DYNAMIC RESPONSES OF UHV TRANSMISSION TOWER-LINE SYSTEM AFTER ICE-SHEDDING IN HEAVY ICE ZONES

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***Abstract**:* The finite element models of typical 1000kV transmission tower-line sections in heavy ice zones are created by means of the ABAQUS/CAE software and the dynamic responses of the models with different structure parameters in different ice-shedding conditions are numerically investigated. Based on the linear relations, two simplified formulas for the maximum jump height and horizontal swing amplitude of the transmission lines with odd number of spans after ice-shedding are proposed for the design of the UHV transmission lines.

1. INTRODUCTION

Ultra-high Voltage (UHV) transmission technology has been widely used in engineering practice. Ice-shedding from transmission line under certain conditions may cause vertical jump and horizontal swing of the line and even leads to trip if the clearances between the different phase conductors and/or between the conductor and ground wire are smaller than the tolerable electric insulation distance, which will jeopardize the safe operation of power supply. Therefore, it is very important to investigate the dynamic responses of the UHV transmission tower-line system after ice-shedding in heavy ice zones.

2. RESULTS AND DISCUSSION

Based on the numerical simulation results, it is found that there is a linear relation between the sag difference Δf of the iced electric line before and after ice-shedding and the maximum jump height H, as shown in Fig.1. A simplified formula for the maximum jump height is obtained as the follows by means of data fitting

$$H = 1.72\Delta f \qquad (1)$$

The relative errors between the jump height determined by the simplified formula and that obtained by numerical simulation are less than 4.6%.

The iced electric line will swing if there is a wind load on the line, and the maximum swing amplitude is also important for the design of the transmission line. In this case, a linear relation between the static swing difference ΔA before and after ice-shedding and the maximum horizontal swing amplitude B is obtained, as shown in Fig.2. A simplified formula for the maximum horizontal swing amplitude is obtained by means of data fitting as follows

$$B = 1.71\Delta A \qquad (2)$$

The relative errors between the horizontal swing amplitude determined by the simplified formula and that obtained by the numerical simulation are less than 6.07%.

Formulas (1) and (2) can be used in the design of UHV transmission lines in heavy ice zones.

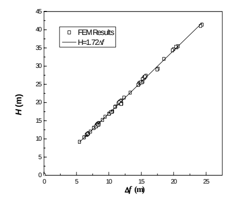

Figure1: Relation between jump height and sag difference of electric line before and after ice-shedding

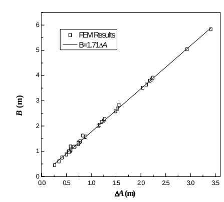

Figure2: Relation between horizontal swing amplitude and swing difference of electric line before and after ice-shedding

3. CONCLUSION

The numerical model of UHV transmission tower-line system is set up, and the dynamic responses of the iced transmission line sections with various structure parameters under different ice-shedding conditions are numerically investigated. based on the numerical results, simplified formulas to determine the maximum jump height of an iced electric line after ice-shedding and the maximum swing amplitude of the iced line after ice-shedding as wind load is taken into account are proposed for the design of UHV transmission line.

4. REFERENCES

[1] T. Kalman, M. Farzaneh, G. McGlure. Numerical analysis of the dynamic defects of shock-load-induced ice shedding on overhead ground wires. Computers & Structures 2007, 85:375-384

[2] KQ. Chen, B. Yan, Y. Guo, M. Liang, J. Chen, Dynamic response of ultra-high voltage transmission line ice-shedding. Journal of Chongqing University (Natural Science Edition)，2007, 30(12): 46-48 (in Chinese)

[3] L. Li, Z. Xia, G. Fu, Ice-shedding induced vibration of a long span electric transmission tower-line system. Journal of Vibration and Shock， 2008， 27 (9): 32-34 (in Chinese).

[4] B. Yan, X. Lin, W. Luo et al. Numerical study on dynamic swing of suspension insulator in overhead transmission line under wind load. IEEE Transactions on Power Delivery, 2010, 25(1): 248-260.

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***Abstract*—The finite element models of typical 1000kV transmission tower-line sections in heavy ice zones are created by means of the ABAQUS/CAE software and the dynamic responses of the models with different structure parameters in different ice-shedding conditions are numerically investigated. A linear relation between the maximum jump height of a line after ice-shedding and the sag difference of the line before and after ice-shedding is obtained based on the numerical results. Moreover, a similar linear relation between the maximum horizontal swing amplitude of the line after ice-shedding and the static wind swing difference before and after ice-shedding, as wind load is taken into account, is also obtained. Based on the linear relations, two simplified formulas for the maximum jump height and horizontal swing amplitude of the transmission lines with odd number of multi-spans after ice-shedding are proposed for the design of the UHV transmission lines.**

Key words: UHV transmission line； ice-shedding； dynamic response ； jump height ； horizontal swing amplitude; numerical simulation

I. INTRODUCTION

Ultra-high Voltage (UHV) transmission technology, which is beneficial for the conservation of resources and large-capacity power transmission, has been widely used in engineering practice [1]. Ice-shedding from transmission line under certain conditions may cause vertical jump and horizontal swing of the line and even leads to trip if the clearances between the different phase conductors and/or between the conductor and ground wire are smaller than the tolerable electric insulation distance, which will jeopardize the safe operation of power supply. Therefore, it is very important to investigate the dynamic responses of the UHV transmission tower-line system after ice-shedding in heavy ice zones.

The jump height of electric line after ice-shedding was firstly investigated by means of simulation test [2,3]. With the development of finite element method and the software, more attention has been paid to the numerical simulation study of the dynamic responses of transmission lines after ice-shedding [4~6]. Kalman *et al* [7] numerically simulated the de-icing process of a single conductor induced by shock-load. Yan *et al* [8,9] numerically investigated the dynamic responses of typical quad-bundled transmission lines with different number of spans and in different ice-shedding conditions and proposed a simplified formula for the maximum jump height of quad-bundled conductor based on the simulated results. A simplified model of a section of UHV overhead transmission line, in which the towers were ignored, was created to investigate its dynamic behavior after ice-shedding by Hou *et al* [10]. Recently, Li *et al* [11] investigated the vibration of a section of 1000kV transmission line with 3 spans induced by ice-shedding by means of finite element method. Yan *et al* [12] set up the finite element model of tower-line system with two spans, in which the bundled conductor is equivalent to a single line, and numerically investigated the jump height, the horizontal swing amplitude and tension of the conductor, as well as the force of the insulators after ice-shedding. However, the comprehensive investigation on the dynamic response of UHV multi-span transmission tower-line systems after ice-shedding has not been reported up to now.

The finite element models including transmission towers, conductor lines, ground wires, insulators and spacers, of typical sections of 1000 kV transmission line in heavy ice zones are created in the ABAQUS/CAE software and the dynamic responses of the tower-line systems with different structure parameters in different ice-shedding conditions are numerically simulated in the paper. Simplified formulas for the jump height and horizontal swing amplitude of electric lines with odd number of multi-spans after ice-shedding are suggested for the design of the UHV transmission lines.

II. FINITE ELEMENT MODEL OF TYPICAL TRANSMISSION TOWER-LINE SYSTEM

A．Description of the typical transmission line section

A typical 1000kV transmission tower-line section is shown in Fig.1. The tower-line section consists of seven spans, each of which is 500m long, four suspension towers (towers II~V) and two dead-end towers (towers I, VII). The type of the eight-bundled conductor is LGJ-630/45, the ground wire is LGJ-210/AC and the spacer FJZ-840/500. In addition, the physical and mechanical parameters of the electric lines are listed in Table 1.

This work was supported in part by the Science and Technology Project of Electric Power Project Consultant Group of China

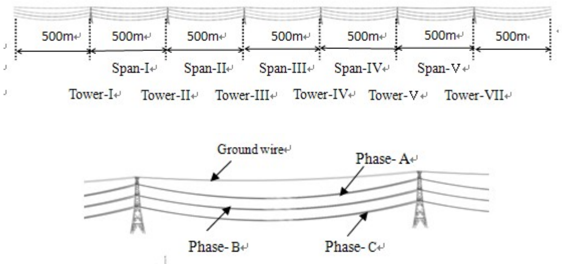


Fig. 1: Transmission tower-line section with seven spans

Table1：Physical and mechanical parameters of electric lines

Electric line	Diameter (mm)	Cross-section area(mm^2)	Young's modulus (MPa)	Density (kg/m^3)	Ice weight (kg/m）
LGJ-630/45	33.60	666.55	6.30 X10^4	3090.5	3.03
LBGJ/210/20AC	18.75	209.85	1.54X10^4	6681.9	2.19

B．Finite element model of transmission tower-line system

The finite element model of the typical transmission tower-line section with seven spans, in which the six towers are modeled with truss and beam elements, the electric lines with truss element by setting its material property as 'NO COMPRESSION', and the suspension insulator strings and spacers with beam element in ABAQUS, is shown in Fig.2.

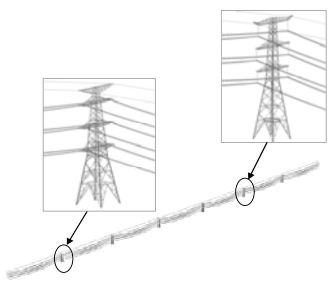


Fig. 2: Finite element model of the typical transmission tower-line system with seven spans

The left and right ends of the conductor lines and ground wires of the system are set to be fixed and the bottom of all the six towers are constrained.

The static equilibrium state of the conductor lines and ground wires under self-weight and ice load is determined with the method proposed by Yan *et al* [13] before the simulation of dynamic response of the tower-line system.

C．Load simulation

The self-weight, ice-weight, wind load and the dynamic load induced by ice-shedding are taken into account in the numerical simulation. In the design of transmission lines, it is usually assumed that the ice is uniformly accreted on the line along the length direction and drops from the line as ice-shedding takes place.

In the finite element analysis, the static ice load on the transmission line and the dynamic load induced by the ice-shedding from the transmission line are simulated by means of the modification of the density and the gravity acceleration of the lines, which is discussed in details in [8].

In the technical code of designing overhead transmission line in China [14], the wind load on per unit length of the conductor is determined as follows

$$p_H = 0.625\alpha\mu_{SC}\beta_C(d+2\delta)l_H\cdot v^2\sin^2\theta\times10^{-3} \qquad (1)$$

where α is heterogeneous coefficient of wind pressure along conductor line; u_{sc} is the body shape coefficient or the so-called drag coefficient dependent on the shape and dimension of cross-section of conductor cable, β_c is the modification coefficient of wind load which is assumed to be 1.0 in this case; and d is the diameter of conductor while l_H span length , v wind velocity.

It is known from (1) that the wind pressure of the iced conductor is different before and after ice-shedding because of the change of the cross-section area of the line in these two cases, so it is reasonable for us to simulate the wind load by means of the modification of the density and the gravity acceleration of the lines.

The ice weight (kN/m^2) and wind load (kN/m^2) on per unit cross-section area of transmission tower are respectively expressed as

$$q_a = 0.6ba_2\gamma\cdot10^{-3} \qquad (2)$$

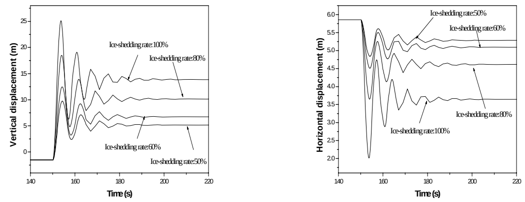
$$\omega_k = \beta_z\mu_s\mu_z\omega_0\beta_i \qquad (3)$$

where b (mm) is the ice thickness, a_2 is the increasing coefficient with height of ice thickness, γ is assumed to be 9 kN/m^3, ω_0 is the standard wind pressure, while u_z is the wind pressure height coefficient at the height of z, β_i is the amplified coefficient of wind load as iced accreted on the structures.

III. DYNAMIC RESPONSE OF TRANSMISSIONT TOWER-LINE SYSTEM AFTER ICE-SHEDDING

The dynamic responses of the tower-line system after ice-shedding with different structure parameters in different ice-shedding conditions are numerically simulated. From the numerical results, it is shown that the maximum jump height of the line occurs as ice-shedding happens on the mid span. Furthermore, the jump height of different phase conductor after ice-shedding is similar, so the dynamic response of any one phase conductor of the mid span is discussed.

The responses of vertical and horizontal displacements at mid-point of the typical transmission line with five spans are respectively showed in Fig.3, and the moving trace of the conductor after ice-shedding is shown in Fig.4.



(a) Vertical displacement (b) Horizontal displacement

Fig. 3 Dynamic displacements of mid-point of conductor line after ice-shedding

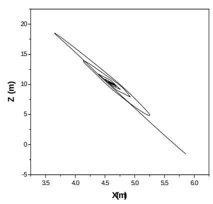
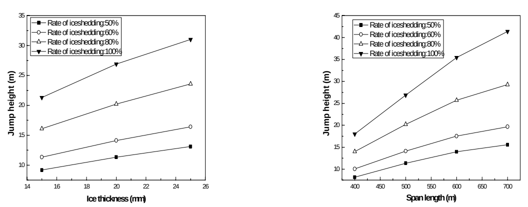


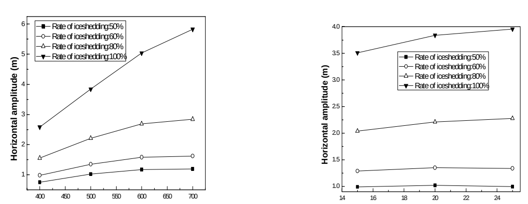
Fig. 4: Moving trace of mid-point of a conductor after ice-shedding

The effects of various factors, including ice thickness and span length, on the maximum jump height and horizontal swing amplitude are shown in Fig. 5 from which it is concluded that the maximum jump height goes up with the ice thickness and the span length. Similarly, the horizontal swing amplitude increases with the span length, but changes slightly with the number of spans, as shown in Fig.6.



(a) Effect of ice thickness (b) Effect of span length

Fig. 5 Effect of different factors on jump height



(a) Effect of span length (b) Effect of number of spans

Fig. 6 Effect of different factors on horizontal swing amplitude

IV. SIMPLIFIED FORMULAS FOR MAXIMUM JUMP HEIGHT AND HORIZONTAL SWING AMPLITUDE

A. Simplified formula for maximum jump height

It is known that the sag of transmission line is closely related to the material properties of the lines, the initial tension stress, the span length and the load applied on lines. Therefore, the change of sag of the iced conductor line may implicate the effect of the ice-shedding load on the jump height of the line after ice-shedding.

Based on the numerical simulation results, it is found that there is a linear relation between the sag difference $\triangle f$ of the iced electric line before and after ice-shedding and the maximum jump height H, as shown in Fig.7. A simplified formula for the maximum jump height is expressed in the follows by means of data fitting

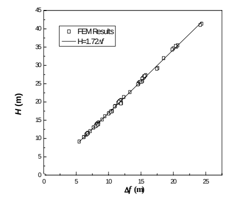


Fig.7 Relation between jump height and sag difference of electric line before and after ice-shedding

$$H = -0.1819 + 1.72045\Delta f \qquad (4)$$

Ignoring the constant term, which could be induced by the numerical error, the following formula is obtained.

$$H = 1.72\Delta f \qquad (5)$$

The relative errors between the jump height determined by the simplified formula and that obtained by numerical simulation are less than 4.6%. So it can be used in the design of UHV transmission lines in heavy ice zones.

B. Simplified formula for the maximum horizontal amplitude

The iced electric line will swing if there is a wind load on the line, and the maximum swing amplitude is also important for the design of the transmission line. According to the numerical results, there exists a linear relation between the static swing difference ΔA before and after ice-shedding and the maximum horizontal swing amplitude B is obtained, as shown in Fig.8. A simplified formula for the maximum horizontal swing amplitude is obtained by means of data fitting as follows.

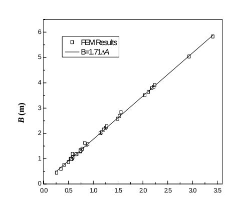


Fig.8 Relation between horizontal swing amplitude and swing difference of electric line before and after ice-shedding

$$B = 0.0618 + 1.7067\,\Delta A \qquad (6)$$

Ignoring the constant term, which could be induced by the numerical error, the following formula is obtained:

$$B = 1.71\Delta A \qquad (7)$$

The relative errors between the horizontal swing amplitude determined by the simplified formula and that obtained by the numerical simulation are less than 6.07%. So it can be used in the design of UHV transmission lines in heavy ice zones.

V. CONCLUSION

The numerical model of UHV transmission tower-line system is set up, and the dynamic response of the iced transmission line section with various structure parameters under different ice-shedding conditions is numerically investigated. It is concluded that (1) The maximum jump height and horizontal swing amplitude of transmission line go up with the increases of the ice thickness, span length and number of spans after ice-shedding; (2) There is a linear relation between the maximum jump height of a line after ice-shedding and the sag difference of the line before and after ice-shedding, and a simplified formula for the jump height of electric lines with odd number of multi-spans after ice-shedding is suggested for the design of the UHV transmission lines; (3) A linear formula for maximum swing amplitude of iced line after ice-shedding as wind load is taken into account is proposed for the design of UHV transmission line.

REFERENCES

[1] Z. Hu, Deep significance of UHV power transmission, Electrical Industry, 2007, 4 : 31-33 (in Chinese)

[2] V. T. Morgan, D. A. Swift. Jump height of overhead-line conductors after the sudden release of ice loads, Proceedings IEE, 1964, 111 (10): 1736-1746

[3] J. R. Stewart, Ice as an influence on compact line phase spacing, Proceedings of IWAIS, Hanover, New Hampshire, 1983: 77-82

[4] A. Jamaleddine, G. McClure, J. Rousselet, R. Beauchenmin, Simulation of Ice-shedding on electrical transmission lines using ADINA, Computers & Structures, 1993, 47: 523-536

[5] G. McGlure, M. Lapointe. Modeling the structural dynamic response of overhead transmission lines, Computers & Structures, 2003, 81: 825-834

[6] M. Roshan Fekr, G. McClure, Numerical modeling of the dynamic response of ice-shedding on electric transmission lines , Atmosphericc Research, 1998, 46:1-11

[7] T. Kalman, M. Farzaneh, G. McGlure. Numerical analysis of the dynamic defects of shock-load-induced ice shedding on overhead ground wires. Computers & Structures 2007, 85:375-384.

[8] KQ.Chen, B.Yan,Y.Guo, M.Liang, J.Chen, Dynamic response of ultra-high voltage transmission line ice-shedding. Journal of Chongqing University (Natural Science Edition), 2007, 30(12): 46-48 (in Chinese).

[9] B. Yan, Y. Guo, K.Chen, M. Liang, Formula for the jump height of overhead transmission lines after ice-shedding. Journal of Chongqing University (Natural Science Edition), 2009, 32 (11):1306-1310 (in Chinese)

[10] L. Hou, L. Wang, P. Zhu, Dynamic behavior computation of ice-shedding of UHV overhead transmission lines. Journal of Electrical Engineering, 2008, 28(6): 1-6 (in Chinese).

[11] L. Li, Z. Xia, G. Fu, Ice-shedding induced vibration of a long span electric transmission tower-line system. Journal of Vibration and Shock, 2008, 27 (9): 32-34 (in Chinese).

[12] Z. Yan. Z. Li, Z. Wang, Simulation of ice-shedding of transmission tower-line system in heavy ice regions. Journal of Engineering Mechanics, 2010, 27 (1): 209-227 (in Chinese).

[13] B. Yan, X. Lin, W.Luo et al. Numerical study on dynamic swing of suspension insulator in overhead transmission line under wind load . IEEE Transactions on Power Delivery, 2010, 25(1): 248-260.

[14] Design Manual of High Voltage Transmission Lines for Electric Engineering.Beijing: China Electric Power Press,2003, Northeast Electric Power Design Institute of National Electric Power Corporation, pp.103-104, pp.166-167, pp.325-327(in Chinese).

[15] Design for Design of High-rising Structures. Beijing: China Planning Press, Shanghai Construction and Transportation Commission,1990(in Chinese) .