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An Artificial Seismic Wave Suitable for Suspended Converter Valve in the UHVDC Transmission Project

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Abstract. The finite element model of suspended converter valve in an UHVDC transmission project with characteristics of flexible is constructed, and its vibration characteristics are simulated and analyzed firstly. The results show that this kind of suspended converter valve has obvious long-period character. Secondly, the long period phase of standard response spectrum in Code for Seismic Design of Buildings (GB50011-2010) is modified, and then the artificial seismic wave is synthesized employing the triangular series method. The result shows that this artificial seismic wave has long-period character. Finally, the time-history seismic dynamic simulation of the converter valve is done, and the seismic responses of the converter valve excited by three kinds of seismic wave with different period characters are compared and analyzed. The results show that the swing and stress of the suspended converter valve are larger under the long-period seismic wave synthesized in this paper. The quasi-resonance damage caused by long-period seismic wave should be concerned specially in the actual UHVDC transmission project.

1 Introduction

UHVDC transmission project in China has been developing rapidly in recent years. The converter valve is one of the core equipment of the converter station or even the whole DC transmission project, therefore, it has complex structure and high operational reliability requirements. Therefore, the safe and reliable operation of the converter valve has attracted more and more researchers' attention. Many experts and scholars have done relevant research on the analysis of seismic characteristics of the suspended converter valve[1-6]. Most of them in China choose real seismic records, such as El-centro wave and Taft wave, or artificial seismic waves obtained through the standard response spectrum in Code for seismic design of buildings (GB50011-2010)[6] as seismic wave data commonly. However, there is a clear note in Code for seismic design of buildings(GB50011-2010) that the seismic impact coefficient for buildings should be specially studied when its natural period is greater than 6.0s. Hence, it is worth further to discuss whether the standard response spectrum is suitable for the seismic research of the converter valve with flexible characteristics.

2 Natural vibration characteristics of suspended converter valve

2.1 Finite element model

Fig.1 shows the finite element model of a suspended converter valve, and its dynamic equation is,

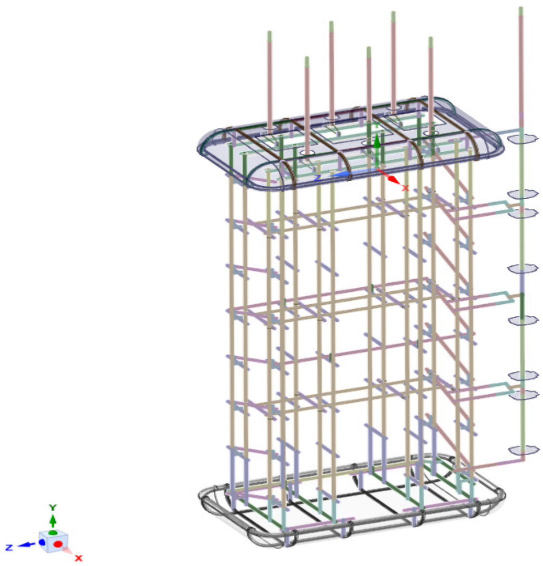

Fig.1 Finite element model of a suspended converter valve

$$[M]\{\ddot{x}\}+[C]\{\dot{x}\}+[K]\{x\}=\{F(x)\} \tag{1}$$

Where, [M], [C] and [K] are the mass matrix, damping matrix and stiffness matrix of the suspended converter valve respectively, $\{\ddot{x}\}$、$\{\dot{x}\}$and$\{x\}$are acceleration vectors, velocity vectors and displacement vectors of the converter valve respectively, $F(x)$is force matrix. Since

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the free vibration mode of converter valve is simple harmonic vibration, equation (1) can be written as,

$$([K]-\omega^2[M])\{\phi\}=0 \tag{2}$$

Where, $\{\phi\}$ is modal shape, ω is circular frequency.

2.2 Natural frequency and period

The modal analysis of the converter valve is done by Workbench software. The converter valve is suspended in the valve hall by insulation rods. General joint is adopted to simulate hinge connection between insulation rods and valve hall. Hinge connection between insulation rods and valve body are treated in same way. The rods and plates are simplified into line element and surface element in modelling.

Table 1 shows top 30 natural frequencies of the converter valve. All of top 6 natural frequencies of it are less than 1Hz, and all of top 30 natural frequencies are less than 3Hz. Therefore, the converter valve has an obvious long-period characteristic, and the first-order natural vibration period reaches 7.5s.

Table 1 Top 30 natural frequencies

Order	Frequency/Hz	Order	Frequency/Hz
1	0.133	16	1.777
2	0.313	17	1.779
3	0.326	18	1.780
4	0.415	19	1.805
5	0.772	20	1.812
6	0.999	21	2.100
7	1.023	22	2.115
8	1.195	23	2.138
9	1.205	24	2.158
10	1.209	25	2.228
11	1.263	26	2.744
12	1.273	27	2.869
13	1.277	28	2.878
14	1.297	29	2.892
15	1.748	30	2.935

3 An artificial seismic wave with long-period character

3.1 Designed acceleration response spectrum

The maximum period of designed acceleration response spectrum in various industries in China is given only as 7 seconds at present, which cannot meet the special requirements of seismic design for structures with long-period characteristic. The function of long-period phase of the standard acceleration response spectrum in Code for Seismic Design of Buildings (GB50011-2010)[7] is modified in Reference [8] in order to extend the period to 10s. The similar method is used in this paper to obtain the period of 9s as the designed acceleration response spectrum (the damping ratio is set as 0.05, the designed earthquake group is set as the second group, and the site category is set as the second class), and the function expression of designed acceleration response spectrum can be written as,

$$S(a)=\begin{cases}[0.45+(10\eta_2-4.5)T_0]\alpha_{max}g & 0<T_g\le 0.1\\ \eta_2\alpha_{max}g & 0.1<T_g\le T_g\\ (T_g/T_0)^{\gamma}\eta_2\alpha_{max}g & T_g<T_0\le T_g\\ (5T_g)^{\varepsilon}\eta_2 0.2^{\gamma}\alpha_{max}(1/T)^{\varepsilon} & 5T_g<T_0\le 9\end{cases} \tag{3}$$

Where, α_{max} is maximum influence coefficient of horizontal earthquake, T_0 is natural vibration period of the structure, g is acceleration of gravity, T_g is characteristic period of site soil (T_g =0.40), γ is attenuation exponent of descending section of the curve （ γ =0.9 ） , η_2 is damping adjustment coefficient （ η_2 =0.1 ） , ε is the descending rate coefficient （ ε =1.3 ） . The designed acceleration response spectrum obtained in this paper is shown in Fig.2.

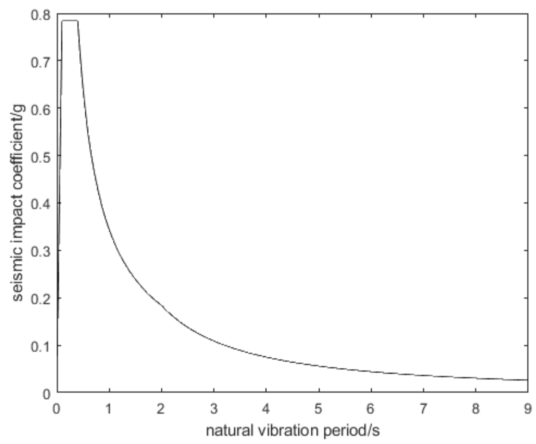

Fig.2 The designed acceleration response spectrum in this paper

3.2 Artificial seismic waves

N triangular series are employed to synthesis an artificial seismic wave by triangular series method, they are functioned as,

$$\alpha(t)=g(t)\sum_{n=1}^{N}A_n\cos(\omega_n t+\varphi_n) \tag{4}$$

Where, $\alpha(t)$ is acceleration value of artificial seismic wave at time *t*, *N* is number of trig series, A_n is amplitude of the N^{th} triangular series, ω_n is the N^{th} series triangular frequency, φ_n is the N^{th} triangular series random phase Angle, $g(t)$ is the envelope function of acceleration amplitude at time *t*.

The approximate conversion relationship between acceleration response spectrum and power spectrum[6] (p=0.85) can be written as,

$$S(\omega) = -\frac{\xi}{\pi \cdot \omega} S_a^{\ 2} \times \frac{1}{\ln\left[-\frac{\pi}{\omega T}\ln(1-p)\right]} \tag{5}$$

The relevant parameters in equation (4) can be obtained from the following equations,

$$\begin{cases} A_n = \sqrt{4S(\omega)\Delta\omega} \\ \Delta\omega = 2\pi / T \\ \omega_n = n\Delta\omega \end{cases} \tag{6}$$

The expression of time envelope function $g(t)$ is,

$$g(t) = \begin{cases} \left(\frac{t}{t_1}\right)^2, 0 \le t \le t_1 \\ 1 \qquad , t_1 \le t \le t_2 \\ e^{-\lambda(t-t_2)}, t_2 \le t \le t_3 \\ 0 \qquad , t_3 \le t \le T \end{cases} \tag{7}$$

Where, c is attenuation coefficient, t_1, t_2, t_3 and T are initial time, end time, end time of attenuation period and total holding time of seismic waves respectively.

Fig.3 shows the artificial seismic wave synthesized in this paper based on the modified acceleration response spectrum. Fig.4 and Fig.5 show the amplitude -frequency characteristic curves of the artificial seismic wave synthesized in this paper and synthesized based on the standard response spectrum (hereinafter referred to as Signal 1 wave and Signal 2 wave) obtained by Fourier transform respectively. It can be seen that the larger amplitudes of Signal 1 wave are appeared obviously in the lower frequency phase by comparing Fig.4 with Fig.5.

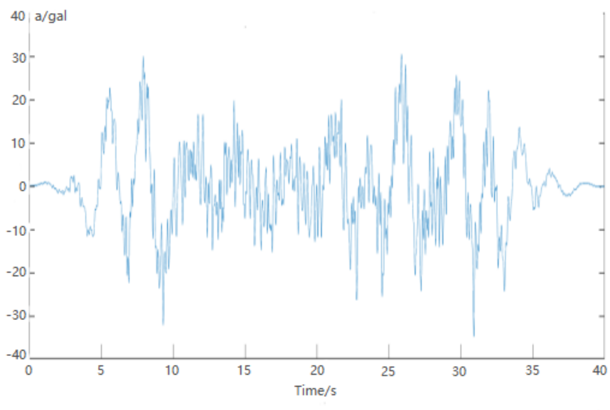

Fig.3 The artificial seismic waves in this paper

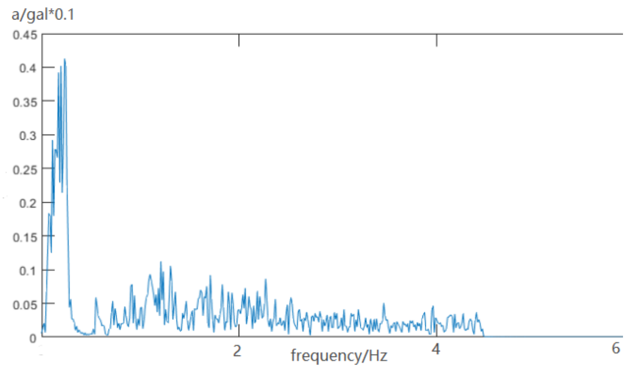

Fig.4 Amplitude-frequency curves of Signal 1 wave

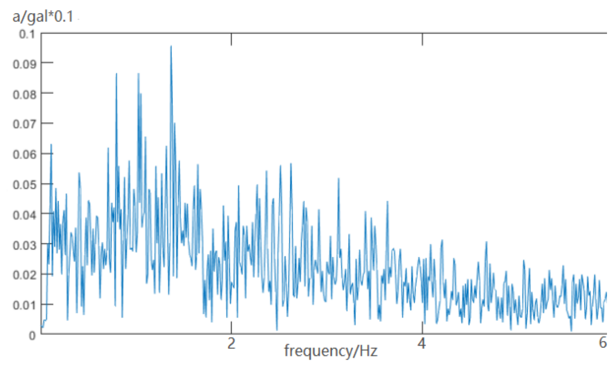

Fig.5 Amplitude-frequency curves of Signal 2 wave

4 Project example

The suspended converter valve shown in Fig.1 is simplified and selected as the example model to simulate. The Signal 1 wave, Signal 2 wave and El-centro wave (hereinafter referred to as Signal 3 wave) are selected as the seismic excitation. The maximum peak acceleration of the three seismic waves are set as 55 gal. The hinge of suspended insulator is constrained by releasing the X-axis rotation degree of freedom and fixing the rest. The gravity load is considered. The direction Z and Y are applied with the acceleration load, and the loading ratio is 1:0.65. Rayleigh damping coefficients[9] are calculated, and alpha=0.0042, beta=0.0941.

The results show that all of the maximum displacements appear at the bottom nodes of converter valve excited by three kinds of seismic wave. Fig. 6, 7 and 8 are the displacement time-history curves in direction Z of the above 3 nodes. The maximum displacement in these 3 nodes appear at 13s, 25s and 29s respectively, and the corresponding comprehensive displacements in these 3 nodes reach 181mm, 24mm and 37mm respectively. The larger stress is mainly distributed at the joint of load-bearing structure with the suspended insulator, and the largest Von-mises stress reaches 3.34MPa, 2.71MPa and 2.82MPa respectively. Obviously, the suspended converter valve appears greater response displacement and stress under the excitation of seismic wave synthesized in this paper due to the quasi-resonance phenomenon.

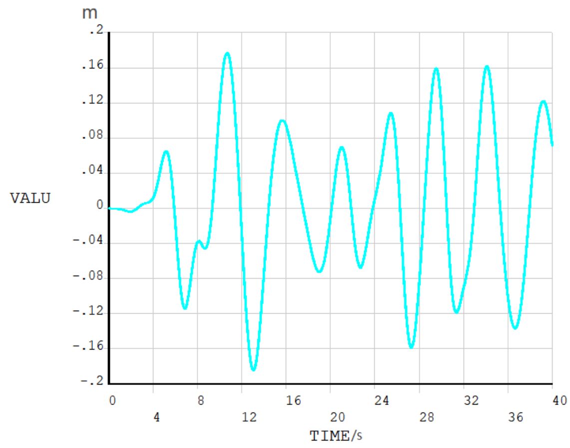

Fig.6 Displacement time-history excited by signal 1 wave

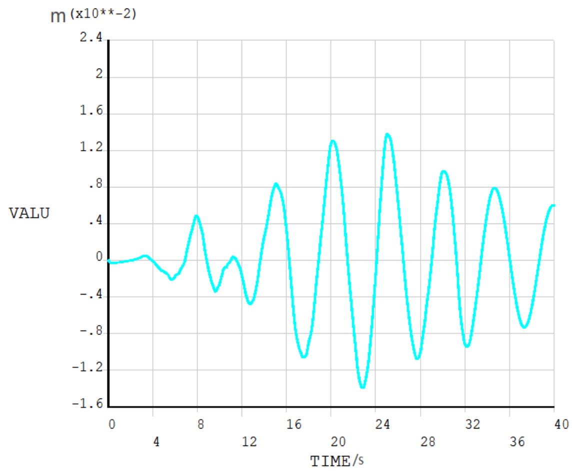

Fig.7 Displacement time-history excited by signal 2 wave

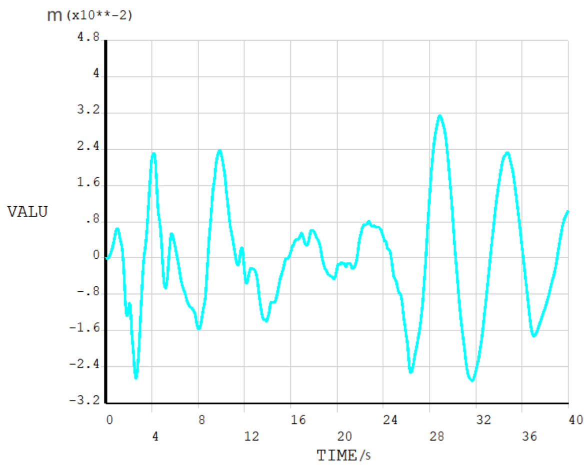

Fig.8 Displacement time-history excited by signal 3 wave

5 Conclusions

The vibration characteristic of suspended converter valve is analyzed, the artificial seismic wave suitable for analysis of ground vibration of the converter valve is synthesized, and an example simulation is done in this paper. The following conclusions are obtained as,

(1) The suspended converter valve is a flexible long-period structure with lower natural vibration frequencies.

(2) The artificial seismic wave synthesized by the modified designed acceleration response spectrum has the long-period character, and it is more suitable for seismic analysis of the suspended converter valve.

(3) The suspended converter valve appears the larger displacement and stress under the excitation of long-period artificial seismic waves because of its quasi-resonance phenomenon. We should deserve to pay particularly attention to the phenomenon in seismic design of the suspended converter valve in UHVDC transmission project.

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