STUDY ON SEISMIC DYNAMIC MAGNIFICATION FACTOR OF UHV CONVERTER TRANSFORMER BODY

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Abstract

UHV converter transformer is the core equipment in converter station， converter transformer bushing has the structural characteristics of "fine, high, heavy and large", The simulation analysis and earthquake disaster investigation results of this kind of equipment show that the bushing is the weak part of the converter transformer. Under the action of earthquake, seismic wave is transmitted to the bushing of converter transformer through the body and elevator of UHV converter transformer. Because the main body of UHV converter transformer is not a rigid body structure, the seismic action transmitted to the bushing of converter transformer will change in varying degrees relative to the initial ground motion in terms of peak ground acceleration and spectrum characteristics. After the bushing is installed on the converter transformer body, the body has dynamic amplification effect on the seismic response of the bushing, which will further threaten the safety of the bushing. At present, there is no relevant research on the seismic dynamic amplification of UHV converter transformer. Therefore, it is urgent to study the dynamic amplification effect and influencing factors of converter transformer body on bushing, and then improve the seismic design level of UHV converter transformer, and maintain the safe and stable operation of power grid under earthquake. In this paper, a 1:3 scale model of ±800kV UHV converter transformer is designed based on the dimension similarity theory. Shaking table test on the single bushing and converter transformer scale model are carried out to study the seismic dynamic amplification effect of the UHV converter transformer body on the bushing. Based on the test data, the acceleration and stress amplification effects of converter transformer body on bushings are analyzed, the mechanism of seismic dynamic amplification of converter transformer body to bushing under earthquake is revealed, the definition of seismic dynamic amplification factor of converter transformer body is proposed. Then the finite element simulation is used to study the influence of the converter transformer body stiffness, bushing dynamic characteristics on the seismic dynamic amplification factor of the UHV converter transformer, and the distribution law of seismic dynamic amplification coefficient of converter transformer body is revealed. Based on the Shaking table test and simulation results, using statistical analysis method, the requirement of 2.0 seismic dynamic amplification factor for UHV converter transformer body is put forward, It provides the basis for the seismic design, test and performance evaluation of UHV converter transformer. When the structural parameters of the converter transformer body are clear, the converter transformer body and bushing should be considered as a whole in the process of seismic design, test and evaluation of converter transformer. When the body parameters are lacking or not available to test the converter transformer body and bushing as a whole, the seismic dynamic magnification factor 2.0 of the converter transformer body should be considered.

Keywords: UHV; Converter transformer; Bushing ;Earthquake; Seismic dynamic magnification

1. Introduction

China is an earthquake prone country, whose continental earthquakes account for 1/3of the global land destructive earthquakes. In recent years, with the rapid development of power grid construction, more and more substations (converter stations), especially UHV stations, are inevitably built in areas with high seismic intensity. All the major earthquakes at home and abroad have caused serious damage to power facilities. Once the power system fails or is damaged, it will cause serious disasters, incalculable direct and indirect economic losses [1, 2], and transformer as the most core and key equipment in the substation or converter station, once damaged, the whole substation or converter station will be shut down, which will bring greater threat to the safe and stable operation of the grid [3].In 2008 Wenchuan earthquake, 2010 Yushu earthquake, 2010 Mexico earthquake[4], [5], 2010 Chile earthquake[6], 2010 Haiti earthquake[7], 2010-2011 New Zealand earthquake[8], 2011 northeast japan earthquake[9], 2013 Lushan earthquake[10], power transformer and other substation equipment suffered from various forms of serious damage, affecting the normal operation of the power system, resulting in huge economic loss and serious social impact[4].

The influence of earthquake on transformer equipment has attracted great attention in the industry. A large number of experts and scholars at home and abroad have carried out a lot of researches on anti-seismic technology for transformer structure. In 1998, Bellorini et al. used the finite element method to analyze the 230 kV transformer−bushing system, and observed that the transformer tank wall and bushing itself have a significant amplification effect on the dynamic effect of ground motion[11]. In 2001, Gilani et al. evaluated the seismic performance of 230 kV bushing, proposed improvement measures for its seismic weak points, and carried out test verification[12]. Whittaker et al. carried out shaking table tests on 196, 230 and 550 kV transformer bushings in 2004 respectively, and verified the seismic performance of different types of bushings[13]. In 2005, Filiatrault et al. analyzed three transformers with different voltage levels. The results showed that due to the flexibility of the top plate of the transformer, it reduced the natural vibration frequency of the transformer bushing and increased the response of the bushing under the action of ground motion[14].In 2013, Zhu Ruiyuan et al. conducted a shaking table test study on 220kV simulation transformer − bushing system, and found that there would be swing at the root of the bushing under strong earthquake[15]. In 2013, Koliou et al. conducted numerical simulation and experimental researches on adding stiffeners to the top plate of the transformer box, which proved that increasing the number of stiffeners and optimizing their layout can significantly reduce the dynamic amplification effect of the transformer box and its rising seat on the bushing, and improve the overall seismic performance of the system[16-17]. In 2017, Chen Chuanxin and other researchers carried out seismic response research on large-scale UHV converter transformer considering liquid-solid coupling, analyzed the influence of transformer oil on seismic response of bushing, and pointed out that bushing is the weak part of converter rheology under seismic action[18]. Ma Guoliang et al. took 500kV transformer as an example, combined with seismic damage investigation and finite element simulation, analyzed the seismic damage mechanism of large transformer in Wenchuan earthquake[19].

The research results show that the bushing is the weak part of transformer equipment under the action of earthquake, and the transformer and the elevating block have amplification effect on the ground motion, which further increases the seismic damage of the bushing under the action of earthquake. At present, there is no relevant research on the seismic dynamic amplification of UHV converter transformer at home and abroad. The amplification mechanism and degree of the bushing under the seismic action are not clear. Therefore, it is urgent to carry out the research on the dynamic amplification effect of converter transformer on the bushing, so as to improve the seismic design level of UHV converter transformer, and maintain the safety and stability of the grid under the seismic action function.

2. Model Design of Converter Transformer

UHV converter transformer is mainly composed of transformer itself (including transformer oil, iron core and winding resistance inside), oil pillow, two valve side bushings, one grid side bushing and one neutral bushing. Figure 1 shows the outline diagram of a typical ±800 kV converter transformer in UHV converter station, in which the length of the converter is 8.97 m, the width is 3.85 m, the height is 4.8 m, the thickness of the steel plate on the side of the converter body is 10 mm, and the thickness of the roof is 25 mm. The total mass of converter transformer is about 542.2 tons, including 310 tons of body weight, 120 tons of transformer oil filled in the tank, 7.8 m long and 1.98 t of grid side bushing, 15.9 m long and 5.12 t of single valve side bushing, 109.98 t of core winding resistance and other auxiliary components. In view of the large size and heavy weight of UHV converter transformer, it is impossible to carry out the prototype seismic simulation shaking table test. Therefore, combined with the test capacity of the existing seismic simulation shaking table, the 1:3 scaled model shaking table test is proposed. Considering that the length of transformer neutral bushing is only 200 mm after the scale reduction which is difficult to process, the neutral bushing is ignored in the model making, the core and winding are arranged and simulated by the counterweight iron block in the same way as the center of gravity, and the transformer oil and water are simulated.

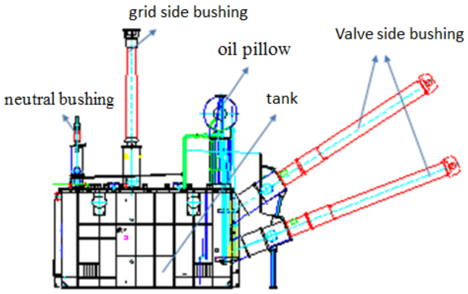


Fig. 1 –Appearance of converter transformer

The material used in the design model is the same as the prototype. The geometric similarity ratio relationship between the model and the prototype is shown in table 1. The size of the converter model is about 2.99 m ×1.28 m ×1.6 m, the total weight of the model is 20.08 tons.

Table 1 –Similarity ratio between different physical quantities of similar model

physical property	physical quantity	similarity ratio
Geometric performance	length	1:3
Material properties	density	1:1
	quality	1:27
	Elasticity modulus	1:1
	stress	1:1
Dynamic performance	time	1:3
	displacement	1:3
	speed	1:1
	accelerate	3:1
	acceleration of gravity	3:1
	frequency	3:1

3. Test Plan and Layout of Measuring Points

In order to study the seismic dynamic amplification effect of the converter transformer on the bushing, the seismic simulation shaking table test is carried out for the single bushing model of the converter transformer, and then the shaking table test is carried out for the whole model of the converter transformer. By comparing the shaking table test results of the whole model with that of the single bushing model, the seismic dynamic amplification effect of the converter transformer on the bushing is analyzed.

3.1 Experimental procedures

Firstly, three bushing models of the converter transformer are installed on the rigid support, and the rigid support is fixed on the vibration table by bolts. Control the vibration table to input seismic wave, and measure the acceleration, displacement and strain response of bushing. The size of the rigid support designed in the test is 0.8m × 0.8m × 1.5m, which is welded by 6 steel plates (20 mm thick). The total weight of the support is 690kg, and the basic frequency of the support is 79 Hz. Then, carry out shaking table test of integral model of converter transformer, figure 2 shows the assembly diagram of the shaking table test of the rheological model. The tank of the converter transformer model is filled with water to simulate the transformer oil. All the experiments in this paper stipulate that the east-west direction is X-direction, and the south-north direction is y-direction.

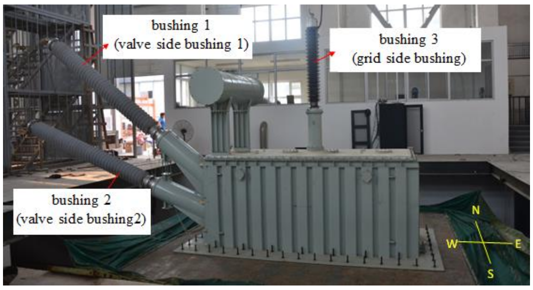


Fig. 2 –Converter transformer model installed on the vibration table

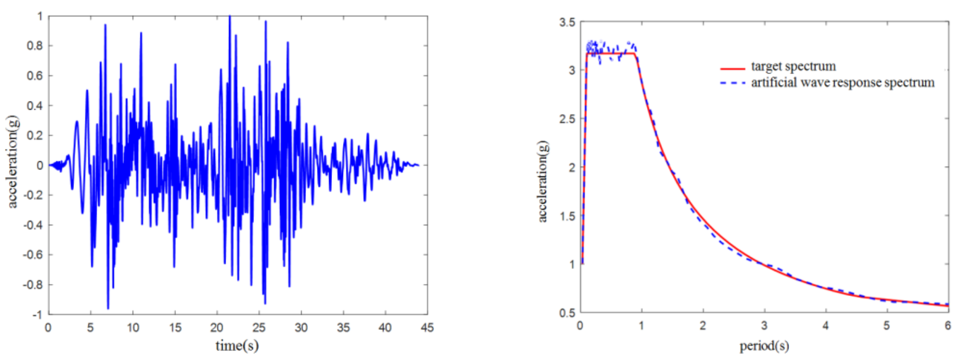
3.2 Layout of measuring points

The test was carried out on a 5 m×5 m three-way seismic simulation shaking table of the Institute of Engineering Mechanics, CEA. The contents of test measurement can be divided into three categories, namely, acceleration measurement, displacement measurement and strain measurement. The measuring instruments used in the test are acceleration sensor, displacement sensor and strain gauge.

For the model shaking table test, in order to measure the acceleration and displacement of the bushings, the support and the transformer box, acceleration sensors and displacement meters were arranged on the top of the bushings, the connection between the bushing and the support, the connection between the bushing and the riser, the top of the transformer box and the top of shaking table. At the root of the bushings, strain gauges were pasted on the opposite side of the X-direction and the opposite side of the Y-direction to measure the strain response.

3.3 Ground motion input and test conditions

The seismic wave data adopts the artificial wave proposed by China Electric Power Research Institute. The artificial wave is obtained by fitting the seismic acceleration response spectrum with a characteristic period of 0.9s, which can envelope the characteristic period of class I ~ III soil site[20]. It is suitable for the seismic design, test and seismic performance evaluation of high-voltage and ultra-high voltage electrical equipment. The artificial wave time history curve and the comparison data curve of artificial wave response spectrum and target spectrum when the peak value of seismic acceleration is 1g are shown in Figure 3.



(a) time history curve of artificial wave (b) comparison data curve of response spectrum

Fig. 3 –Time history curve and response spectrum comparison curve of artificial wave

The test shall be carried out in accordance with the requirements of Code for seismic design of electric installations (GB 50260-2013), Technical Specification for seismic design of ultra-high voltage porcelain insulating equipment and installation/ maintenance to energy dissipation devices (Q / GDW 11132-2013) and Technical code for seismic test of high voltage pillar electrical equipment (Q / GDW 11391-2015). When considering the combination of vertical seismic action, the combination coefficient is 0.8. Since the test object of the shaking table is the scale model of UHV converter transformer, the time history wave input to the shaking table should be compressed according to the similarity relationship. According to the similarity theory, the time data of input time history wave should be divided by 3, and the acceleration data should be multiplied by 3. See table 2 for specific test conditions. Input white noise before and after each group of conditions to test the dynamic characteristics of the structure.

Table 2 –Input conditions of artificial wave ground motion

direction	prototype acceleration/g	model input acceleration/g
X	0.1/0.2/0.3	0.3/0.6/0.9
Y	0.1/0.2/0.3	0.3/0.6/0.9
X+0.8Z	0.1/0.2/0.3	0.3/0.6/0.9
Y+0.8Z	0.1/0.2/0.3	0.3/0.6/0.9

4. Analysis of Test Results

In this chapter, the acceleration, strain and other seismic responses of the key measuring points of the converter transformer model under the earthquake are analyzed to study the seismic dynamic amplification effect of the converter transformer on the bushing. The data in the analysis results are model test data, whose acceleration response is three times of the prototype structure, and the strain response is consistent with the prototype structure. Because the model test results are proportional to the prototype results, the conclusions and rules obtained by using the model test results to study the seismic dynamic amplification effect of converter transformer body are exactly the same as those obtained by using the results converted to the prototype.

4.1 Test results of single bushing and overall model of converter transformer

Table 3 shows the peak acceleration of the top measuring point of the single bushing model and converter transformer model corresponding to the excitation direction under the action of artificial waves in X, Y, X + Z and Y + Z directions. Table 4 shows the maximum strain response of single bushing model and converter transformer model under various working conditions.

It can be seen from the data in the table that under the earthquake action of 0.3g, 0.6g and 0.9g, the maximum acceleration response at the top of the single bushing model on the grid side is 2.14g, 2.98g and 5.74g respectively, the maximum acceleration response at the top of the bushing 1 on the valve side is 7.34g, 11.47g and 12.82g respectively, and the maximum acceleration response at the top of the bushing 2 on the valve side is 8.79g, 12.04g and 12.35g respectively. Under the earthquake of 0.3g, 0.6g and 0.9g, the maximum strain response of the root of the single bushing model on the network side is 36.70, 60.79 and 126.55 respectively, the maximum strain response of the root of the bushing on the valve side is 287.16, 666.91 and 1027.56 respectively, and the maximum strain response of the root of the bushing on the valve side is 355.47, 645.22 and 948.70 respectively.

For the overall model of converter transformer, it can be seen that under the earthquake action of 0.3g, 0.6g and 0.9g, the maximum acceleration response at the top of the bushing on the grid side is 7.43g, 14.18g and 17.18g respectively, the maximum acceleration response at the top of the bushing 1 on the valve side is 6.25g, 11.07g and 12.51g respectively, and the maximum acceleration response at the top of the bushing 2 on the valve side is 10.35g, 8.04g and 9.37g respectively. Under the earthquake of 0.3g, 0.6g and 0.9g, the maximum strain response of the root of the bushing on the network side is 40.15, 79.06 and 258.32 respectively, the maximum strain response of the root of the bushing 1 on the valve side is 334.20, 699.76 and 940.74 respectively, and the maximum strain response of the root of the bushing 2 on the valve side is 354.65, 643.81 and 953.80 respectively.

Table 3 –Peak acceleration of corresponding excitation direction at the top measuring point of single bushing model, unit:g

bushing name and measuring point location	**direction of earthquake excitation**	**acceleration direction of measuring point**	**peak value of ground motion excitation**					
			single bushing model			**overall model of converter transformer**		
			0.3g	**0.6g**	**0.9g**	**0.3g**	**0.6g**	**0.9g**
top of grid side bushing	X	X	1.73	2.91	5.08	3.34	12.09	17.10
	Y	Y	2.14	2.98	3.77	3.34	8.34	12.48
	X+Z	X	2.05	2.93	5.74	7.43	14.18	17.18
		Z	0.77	1.37	2.81	1.03	7.85	11.70
	Y +Z	Y	1.41	2.36	3.77	4.84	8.22	14.01
		Z	0.47	1.22	3.45	1.10	5.94	7.98
top of valve side bushing 1	X	X	5.33	6.94	8.18	2.66	5.64	8.97
	Y	Y	6.33	7.25	11.72	5.32	9.51	10.18
	X+Z	X	3.01	6.23	8.76	3.57	7.63	6.47
		Z	7.34	9.87	14.89	4.52	6.93	10.06
	Y +Z	Y	5.22	8.34	12.82	6.25	11.07	12.51
		Z	7.33	11.47	11.45	4.96	7.39	9.14
top of valve side bushing 2	X	X	2.54	5.75	8.84	0.92	5.29	9.49
	Y	Y	4.78	7.81	11.24	2.60	5.82	8.37
	X+Z	X	5.41	7.22	7.65	4.20	7.84	6.33
		Z	8.79	12.04	12.35	10.35	8.04	9.37
	Y +Z	Y	6.15	7.47	12.13	3.69	5.97	13.50
		Z	8.69	9.37	12.31	5.95	4.94	14.49

Table 4 –Maximum peak strain response of single bushing model, unit: micro strain

bushing name and measuring point location	**direction of earthquake excitation**	**single bushing model**			**overall model of converter transformer**		
		0.3g	**0.6g**	**0.9g**	**0.3g**	**0.6g**	**0.9g**
grid side bushing root	X	24.50	52.67	92.11	39.19	77.94	258.32
	Y	29.94	53.57	81.08	37.09	68.84	76.59
	X+Z	36.70	60.79	118.82	40.15	79.06	193.89
	Y+Z	21.61	60.23	126.55	32.67	71.60	89.41
valve side bushing root 1	X	170.82	356.87	545.57	223.16	479.46	/
	Y	287.16	666.91	1004.16	304.40	492.52	685.39
	X+Z	216.32	373.65	666.96	261.96	699.76	/
	Y+Z	283.13	627.67	1027.56	334.20	606.48	940.74
valve side bushing root 2	X	135.60	294.31	467.18	208.10	342.63	489.26
	Y	334.77	625.25	929.27	332.14	643.81	927.62
	X+Z	332.09	559.87	744.93	344.76	513.85	612.29
	Y+Z	355.47	645.22	948.70	354.65	625.80	953.80

4.2 Seismic dynamic amplification effect of converter transformer on bushing

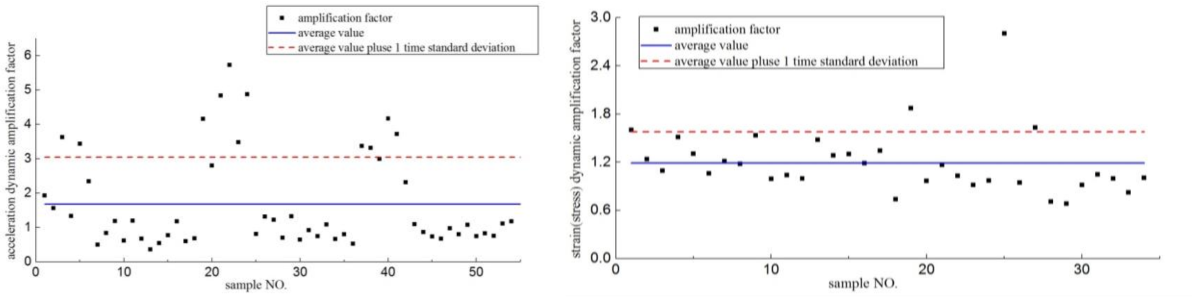
By comparing the seismic response test results of bushing in the whole model of converter transformer with that of single bushing model under the same working condition, the seismic dynamic amplification effect of converter transformer on bushing is analyzed. The seismic response value of the bushing in the overall model of converter transformer corresponding to section 4.1 is divided by the seismic response value of the single bushing model under the same working condition, and the acceleration seismic dynamic amplification factor and strain seismic dynamic amplification factor of converter transformer body are calculated respectively. The stress is equal to the strain multiplied by the elastic modulus of the bushing, therefore the dynamic amplification factor of strain earthquake can also be called the dynamic amplification factor of stress earthquake.

Figure 4(a) and Figure 4(b) are the statistics of acceleration seismic dynamic amplification factor and strain (stress) dynamic amplification factor, respectively. The scatter in the figure is the distribution of seismic dynamic amplification factor under various working conditions, the solid line is the average value of dynamic amplification factor, and the dotted line is the value of seismic dynamic amplification factor plus one time of standard deviation. From the data in the figure, the acceleration seismic dynamic amplification factor of UHV transformer body to bushing is distributed between 0.36-5.73, with an average value of 1.68 and a standard deviation of 1.36. The data distribution is relatively discrete, with an average value plus one time of the standard deviation of 3.04. The dynamic amplification factor of strain (stress) earthquake is distributed between 0.68-2.80, the average value is 1.19, the standard deviation is 0.39, the relative acceleration amplification factor, the data distribution is relatively compared, the average value plus one time of the standard deviation is 1.58.

The acceleration amplification factor and strain (stress) amplification factor are quite different in both numerical value and size distribution. Figure 5 shows the acceleration power spectral density curve of the vibration table, the bottom of the rising seat of the valve side bushing 1 and the connection between the rising seat and the valve side bushing 1of typical working condition (X-direction artificial wave action, peak acceleration is 0.3 g). It can be seen that the converter body and the riser change their spectral characteristics while amplifying the input acceleration of the ground motion. This is mainly because the converter body and the riser can not be regarded as a rigid body structure, especially the connection parts such as the riser, which have large stiffness mutation. When the seismic wave is transmitted to the top of the bushing riser, the peak acceleration and spectrum characteristics are changed to a greater extent than the initial seismic input. Therefore, the stress (strain) response of bushing under seismic action will not become a linear amplification effect with the acceleration amplification, and the amplification effect of the peak acceleration at the top of bushing can not fully represent the real seismic amplification effect of the converter on the bushing. Because the stress response is often an important index to evaluate the intensity of seismic response of bushing, and also an important basis to judge whether the structure is damaged or not, it is more reasonable to use the stress amplification effect as the definition and evaluation basis of the seismic dynamic amplification factor of the main body. The seismic dynamic amplification factor is defined as:

$$D = R_k / R_s$$

Among them, D is the seismic dynamic amplification factor, R_k is the maximum strain (stress) response of the bushing root in the UHV converter transformer overall model, and R_s is the maximum strain (stress) response of the bushing root in the single bushing test under the same working condition.



(a) acceleration dynamic amplification factor (b) strain (stress) dynamic amplification factor

Fig. 4 –Statistics of acceleration and strain (stress) seismic dynamic amplification factor

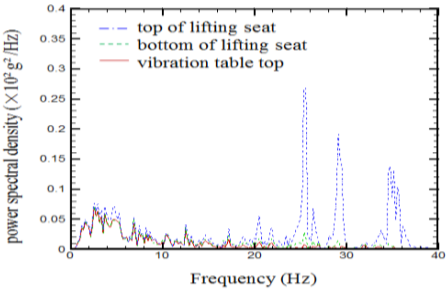


Fig. 5 –Power spectral density comparison curve

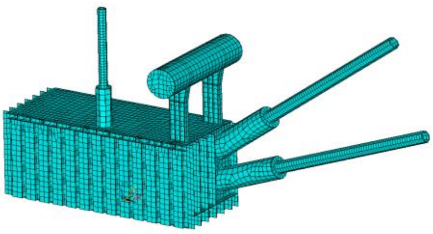
5. Numerical Simulation

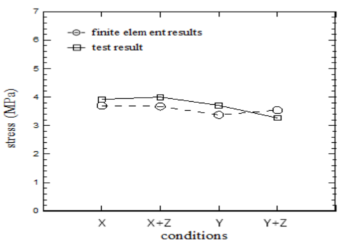
On the basis of shaking table test of seismic simulation for the bushing and the whole structure model of the rheological fluid model, the numerical model of the rheological fluid is established, which is consistent with the test conditions, and the mutual verification of the test and simulation results is carried out. On this basis, the seismic response law of the rheological fluid structure is studied, and the influencing factors of the seismic dynamic amplification factor of the rheological fluid body are further analyzed according to the test results, the value of seismic dynamic amplification factor of the converter transformer body is proposed, which provides the basis for the seismic design and seismic performance evaluation of the converter transformer structure.

5.1 Establishment of the numerical model

The large-scale finite element software is used to establish the numerical model of the single bushing and the whole structure. The geometric dimension of the model is 1/3 of the prototype, and the material properties of each component are consistent with the prototype structure. When establishing the numerical model, the bushing is simulated by beam element, the case in the converter transformer, the reinforcing iron on the case surface, the stiffener on the case cover, the rising seat and the oil conservator are simulated by shell element, the core, winding resistance and other components in the case are not important parts of concern, so only considering its mass and the position of the center of gravity, they are unified simplified as a box, and the shell element is used for modeling. Because the transformer oil in the converter is completely filled with the oil tank, its sloshing effect is very small, so the influence of liquid-solid interaction is ignored when establishing the finite element model, only the weight of transformer oil is considered, and its mass is distributed to the winding model in the oil tank. Fig. 6(a) shows the numerical model of 1:3 scaled overall converter transformer structure.

The rationality of the numerical model is directly related to the accuracy of the simulation results. Take the results of 0.3g horizontal earthquake and 0.3g horizontal earthquake combine 0.8×0.3g vertical earthquake as examples to verify the accuracy of the numerical simulation model. Taking the bushing at the grid side of converter transformer structure model as an example, the comparison of test and simulation results under various working conditions is shown in Figure 6(b). It can be seen that the error between the finite element simulation result and the test result is small, and the result between test and simulation is within the acceptable range, which shows that the finite element model established is reasonable.


(a)numerical model



(b)comparison between simulation and test

Fig. 7 –Comparison between simulation and test results of peak stress response of grid side bushing

5.2 Study on the influence factors of seismic dynamic amplification factor of converter transformer

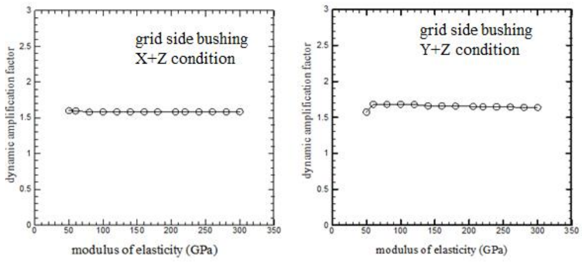
This section studies the influence of the stiffness of UHV transformer body and the dynamic characteristics of bushing on the seismic dynamic amplification factor of converter transformer body. According to the above research results, seismic dynamic amplification factor is defined by stress amplification factor. Since the research is based on the simulation of elastic theory, the influence rule of different seismic excitation intensity on the dynamic amplification factor of earthquake is consistent, this section only analyzes the results under 0.3g earthquake.

5.2.1 Influence of body stiffness

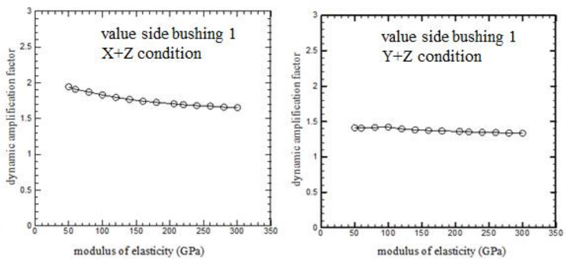
By changing the bulk modulus of UHV converter transformer, the influence of bulk stiffness on the seismic amplification factor of bushing is studied. Since the elastic modulus of commonly used metal is usually between 70-230 GPa, the change of seismic dynamic amplification factor of each bushing is studied when the elastic modulus of bulk material of converter transformer increases from 50 GPa to 300 GPa.

Figure 8(a) shows that the dynamic amplification factor of bushing at the grid side of converter transformer changes with the elastic modulus of the transformer body material under X+Z load input and Y+Z load input. The seismic dynamic amplification factor is not sensitive to the change of the elastic modulus. In the range of elastic modulus (transformer body) in current research, the seismic dynamic amplification factor is between 1.58 ~ 1.60 under X+Z condition and 1.57 ~ 1.68 under Y+Z condition. Figure 8(b) shows the change of dynamic amplification factor of bushing 1 on valve side of converter transformer with transformer body material elastic modulus under X+Z load input and Y+Z load input. The seismic dynamic amplification factor under X+Z condition is between 1.65 ~ 1.94, and the seismic dynamic amplification factor under Y+Z condition is between 1.33 ~ 1.42. Figure 8(c) shows the change of dynamic amplification factor of bushing 2 on valve side of converter transformer with transformer body material elastic modulus under X+Z load input and Y+Z load input. The seismic dynamic amplification factor under X+Z condition is between 1.0 ~ 1.28, and that under Y+Z condition is between 1.51 ~ 1.73.

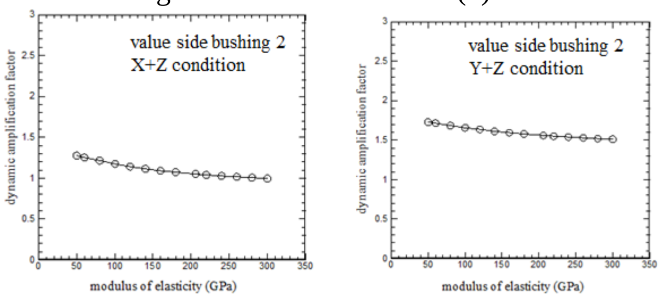
Based on the above results, the seismic dynamic amplification factor decreases with the increase of the stiffness of the bulk material. When the stiffness of the bulk material is small (for example, when the elastic modulus of the bulk material is 50 GPA), the maximum dynamic amplification factor is 1.94.



(a) grid side bushing



(b)value side bushing 1



(c)value side bushing 2

Fig. 8 –Comparison between simulation and test results of peak stress response of grid side bushing

5.2.2 Influence of bushing dynamic characteristics

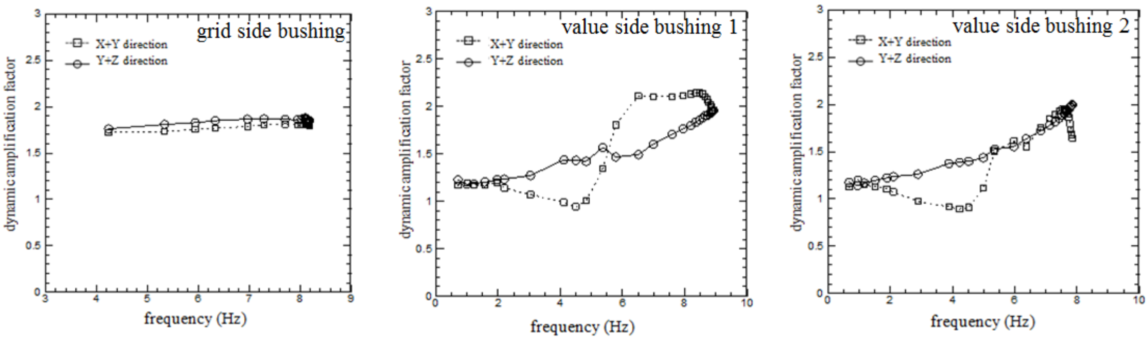
By changing the elastic modulus of the bushing to adjust the stiffness and natural frequency of the bushing, the influence of the dynamic characteristics of the bushing on the seismic dynamic amplification factor of the converter fluid body is studied. Figure 9 shows the relationship between the stress seismic dynamic amplification factor of bushing and bushing frequency.

It can be seen that the seismic dynamic amplification factor of stress increases with the increase of grid side bushing frequency, and the seismic dynamic amplification factor caused by the change of grid side bushing frequency is between 1.72 and 1.88.

For the valve side bushing 1 used in the test, the frequency is 5.78 Hz. When the frequency changes by -20%~20% (4.62 Hz~6.94 Hz), the seismic dynamic amplification factor caused by the change of bushing frequency is between 0.94~2.11.

For the valve side bushing 2 used in the test, its frequency is 5.35 Hz. When the frequency changes from - 20% to 20% (4.28 Hz to 6.42 Hz), the seismic dynamic amplification factor increases with the increase of bushing frequency, and the seismic dynamic amplification factor caused by the change of bushing frequency is between 0.89 to 1.76.

In conclusion, when the bushing frequency changes within a certain range (- 20% ~ 20%), the seismic dynamic amplification factor of stress increases with the increase of bushing frequency, but the seismic dynamic amplification factor is always less than 2.11. When the bushing frequency is its actual frequency, the seismic dynamic amplification factor of all working conditions is less than 2.0.



(a)grid side bushing (b)value side bushing 1 (c) value side bushing 2

Fig. 9 –Relationship between seismic dynamic amplification factor and bushing frequency

6. Value of seismic dynamic amplification factor of UHV converter transformer

It can be seen from the above analysis that the strain (stress) amplification should be taken as the basis for the value of seismic dynamic amplification factor of converter transformer body. The shaking table test results of the scale-up model of UHV converter transformer show that the seismic dynamic amplification factor of the body strain (stress) of converter transformer is between 0.68-2.80. Among the 34 valid test data, the seismic dynamic amplification factor under only one condition is 2.8, the other values are all below 1.87, and the average value and average value plus one time standard deviation are 1.19 and 1.58 respectively.

Through the finite element simulation, the influence factors of the seismic dynamic amplification factor of the converter transformer body are studied. The results show that the seismic dynamic amplification factor decreases with the increase of the rigidity of the converter body material. When the rigidity of the converter body material is small (for example, the elastic modulus of the body material is 50 GPa), the maximum dynamic amplification factor is 1.94. When the bushing frequency changes in a certain range (- 20% ~ 20%), the seismic dynamic amplification factor of stress increases with the increase of bushing frequency. In most cases, the seismic dynamic amplification factor of bushing is below 2.0 (only in some extreme cases, the seismic dynamic amplification factor reaches 2.11). When the bushing frequency is its actual frequency, the seismic dynamic amplification factor of all cases is less than 2 .0.

Combined with the simulation and test results, it is suggested that the seismic dynamic amplification factor of UHV converter transformer should be 2.0, which can not only envelope the maximum value of the actual seismic dynamic amplification factor, but also slightly larger than the standard value obtained by the test plus one time of the standard deviation.

7. Conclusions

Through shaking table test, the seismic dynamic amplification effect of UHV converter transformer on the bushing is studied. Combined with the simulation analysis, the influencing factors of the seismic dynamic amplification factor of converter transformer are further analyzed, then the value of the seismic dynamic amplification factor of converter transformer is proposed, which provides the basis for the seismic design and seismic performance evaluation of UHV converter transformer. The main conclusions are as follows:

（1） The seismic input acceleration is amplified and the frequency spectrum characteristics are changed by the converter body and the riser at the same time. The amplification effect of the peak acceleration at the top of the bushing can not fully represent the real seismic amplification effect of the converter body on the bushing. Since strain (stress) response is often an important index to evaluate the intensity of seismic response of bushing, this paper puts forward the definition of strain (stress) amplification as the seismic dynamic amplification of the main body of UHV converter transformer.

（2） The test results show that the seismic dynamic amplification factor of the body strain (stress) of converter transformer is between 0.68-2.80. Among the 34 valid test data, the seismic dynamic amplification factor under only one condition is 2.8, the other values are all below 1.87, and the average value and the average value plus one time standard deviation are 1.19 and 1.58 respectively.

（3） The simulation results show that the seismic dynamic amplification factor decreases with the increase of the stiffness of the converter transformer body material. When the stiffness of the converter body material is small (the elastic modulus of the body material is 50 GPa), the maximum dynamic amplification factor is 1.94. When the bushing frequency changes in a certain range (- 20% ~ 20%), the seismic dynamic amplification factor of stress increases with the increase of bushing frequency. In most cases, the seismic dynamic amplification factor of bushing is below 2.0 (only in some extreme cases, the seismic dynamic amplification factor reaches 2.11). When the bushing frequency is its actual frequency, the seismic dynamic amplification factor of all cases is less than 2 .0.

（4） When the seismic dynamic amplification factor of converter transformer body is taken as 2.0, it can basically envelope the influence of the change of stiffness of converter body, dynamic characteristics of bushing and the change of connection mode between the body and bushing on the seismic dynamic amplification of bushing. Therefore, it is proposed that the seismic dynamic amplification factor of UHV converter body to bushing should be taken as 2.0. This value can be used for seismic evaluation and seismic design for UHV converter transformer.

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9. Copyrights

10. References

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