The Numerical Analysis for Jump Height of Multi-two-spans Ice-shedding at Different Time Intervals of Overhead Transmission Line

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Abstract: **Transmission line ice-shedding is the typical fault inducement. The decreasing of the electric clearance and increasing of the dynamic tension are usually caused by ice-shedding vibration of overhead transmission line. Flashover, fittings damaged, or even wire breakage and tower collapses may be occurred if the ice-shedding vibration is serious which pose a threat to the safe operation of power equipment. According to different parameters of transmission line such as spans, span length, ice thickness, a finite element analysis model of wire-insulator was established, and the simulation of ice-shedding from overhead transmission line was adopted by additional force method. Then, the jump height of multi-two-spans at different time intervals can be got. The result shows that the amplitude of jump height decreased when the same time of ice-shedding on multi-two-spans which effect was equivalent to unilateral strain tower. The amplitude of previous ice-shedding spans is easily exceeded by the later spans when the vibration cycle of multi-two-spans interval was about 5/8. Besides, it was great impact on spans coupling such as the weight of the ice, spans, span length, damp and other factors. When the mass of the ice and spans is larger, the jump height of previous ice-shedding spans can easily passed by the later spans, but the effect of damp, span length is just the opposite.**

Keywords: transmission line; ice-shedding; jump height; ice-shedding interval; spans coupling

INTRODUCTION

Icing caused serious impact on the safe operation of overhead line worldwide by the influences of climate. In early 2008, the ice disaster in southern China caused 10kV overhead line tower damaged 140000, 220kV tower damaged more than 1500 and economic losses of billions. According to post-survey, 90% tower collapses accidents related to the ice-shedding vibration of overhead line [1]-[2]. Overhead line covered ice chunks fall off causing the overhead line vibration and horizontal swing subject due to weather conditions (temperature, wind) or artificial mechanical deicing, the typical dynamic impact effect can easily cause the overhead line fault. Transmission line de-icing fault mainly include mechanical and electrical: First, the vibration of overhead line results in a significant change in dynamic tension which cause additional impact load on fittings, it will lead to more serious fittings damage, line break, tower breakage, tower collapses and other mechanical accidents; Second, a significant jump of overhead transmission line, causing the wire-wire, wire-ground electrical clearance reduction and the transmission line flashover, transmission line burning and other issues[3]-[4]. The dynamic response of overhead transmission line ice-shedding has important theoretical and practical value.

Under natural conditions, transmission line ice-shedding with great unpredictability and unrepeatable, it is difficult to achieve the desired effect through natural observation. Overhead transmission line ice-shedding is difficult to carry out by artificial icing limited to the phytotron venue requirements. The current overhead transmission line ice-shedding experimental study simulated through lumped mass method or overhead line miniatures method. Jamaleddine [5]-[6], Kollár [7]-[8] built a miniature model of overhead line, simulated the dynamic response of overhead line ice-shedding by artificial icing and concentrated load. Morgan [9], Meng Xiao-bo [10] preformed separated span and continuous spans ice-shedding experiment to research jump height amplitude, dynamic tension vibration attenuator rate and other dynamic response by concentrated load on real transmission line span to simulate overhead line icing. Zhangqi Wang [2] conducted comparative experiments between concentrated load method and artificial real de-icing on isolation overhead transmission line model, he got the overhead line tension curve under different conditions by changing the ice thickness, suspended span ratio, amount of de-ice and shedding location. Most of these studies focus on the relationship between de-ice dynamic response and factors such as tower line parameters, spacers, ice thickness and ice-shedding rate on one single overhead line span, and lack of research on continuous spans situation. In this paper, the wires-insulator finite element analysis model was established by professional software; the additional force method was used to simulate the response process of overhead transmission line ice-shedding and got the ice-shedding jump height at different time intervals on two continuous spans. At last we analyzed the influence of ice thickness, span length, spans, the damping, height and other parameters on the ice jump amplitude during ice-shedding occurred at two continuous spans non-simultaneous.

I. NUMERICAL SIMULATION METHOD ON ICE-SHEDDING OF OVERHEAD LINE

A. *Wires-insulator finite element analysis model*

Based on relevant studies about the finite element model of conductor-insulator, the structure of tower ignored because of little effect to the ice-shedding of overhead line, that only need to establish the finite element model of wires-insulator is shown in figure 1. Link 10 be used for simulate transmission line due to the characteristic of tensioning without pressure to the wires and ground line. This unit has the stress stiffening, large deformation function and geometric nonlinearity, which is very suitable for the simulation cable or chain. Insulator structure is relatively complex, but the insulator type and material have little impact on dynamic characteristic of ice-shedding, It is possible that by modeling and analyzing the insulator mandrel only. In addition, the insulator adapts to link 8 to simulator and hinged connection with overhead line.

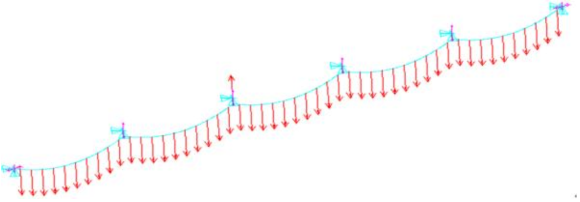

Figure 1: Finite element model of conductor-insulator

The overhead transmission line is multi-gear combination, tension tower on both sides, suspension point is equivalent to a fixed point and suspension insulator on straight tower in the middle, the suspension insulator was set at 5m, sectional area was 2500mm2 and the elastic modulus was 63000Mpa with swing degrees of freedom in the middle towers. Meanwhile, LGJ-400/50 ACSR conductor is selected as analysis object, which has some features such as wire diameter of 27.63 mm, the total sectional area of 451.55mm2, the quality of per unit length of 1511kg/km, tension force of 123.4KN and the elastic modulus of 69000Mpa. It is 400m for the span of overhead line and 24KN for the operator tension, and its thickness is 15mm.

B. *The FEA process of the ice-shedding process*

The transmission line elastic potential energy can get release in the ice-shedding process, rapid rebound oscillation, running tension rapid change. Influenced by wire damping and other factors, the ice-shedding oscillation gradually tends to rest. The numerical simulation of the transmission line ice-shedding is based on the three, which are the additional concentrated force method, the element birth and death method, the density change method, and the better accuracy is obtained [12]. The main steps of the finite element analysis of the ice-shedding are:

(1) The transmission line form finding, catenary equilibrium calculation of overhead transmission line in operation under the action of self weight and tension;

(2) The catenary equilibrium calculation overhead line with ice loads;

(3) The ice cover in the overhead line at a certain time is detached in some form, and the process is mainly simulated by the additional concentrated load method, the element birth and death method or the changing density method.;

(4) The response of the tower line after the ice-shedding.

C. *Overhead transmission line finite element form finding*

The overhead transmission line is a typical cable structure, with a catenary shape under self weight and ice load. Overhead transmission line form finding is calculated catenary weight and run under the action of the tension of the equilibrium state, the equilibrium state is the premise and basis of the calculation of transmission line galloping, ice-shedding, aeolian vibration model, the correct calculation will directly affect the dynamic analysis accuracy. Generally use the professional software, The analysis of overhead line form finding will be formed with and without the icing, get the overhead line sag value, the maximum tension value, the length of the wire, hanging points stress value, the calculation error is within the scope of the engineering [13]-[14]. Figure 2 shown the direct iteration method for overhead line form finding, first set the wire diameter, cross-sectional area, the gravity load numerical, running tension, elastic modulus, Poisson's ratio, linear expansion coefficient and initial strain and other parameters and create overhead line finite element model, applied value from a heavy load and solving the overhead line state, get the overhead transmission line horizontal tension value iteration for convergence condition, until meet the set of horizontal tension convergence conditions, the output is the state of overhead transmission line under the self loading.

D. *Calculation of additional force*

Overhead transmission line icing and snowing is a uniformly distributed along the span of the vertical load, the additional force method is that the uniform of ice quality to a plurality of discrete points. With the number of additional force points increases, the single concentrated load value decreased, and the overhead line static and dynamic response for additional force method is very similar to uniformly distributed load, the calculation precision can meet the needs of the engineering. As shown in Figure 3, according to the thickness of the hollow cylindrical transmission line icing considered, additional force method only needs the space overhead line icing load of the equivalent load. The calculation formula is shown as [2]:

$$F=\rho g\pi bL\,(D+b)\,/n \tag{1}$$

Where F is overhead line concentrated load, ρ is ice density, in this paper $\rho=900\mathrm{kg/m^3}$; D is wire outside diameter; b is ice thickness; L is the actual length of transmission line; n is dividing unit number. In this paper, the finite element model is set for each meter as an analysis unit, and each element of the load equivalent of ice load is equivalent to an additional force.

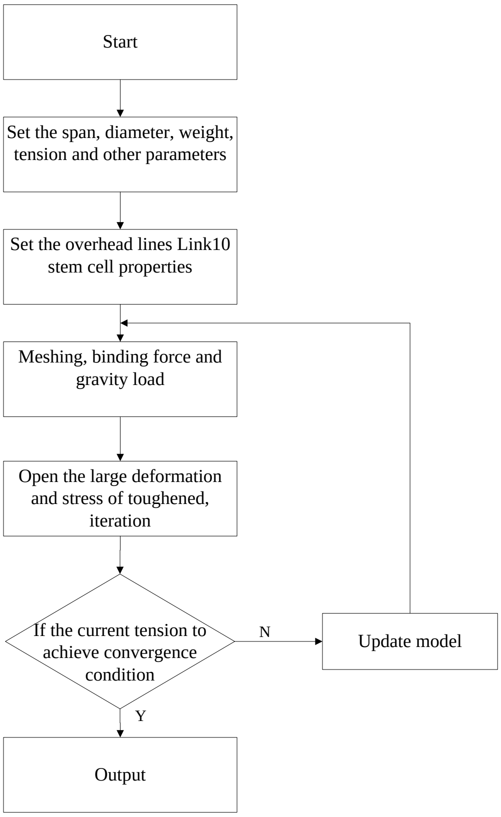

Figure 2: Basic steps of overhead line finite element form finding

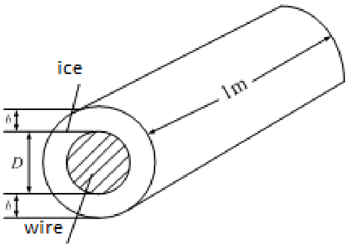

Figure 3: Calculation of ice thickness

II. THE EFFECT OF THE DIFFERENT TIME INTERVALS FOR TWO-SPAN ICE-SHEDDING JUMP HEIGHT

After the free combination with different time, different mass of ice-shedding and different tower -line system, ice-shedding form is varied. At different time intervals for two-span ice-shedding model is shown in Figure4.

The setting pattern of 7 tower 6 spans overhead transmission line is shown in figure 5. The middle two spans are the span of ice-shedding (span A ice-shedding firstly, followed by B) and the rest is not. 1 #, 7 # for tension insulator is equivalent to fixed point, don't have swinging degrees of freedom. 2-6# for suspension insulators have the swinging degrees of freedom.

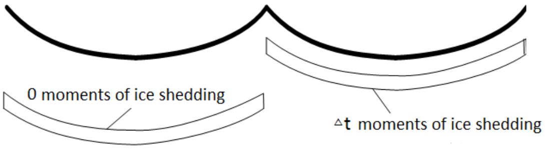

Figure 4: The way at different intervals times for adjacent two-span ice-shedding on overhead line

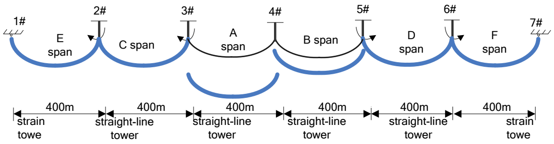

Figure 5: Transmission line with 7 tower and 6 span

When the damping coefficient is 0.1, maximum ice-shedding jump height on the A single span is 11.98 m and oscillation period T is 15.2 s. Based on the periodic T, time history of displacement responses at midpoints of span B of the different time intervals combined ice-shedding is obtained, as shown in Figure 6.

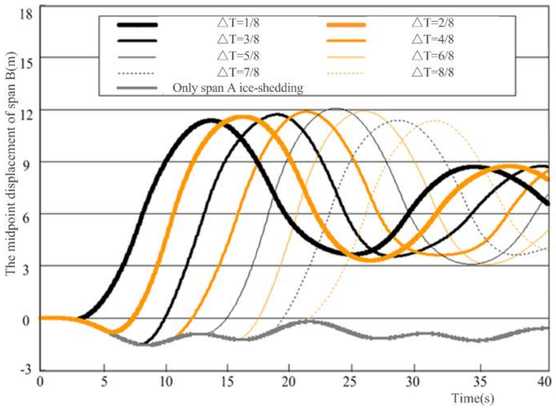

Figure 6: Time history of displacement responses at midpoints of span B for two-span assembling ice-shedding

As shown in Figure 6, after span A ice-shedding about 2s, the oscillating wave propagates to the midpoint of span B, with shift direction is negative, and the elastic potential energy of the span B is increased. By shock wave transmission delay and overhead line damping effect, in the time intervals range of 0 and 5T/8, the span B ice-shedding wire elastic potential energy with ΔT increased, and it is the same with the ice-shedding bounce height. The opposite effect is obtained when the ΔT is between 5T/8 and 1T, overhead transmission line maximum bounce height decreases with the ΔT.

Ice-shedding jump amplitude of two-span ice-shedding at different times intervals is shown in Table 1. When ΔT is equal to 0, the adjacent two spans ice-shedding at the same time, 4# insulator on both sides of the overhead line vibration offset each other, the insulator can be kept stationary state, unbalanced tension is null, The dynamic response process of A, B span is similar to the unilateral tension tower ice-shedding and maximum bounce height less than single span condition. The B span bounce height reached the maximum when 4T/8< ΔT <6T/8, B span midpoint ice jump amplitude is close to or more than A. When 0<ΔT<4T/8, ice-shedding process of span B leads to reduce the rising trend of span A, the jump height of span A not yet reached the point of the maximum displacement for the single span ice-shedding. When 4T/8< ΔT <1T, the midpoint of span A reached maximum displacement followed by span B ice-shedding. Influence by span B ice-shedding and damping conductor, the effect on span A maximum ice jump amplitude does not increase any more.

Table 1: Ice jump amplitude of two-span ice-shedding at different times

ΔT (T)	A jump amplitude (m)	B jump amplitude (m)	B > A
0	10.97	10.97	
1/8	11.28	11.35	
2/8	11.85	11.57	
3/8	11.96	11.70	
4/8	11.98	11.87	
5/8	11.98	12.08	YES
6/8	11.98	11.91	
7/8	11.98	11.37	
8/8	11.98	11.34	

III. ANALYSIS OF THE INFLUENCE FACTORS IN TWO-SPAN ICE-SHEDDING JUMP HEIGHT

A. Impact of ice weight for two-span ice-shedding jump height

Transmission line ice weight is the important influential factor of ice-shedding, which increased jump height of overhead line. Holding section 2 model parameters unchanged, respectively to simulate dynamic response of ice-shedding in 10 mm, 15 mm, 20 mm three different ice thickness. In order to analysis the impact of ice weight for two-span ice-shedding jump height at different time course, the numerical simulation results are shown in table 2.

Same as section 2, the largest ice jump amplitude of span B still appeared on the ΔT = 5 T / 8 for the asynchronous ice-shedding. When the ice thickness is 10 mm, the span B midpoint bounce height is less than span A in the time intervals of 4 T / 8, 5 T / 8, 6T/ 8. The dynamic response of span A ice-shedding results in the decrease of span B to ice jump height. When ice thickness is 20 mm, B span midpoint bounce height is more than span A on 5T/ 8, 6 T / 8 two time intervals, the dynamic coupling of the A span ice-shedding caused by the ice increases the jump height of the B.

Table 2: Ice jump amplitude of two-span ice-shedding at different weight

ΔT (T)	Icing thickness (mm)	A jump amplitude (m)	B jump amplitude (m)	B > A
0	10	7.4	7.4	
4/8	10	8.35	8.19	
5/8	10	8.35	8.21	
6/8	10	8.35	8.02	
0	15	10.98	10.98	
4/8	15	12.04	11.87	
5/8	15	12.04	12.08	YES
6/8	15	12.04	11.91	
0	20	14.2	14.2	
4/8	20	15.28	15.03	
5/8	20	15.28	15.54	YES
6/8	20	15.28	15.51	YES

B. Impact of span length for two-span jump height

It is report that the span length significantly affected ice-shedding jump height. When the span length increased, the Ice-shedding jump height also increased. In order to analysis the influence of overhead line span length for jump amplitude of two-span ice-shedding, holding Section 2 model parameters unchanged, the overhead transmission line were set up to 300m,400 m,500m. Ice-shedding jump height numerical simulation results are shown in table 3.

The span B bouncing height decreases with span length. The midpoint bounce height of span A were higher than span B at 4 t / 8, 5 t / 8, 6 t / 8, while the span length is 500m. When overhead line distance is 300 m and 400 m, ΔT = 5 T / 8, span B bounce height is greater than span A, the coupling caused by span A ice-shedding increases the jump amplitude of span B, the longer the length of span, the weaker the coupling effect, the jump height of previous ice-shedding spans hardly passed by later ice-shedding spans.

Table 3: Ice jump amplitude of two-span ice-shedding at different span length

ΔT (T)	span length(m)	A jump amplitude(m)	B jump amplitude(m)	B > A
0	300	6.94	6.94	
4/8	300	7.55	7.44	
5/8	300	7.55	7.61	YES
6/8	300	7.55	7.52	
0	400	10.98	10.98	
4/8	400	12.04	11.87	
5/8	400	12.04	12.08	YES
6/8	400	12.04	11.91	
0	500	15.21	15.21	
4/8	500	17.12	16.63	
5/8	500	17.12	16.81	
6/8	500	17.12	16.53	

C. Impact of spans for two-span ice-shedding jump height

The actual number of span have a significant impact on the bounce height off the ice, the dynamic response of isolated tower-line system is much smaller than that of multiple tower-line system after ice-shedding. The jump height of ice-shedding slight increases with the number of transmission line spans. The jump height of intermediate span ice-shedding is an isolated value when the span number is greater than five. Holding Section 2 model parameters to analysis the impact of spans number for two-span ice-shedding jump height .The dynamic response of ice-shedding are simulated for span 4, 6 and 8 of overhead transmission line. The results of numerical simulation are shown in table 4.

The bounce height of span B is less than A when the spans number is 4 and the interval is 4T/8, 5T/8, 6T/8, the dynamic response caused by the previous span reduced the jump height of the latter ones. When the span number are 6 and 8, and ΔT equal to 5T/8, the maximum amplitude of ice shedding of B span is larger than A span. The coupling effect enhanced with the increase of the span number and the ice-shedding height of the latter span increased.

D. Impact of height difference for two-span ice-shedding jump height

Ice-shedding jump height is affected by height difference very little. Numerical simulation shows that the ice-shedding height reduced with the increased of height difference. Maintaining the parameters of Sections 2 model unchanged, 40 meters height difference of overhead transmission line was set. The results of dynamic response for two-span asynchronous ice-shedding as shown in table 5. The height difference makes the overhead transmission line span coupled weakened, the jump height of previous ice-shedding spans can easily passed by later ones.

Table 4: Ice jump amplitude of two-span ice-shedding at different spans

ΔT (T)	spans (m)	A jump amplitude(m)	B jump amplitude(m)	B > A
0	4	10.01	10.01	
4/8	4	11.66	11.29	
5/8	4	11.66	11.48	
6/8	4	11.66	11.15	
0	6	10.98	10.98	
4/8	6	12.04	11.87	
5/8	6	12.04	12.08	YES
6/8	6	12.04	11.91	
0	8	11.33	11.33	
4/8	8	12.2	12.09	
5/8	8	12.2	12.29	YES
6/8	8	12.2	12.14	

Table 5: Ice jump amplitude of two-span ice-shedding at different height difference

ΔT (T)	height difference(m)	A jump amplitude(m)	B jump amplitude(m)	B > A
0	0	10.98	10.98	
4/8	0	12.04	11.87	
5/8	0	12.04	12.08	YES
6/8	0	12.04	11.91	
0	40	11.26	11.26	
4/8	40	11.96	11.59	
5/8	40	11.96	11.68	
6/8	40	11.96	11.44	

E. Impact of damp coefficient for two-span ice-shedding jump height

The structural damping coefficient of transmission line is mainly derived from the axial friction of the twisted wire during the process of the ice-shedding. Roshan Fekr [15] and others put forward in the study of mathematical model for overhead transmission line to proposed iced conductors damping coefficient of 0.1, the bare wire damping coefficient is 0.02, then McClure [16], Chen Kequan [17] and other people in their own research using the parameter values. In order to analyze the overhead line damping effect two-span asynchronous ice-shedding jump amplitude. Set the structural damping coefficient to 0.02, 0.06, 0.1, the numerical simulation results of overhead transmission line ice-shedding jump height as shown in table 6.

The midpoint of span B jump height was greater than span A in 4T / 8, 5T / 8, 6T / 8 three time intervals when overhead line damping coefficient was 0.02, the ice-shedding response of second span had obvious enhancement; With the increase of damping coefficient, the maximum jump height of span B slow decline compared to span A, on the condition of damping coefficient equal to 0.06 and time intervals equal to 5T / 8, 6T / 8, span B overhead transmission line jump height is greater than the midpoint of span A; When the damping coefficient is 0.1, only when time intervals is 5 T / 8, span B bounce height just greater than A's . With the increase of the damping coefficient of overhead transmission line, the elastic potential energy absorbed by overhead transmission line is more, and the amplitude of the ice-shedding decreases as well.

Table 6: Ice jump amplitude of two-span ice-shedding at different damp

ΔT (T)	damp	A jump amplitude(m)	B jump amplitude(m)	B > A
0	0.02	12.61	12.61	
4/8	0.02	13.76	13.88	YES
5/8	0.02	13.76	14.53	YES
6/8	0.02	13.76	14.26	YES
0	0.06	11.74	11.74	
4/8	0.06	12.84	12.806	
5/8	0.06	12.84	13.17	YES
6/8	0.06	12.84	12.95	YES
0	0.1	10.98	10.98	
4/8	0.1	12.04	11.87	
5/8	0.1	12.04	12.08	YES
6/8	0.1	12.04	11.91	

IV. CONCLUSION

(1) Tower has little effect on the dynamic response of overhead transmission line ice-shedding, the conductor-insulator finite element analysis model is built in this paper by additional force, and the jump height of ice shedding was obtained with different time intervals and other parameters for multi-two-spans overhead transmission line;

(2) Dynamic response process on overhead transmission line ice-shedding is similar to the unilateral strain tower conditions, the maximum jump height is less than single span ice-shedding, when the multi-two-spans ice-shedding at the same time, the insulator will be kept stationary state, and unbalanced tension is 0 .

(3)Base on period of oscillation T of single span ice-shedding. The jump height of first ice-shedding spans may be exceeded by later spans when the multi-two-spans interval was about 4T/8-6T/8.

(4)It was great impact on spans coupling such as the weight of the ice, spans, span length, damp coefficient and other factors. When the mass of the ice and spans is large, the jump height of previous ice-shedding spans can easily surpassed by the later spans, but the effect of damp, span length is just the opposite.

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