high voltage electrical equipment.

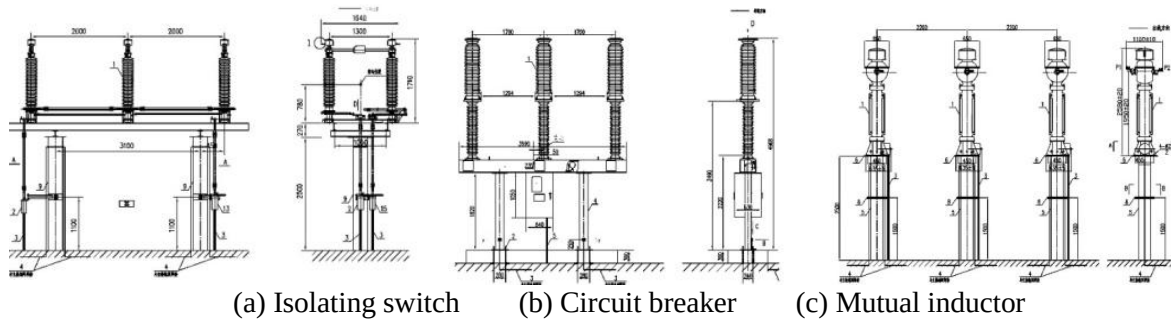
1. Introduction

The previous seismic performance analysis of the substation electrical equipment often only studied on particular electrical equipment, and the same was true of traditional shaking table tests. However, in the actual structure, the electrical equipment constituted the substation system, and there was soft bus connection between the equipment. The simple analysis of seismic performance of the equipment monomer would ignore the coupling effect of the soft bus and had an effect on the analytical results. After wenchuan earthquake, the investigation of seismic damage showed that the complex coupling of soft busbar is one of the main reasons for the destruction of electrical equipment [1]. In 2004, Song J studied on the interaction between the equipment and devices connected by cable, and pointed out the dynamic amplification of the connecting wire to the electric equipment can not be ignored [2]. In the same year, domestic scholar Li Yaqi studied on the influence of conductor on seismic performance of electrical equipment, the results showed that wires significantly increase the seismic response of the equipment [3]. In April of 2013, Liu Min studied on the seismic performance of GIS high voltage electrical equipment, and the feasibility of test scheme was verified and its finite element model was established by comparing the shaking table tests with the finite element model [4]. However, these studies were only aimed at the single subject of electrical equipment, and the actual complexity was not completely reacted because of some limitations and lack of persuasion. This paper applied the structural system of practical substation design and studied on specific reaction of the structure for further study on the seismic performance.



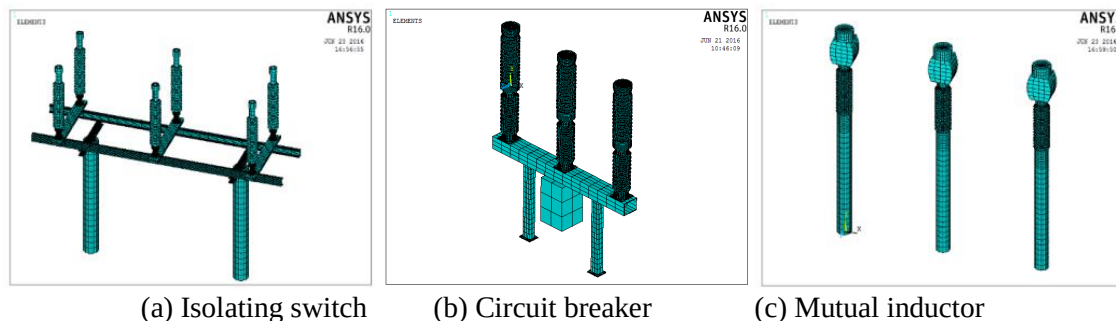
2. Modelling of high voltage electrical equipment

This paper selects three groups of high voltage electrical equipment, including high voltage isolating switch, high voltage circuit breaker, high voltage current transformer, three sets of electrical equipment are connected with soft bus, which consists of the substation power transmission system. The finite element model was established by Ansys. Figure 1 gives the structural size of three groups of electrical equipment.



(a) Isolating switch (b) Circuit breaker (c) Mutual inductor
Figure 1. The structural size of high voltage electrical equipment

The high voltage isolator selects GW4-126DW, mainly including an insulation porcelain column, knife, aluminum alloy bracket, cement pillar, and the finite element model applies SOLID45 element; High voltage circuit breaker selects LW-126, mainly including a lower bracket, a control box, aluminum alloy flange, porcelain column, wiring board, wherein the control cabinet uses SHELL281 element, and remainder applies SOLID45 unit; Figure 2 gives the high voltage current transformer selects LVB-110, mainly including the lower cement column, bracket, ceramic column, flange and et al. All use SOLID45 unit.



(a) Isolating switch (b) Circuit breaker (c) Mutual inductor
Figure 2. The finite element model of high voltage electrical equipment

3. Analysis of seismic response of high voltage electrical equipment monomer

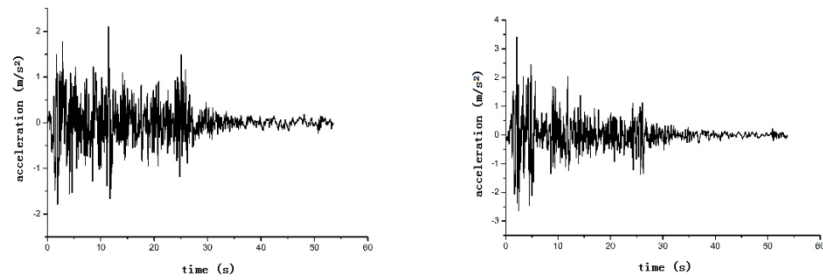
3.1. Selection of earthquake waves

In this paper, the analysis of the seismic response of electrical equipment was conducted based on El-Centro and Taft two groups of seismic wave, each group of seismic wave contains two components, as shown in Figure 3 and Figure 4. El-Centro is the actual recorded seismic wave of the Imperial Valley earthquake in California of United States in 1940, which is suitable for the type of soil II; Taft is the actual recorded seismic wave in California of United States in 1952, which is suitable for the type of soil III.

3.2. Analysis of seismic response of electrical equipment monomer

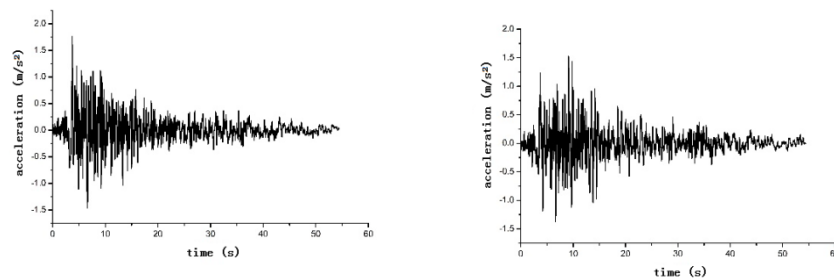
The transient time history analysis of seismic response of high voltage electrical equipment is conducted based on Ansys. Porcelain column root of high voltage isolating switch, connection of flange, and the support joint of stress concentration are prone to damage, and the maximum

displacement is at the top, and the side pole displacement is intermediate pole column. Figure 5 and Figure 6 shows the time history curve of top displacement and acceleration of B pole under different seismic waves, the curves indicate that the equipment is relatively significant in the earthquake phase displacement and acceleration.



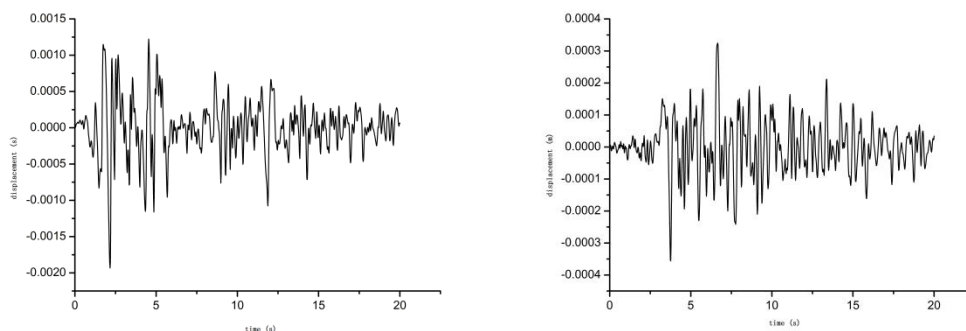
(a) E-W component

(b) N-S component

Figure 3. Acceleration of EL-Centro seismic wave

(a) E-W component

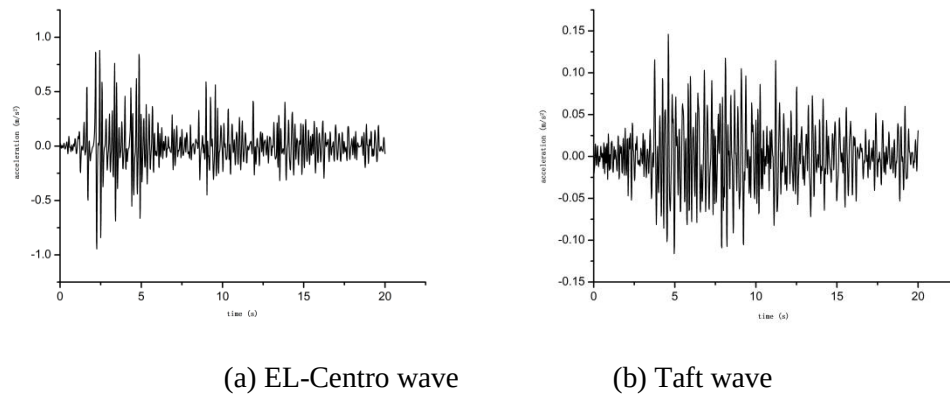
(b) N-S component

Figure 4. Acceleration of Taft seismic wave

(a) EL-Centro wave

(b) Taft wave

Figure 5. Displacement curve

**Figure 6.** Acceleration curve**Table 1.** The stress of circuit breaker three-phase polar column under the seismic action/Pa

Terminal	Direction	EL Centro Seismic wave		Taft Seismic wave	
		Minimum stress	Maximum stress	Minimum stress	Maximum stress
A-pillar	X Direction	-816985	757606	-314145	286336
	Z Direction	-655480	613028	-252771	225969
B-pillar	X Direction	-229794	205720	-108192	82843.2
	Z Direction	-378321	312740	-163768	125569
C-pillar	X Direction	-147303	161028	-115583	86528.2
	Z Direction	-224396	195077	-88207.8	70657.5

The quality of high voltage circuit breaker has much greater mass than isolating. With the comparison of electrical equipment, the top displacement of pole is larger under the external seismic loading. Three poles of high voltage circuit breaker are asymmetric installed on the same bracket, the top displacement exists difference. Table 1 gives the root stress of poles. From table 2, we can see that the x direction displacement of three poles of high voltage circuit breaker is very small, the z direction displacement is larger, and the maximum displacement occurs in the column A under El-Centro earthquake wave. The x direction displacement is smaller, the z direction displacement is large, and the displacement of column A and C is larger and the values are similar under Taft earthquake wave. Therefore, under the earthquake load, three poles broken most easily occurred in column A and C, and column A more easily damaged in a strong earthquake [5].

Table 2. The top displacement of circuit breaker three-phase polar column/mm

Seismic wave	Direction	Displacement		
		A-pillar	B-pillar	C-pillar
EL-Centro Seismic wave	X Direction	0.696	0.587	0.505
	Z Direction	17.84	15.368	12.979
Taft Seismic wave	X Direction	0.69	0.43	0.7
	Z Direction	11.4	11.2	11.7

Figure 7 and Figure 8 gives the response of displacement and acceleration of the top of breaker pole under different seismic waves. We can see that the peak value of displacement and acceleration response is larger than isolating switch, main reason is that the whole structure of the circuit breaker is unevenly distributed in quality.

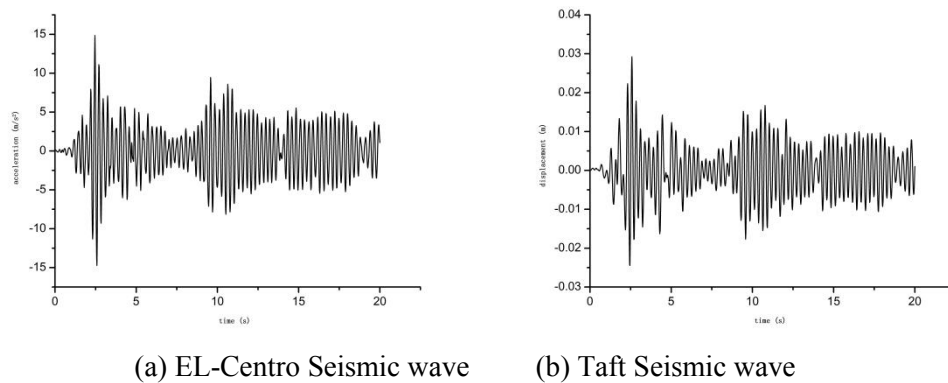


Figure 7. The displacement time history curve of the high voltage circuit breaker

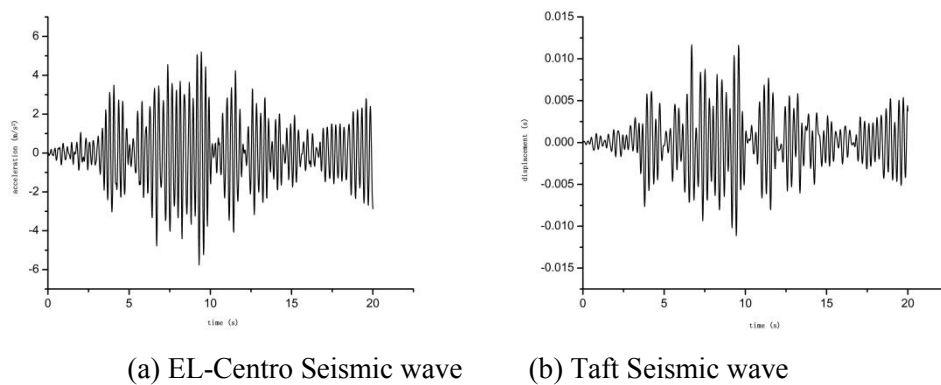


Figure 8. The acceleration and time curve of circuit breaker

The voltage transformer belongs to an independent structure. In the coupling system, three groups of transformers are required to work together, and each group of transformers is independent, and there is no interaction. Table 3 shows the maximum value of displacement and acceleration response of transformers in x and z direction under different seismic waves. Numerical analysis shows that the z displacement and acceleration response of the transformer are larger, and the x is relatively small.

Table 3. The response of voltage transformer under seismic wave

EL-Centro		Z Direction		Taft		Z Direction	
X Direction				X Direction			
Displacement (mm)	Acceleration (m/s ²)	Displacement (mm)	Acceleration (m/s ²)	Displacement (mm)	Acceleration (m/s ²)	Displacement (mm)	Acceleration (m/s ²)
2.47	0.686	4.65	1.763	1.106	0.383	1.08	0.5222

Table 4. The parameters of the conductor LGJ240/30

Calculated outside diameter (mm)	Direct-current resistance (Ω/km)	Quality (kg/km)	Elastic modulus (N/mm ²)	L-expansion coefficient (1/ °C)	Breaking force (N)	Instantaneous failure stress (MPa)
21.60	0.1181	922.2	72569	19.6×10 ⁻⁶	75620	274.02

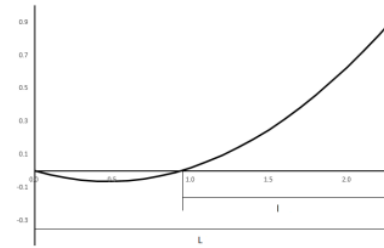
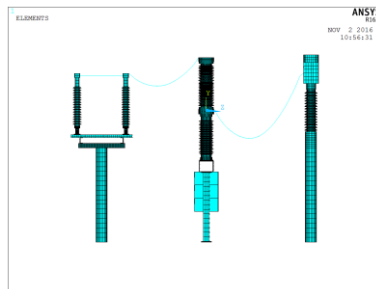


Figure 9. Finite element model of monomer flexible system **Figure 10.** Flexible busbar shape diagram

4. Analysis of seismic response of high voltage electrical equipment system connected with soft bus

4.1. Finite element model of soft bus coupling system

The soft bus is made of the conductor LGJ240/30, and its main parameters are shown in Table 4. According to its main parameters, the finite element modelling is carried out by using link180 unit. The finite element model of monomer flexible system is shown in Figure 9.

Table 5. Seismic response of different linear flexible busbars

C_1 - C_2	Isolating switch		Circuit breaker		Mutual inductor	
	Displacement (m)	Acceleration (m/s^2)	Displacement (m)	Acceleration (m/s^2)	Displacement (m)	Acceleration (m/s^2)
0.2-0.2	0.01363	3.6022	0.02142	5.19285	0.01495	6.53148
0.4-0.2	0.02815	5.10595	0.01972	5.35657	0.01495	6.5323
0.6-0.2	0.03342	5.72878	0.02175	5.62671	0.01495	6.53176
0.8-0.2	0.03517	5.93835	0.02252	5.73394	0.01495	6.53162
1.0-0.2	0.03583	6.00856	0.02283	5.77684	0.01495	6.53158
1.0-0.4	0.03545	5.97743	0.02498	6.12407	0.01452	6.5294
1.0-0.6	0.03543	5.9717	0.02567	6.22499	0.01461	6.78012
1.0-0.8	0.03544	5.97061	0.02585	6.2456	0.01479	7.02982
1.0-1.0	0.03544	5.9702	0.02590	6.24445	0.01498	7.25598

4.2. Analysis of seismic response of coupled system

Figure 10 gives a soft bus shape diagram, where L is the distance between electrical equipment, and l is the distance between the horizontal intersection point on the right side of the soft bus and the electrical equipment on the right. C is defined as the ratio of l to L ($C = l / L$), C_1 is obtained from the disconnecting switch and the high voltage circuit breaker. C_2 is obtained from the voltage transformer and high voltage circuit breaker. The C values are taken from 0 to 1, and select one group every 0.2. Then further study on the seismic response of system under different C values.

The table 5 shows the response of displacement and acceleration of coupling system, isolating switch, circuit breaker and mutual inductor. It can be seen that the influence of different soft bus length connection on the electrical equipment is different, and there is certain regularity.

Figure 11 shows the regularities of displacement acceleration response of three kinds of electrical equipment under the coupling system. The analysis results show that the acceleration and displacement response of the high voltage isolation switch increases with the increase of C_1 value, and decreases with the increase of C_2 value, and the response is the biggest when C_1 and C_2 is 1.0-0.2; The acceleration and displacement response of the high voltage circuit breaker increases with the increase of the value of C_1 and C_2 , and the response is the biggest when C_1 and C_2 is 1.0-1.0; The acceleration response of voltage transformer decreased gradually with the increase of C_1 , increased with the increase of C_2 , the displacement response decreased gradually with the increase of the C_1 , decreased

slowly with the increase of C_2 at first then gradually increased, and the response is the biggest when C_1 and C_2 is 1.0-1.0.

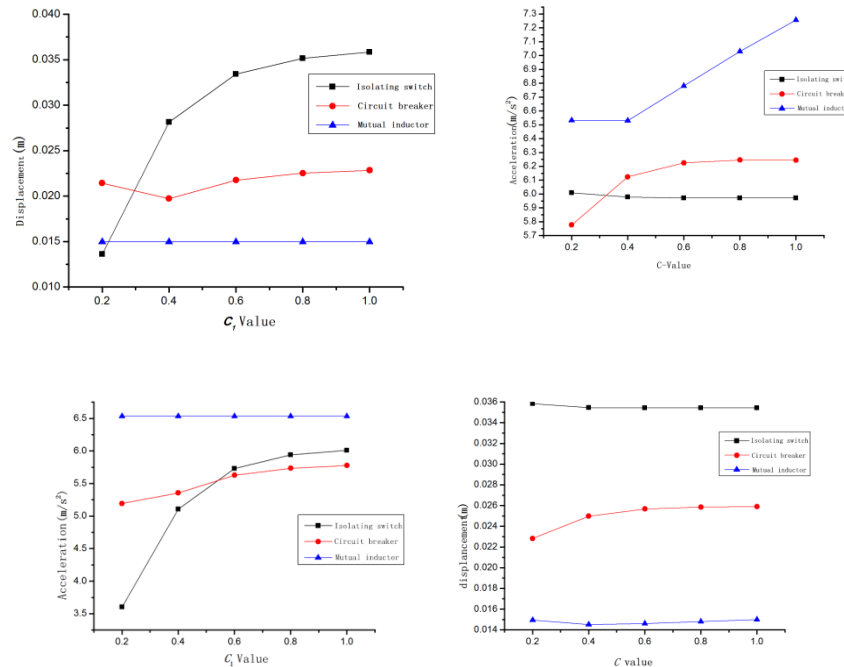


Figure 11. The regularities of electrical equipment response

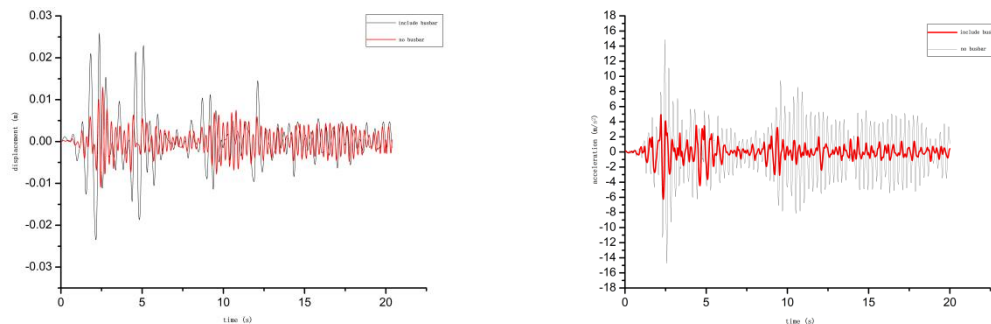


Figure 12. Comparison of displacement time history **Figure 13.** Comparison of acceleration time history

Figure 12 shows the displacement time history diagram of the high voltage circuit breaker connecting the soft bus and the unconnected soft bus. It can be seen that the displacement increases greatly during the period of seismic excellence when connects the soft bus; When the soft bus is connected, the acceleration of the coupling system is smaller than that of the single electric equipment, although the acceleration decreases, the excessive displacement will cause the soft bus to break the electric equipment, as shown in Figure 13.

5. Conclusions

In this paper, the finite element model of high voltage disconnecting switch, high voltage circuit breaker and voltage transformer is established. The main conclusions are as follows:

(1)The electric equipment belongs to large quality high-rise structure, and porcelain columns of electrical equipment are subject to greater outward tension under seismic loading because of the connection of soft bus coupling, which leads to brittle fracture at the joint between the flange and the porcelain column.

(2)The influence of the length of different soft bus connections on the main structure is different. The long soft bus has little influence on the top displacement of the main body, and the shorter bus will greatly increase the top displacement and reduce the peak acceleration at the same time.

(3)Through the time history analysis of soft bus, it is concluded that the connection of soft bus increases the peak value of displacement to some extent, while the vibration attenuation has little effect on the displacement. When the soft bus is not connected, the top acceleration of the equipment monomer is larger, and after the connection of the soft bus coupling system, the acceleration is smaller in the vibration period.

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