Analysis on Galloping of iced conductor of Transmission Tower-line System

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Keywords: tower-line system; galloping; numerical simulation; conductor tension; unbalanced tension

Abstract. Nonlinear finite element model of a transmission tower-line system was set up and galloping of iced bundle conductors in the system was numerically simulated by means of ANSYS software. The galloping trajectories，vibration frequency, galloping order, conductor tension and unbalanced tension characteristics of iced conductors were obtained. The conclusions can be drawn that values of the galloping order is different for different span, due to the impact of the order of galloping. The amplitude of the vertical galloping is increasing while the increasing span, but it is not linear increase.

Introduction

According to current statistic documents 1276 times conductor galloping occurred in our country from 1980 to 2010, it is related to 1031 lines. Number of the galloping lines in whole country was 634 from 2009 to winter of 2010, which shares more than half total galloping number in recent thirty years, shown as table 1. Following quick development of construction scale of the grid, galloping accident in the power transmission conductor occurs frequently, which causes serious threat on safe and stable operation of the grid [1-3].Even though a large quantity of research achievements have been achieved in galloping mechanism of the icing conductor [4-6], galloping value calculation method of the conductor [7-10] and anti-galloping measures of the conductor [16-17] etc, but research history and achievement on galloping analysis of the power transmission line show relevant research works in this field are not mature, there are many defect no matter in theoretical research and analysis calculation or in anti-galloping application aspects. In particularly most research on galloping of the power transmission line only take the conductor at research object, influence of the tower and the adjacent span are not considered. At present research on influence of galloping on every component in the power transmission line have not been paid enough attention.

There is great instruction value on anti-galloping design of the power transmission tower and the fitting etc to further analyze forcing, mechanical destruction and electrical fault characteristic of every component in the line during galloping of the icing conductor, which provides strong technical support to further develop the icing anti-galloping device in the power transmission line. The tower line system finite element model in continuous five span and two strain sections are established in this paper, dynamic characteristic of coupling vibration of the tower line system is calculated when galloping occurs in the icing conductor, calculation result has significant instruction value on dynamic tension analysis of the conductor and safe design of the tower frame, the cross arm etc support structures.

Table 1 Galloping condition statistic of line from 1980 to 2010

Voltage class (kV)	35	66	110	220	500（330）	750	1000	In total
Galloping line (piece)	1	284	197	359	188	1	1	1031
Galloping times	1	386	234	417	236	1	1	1276

Simplified model of line

Establish finite element model of the tower line system with continuous five span and two strain section, the tower line system is arranged according to strain – straight – strain – straight – straight – strain, the tower, the conductor, the grounding line and the insulator apply the beam unit to establish model. Model of the tower line is shown as figure 1. Refer to table 2 for span and tower type of two continuous strain section. Refer to table 3 for initial calculation parameters of galloping. In which, air dynamic parameters of the D type icing conductor is obtained from air tunnel test, D type icing conditions are obtained after fitting, rise force coefficient curve, resistant force coefficient curve and torsion coefficient of the icing conductor are changed following attack angle, its curve after fitting is shown as figure 2.

Figure 1 Linear model of continuous five span tower

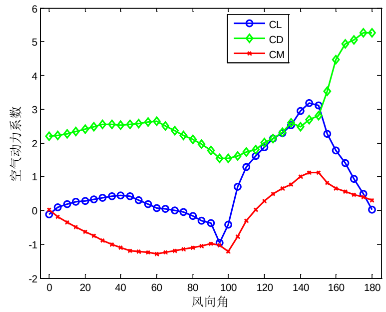


Figure 2 Air power coefficient curve

Firstly the static balance status analysis of the tower line system was carried out. The purpose of static force analysis at constant load (weight, icing) is to obtain geometrical position of the structure at balance status. Now balance status of the overhead conductor under weight and icing is linearly stable, internal force and external force of the structure are balanced; every component of the structure has initial stress. Initial geometrical shape of the conductor is determined by parabolic curve to ignore rigidity of the material; geometrical position determined by this equation is actual position after deformation stability of this conductor under action of dead weight. The structure of the overhead conductor finite element model under action of dead weight is very close geometrical calculation of the parabolic curve equation calculation. In another word, it shoude make the conductor having initial stress and not having initial displacement during calculation of the model. Initial stress file is output and it is solved by static force through imposing dead weight of the structure in this sample. Initial displacement is eliminated through analysis and calculation through imposing of initial stress file and gravity, but initial stress originates from dead weight. Carry out form finding analysis of the tower line system in this line section under action of dead weight – tension.

Table 2 Tower type and span of strain section

Tower number	Tower type – vertical height (m)	Span (m)
J1	J16-30	200
Z1	ZB4-54	300
J2	J16-30	400
Z2	ZB4-54	500
Z3	ZB4-54	400
J3	J16-30	

Table 3 Calculation parameters of galloping

Conductor type	LGJ-400/35
Ice thickness (mm)	12
Ice type	D
Wind velocity （m/s）	4
Initial attack angle	-15
Initial operation tension of conductor	25%RTS

In order to learn dynamic characteristic of the tower line coupling system and single body of the transmission tower, it shoude carry out calculation analysis of two single tower model and dynamic characteristic of the model in the tower line coupling system. Calculation result shows that former 800 order frequency scope of the tower line coupling system is 0.12749Hz to 3.2964Hz, frequency of every order is very close. Most vibration model takes induction mode of the tower line as primary, take induction mode of the power transmission tower and coupling mode of the tower line as secondary. Vertical vibration mode and frequency of several typical conductors in the tower line system are shown in figure 3, two vibration mode and frequency taking vibration of the power transmission tower in the power transmission tower system as primary are shown in figure 4.

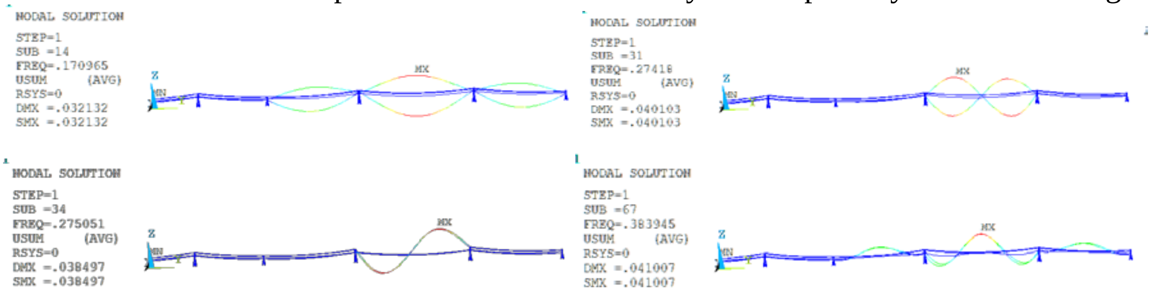
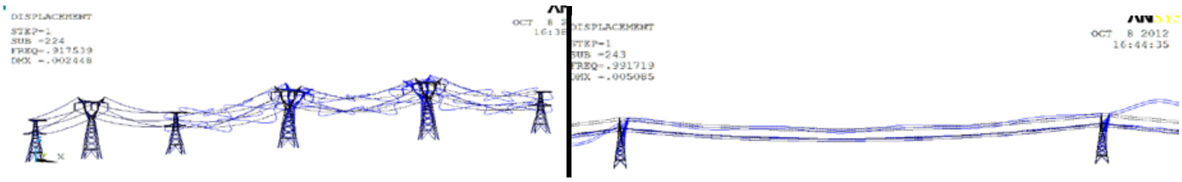


Figure 3 Vibration model figure of tower line system



(a) (b)

Figure 4 Vibration model figure of tower line system

(a) First order vibration model **(b) Second order vibration model**

Figure 5 Former two order vibration models of single model of power transmission tower

Former two order vibration models of single model of the power transmission are shown in figure 5. Learn from this figure, the plane vibration model of the power transmission tower in the tower line system is mostly liable to couple with vibration of the conductor, and its coupling frequency is far lower than self-vibration frequency of same order vibration model in the same tower. The plane vibration model of the power transmission tower in the tower line system and vibration coupling frequency of the conductor are slightly higher than vibration model coupling frequency out of the plane, but its coupling frequency is also far lower than self-vibration frequency of the same order vibration model of the single tower. Former two order frequencies are given in table 4 when steel tower in single tower and the tower line system are lead vibration models. Learn from comparison results of two models, frequency of the tower in the tower line system and corresponding frequency of the tower in the single tower model are obviously small; frequencies of former two order vibration model have 48% reduction.

Table 4 Main vibration model and frequency of power transmission tower (Hz)

Vibration model	Single tower model	Tower line model
First order	1.774	0.9175
Second order	1.898	0.9917

Dynamic response of galloping in typical strain section tower line

Galloping trace in conductor and strain of conductor

It is assumed that galloping occurs in five spans conductors in the whole line, calculate dynamic response of the tower line system during galloping.

Figure 6 is displacement response of the tower line system at some moment during galloping process, figure 7 is galloping displacement time of every icing conductor, galloping trace and tension time of conductor. Learn from the figure, galloping occurs in the five span icing conductor under wind load, Order of every span of galloping is also different because span is different. First span (span of 200m) is first order galloping, second span, third span and fifth span are two order galloping, fourth span is third order galloping. Even though amplitude of vertical galloping is increased following increasing of the span because of influence of galloping order, but it isn' t increased linearly; because spans of third span and fifth span are same, and maximum galloping amplitude is also different. Shown as figure 5, dynamic tension of the conductor is increased following increasing of galloping amplitude, maximum power amplification coefficient of every span is about 1.5, it is about 37.5% calculation breakage force of the conductor.

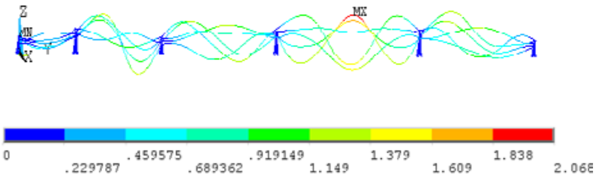


Figure 6 Whole displacement response at some moment during galloping of tower line system

Hang point load of tension string

Figure 8 is hang point load time figure of some one phase of insulator of the tension string and hang point tension difference time at two sides at wind speed of 4m/s. Learn from figure, when wind speed is 4m/s, spans at two sides of the tension tower are 300m and 400m, maximum galloping amplitude of one phase of the conductor are 3.21m and 3.43m， maximum galloping mechanical load of strain string for 4XLGJ-400/35 icing conductor is 200kN； maximum insulator hang point hang point borne by the tension tower is 80kN, which is lower than valve of the horizontal unbalance tension of the tension tower specified in 《Design specification of 110kV~750kV overhead power transmission line》.

Hang point load of suspension

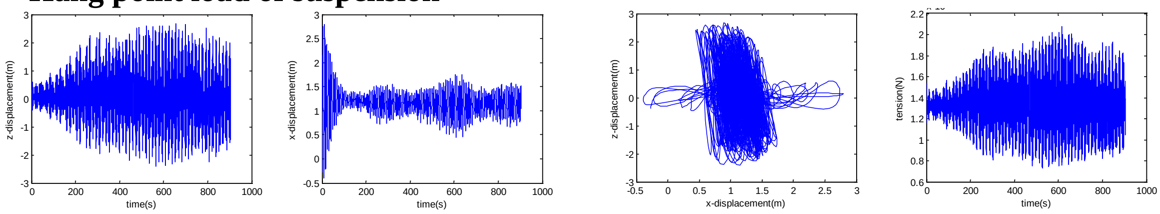


Figure 7 Galloping trace of every span and conductor tension time history of tower line system

Table 5 Conductor amplitude and conductor tension of tower line system at wind speed of 4m/s

	Span distance	Order	Position	Vertical amplitude (m)	Horizontal amplitude (m)	Static tension of conductor （N）	Maximum dynamic tension of conductor (kN)	Tension amplification coefficient of conductor
First span	200	1	Middle point	2.88	0.31	123	181	1.48
Second span	300	2	Middle point	1.78	0.25	122	180	1.47
			1/4 point	3.21	0.46	123	180	1.47
Third span	400	2	Middle point	1.73	0.273	134	205	1.53
			1/4 point	3.43	0.37	134	205	1.53
Fourth span	500	3	Middle point	4.88	0.67	135	208	1.54
			1/4 point	4.03	0.69	1351	207	1.54
Fifth span	400	2	Middle point	1.93	0.36	134	206	1.53
			1/4 point	3.43	0.53	135	207	1.53

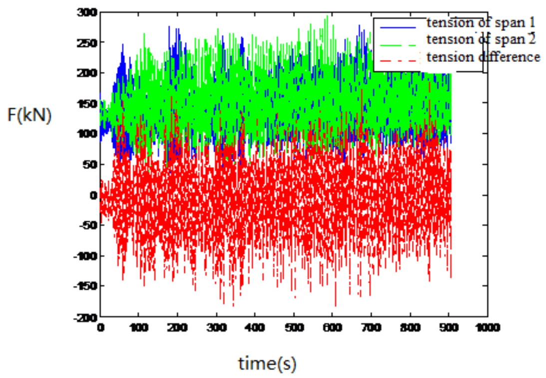


Figure 8 Hang point tension and tension difference of strain tower at wind speed of 4m/s

maximum tension load of the single suspension insulation string is 30Kn. Figure 9 shows tension time history and its tension difference time history of the conductors at two sides of the hang points of the straight tower. Learn from the figure, tension difference is very small.

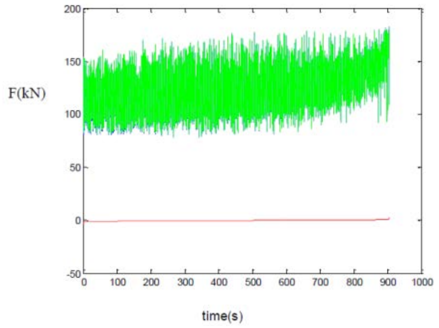


Figure 9 Tension difference of hang point in straight line tower

Forcing of cross arm in steel tower

General finite element program ANSYS is applied to establish finite element model of the steel tower, main material, slope material and auxiliary materials are simulated by BEAM beam unit. When five span of the conductors are galloped completely, carry out instantaneous analysis of the steel tower conductor system under galloping load, study forcing and displacement change condition of the cross bar of the steel tower and the tower body bar member during galloping of the conductor. The actual line is a 4 split conductor, tension takes 4 times tension of the single conductor.

(1) Forcing analysis of cross bar of strain tower

Span at left side of the strain tower is 300m, span at right side is 400m, and galloping shape is two half wave. When galloping amplitudes are 3.2 m and 3.4m respectively, and unbalance strain of hang point of the strain tower is less than specified strain percentage of the broken wire, therefore the strain tower will not be damaged. Furthermore, comparison between peak axle force of every bar member of the strain tower and design bearing force of the member also shows axle force of the main material and the slope material of the cross bar don’t exceed designed bearing force.

(2) Forcing analysis of cross bar of straight tower

Corresponding to the strain tower, influence of galloping on tension change at the hang point of the straight tower is small because suspension way is different. For power load generated under same galloping conditions, load of the straight tower is smaller than that of the strain tower, galloping is liable to cause the strain tower destructed, damage of the straight tower mainly caused by horizontal unbalance strain after the strain tower is damaged.

Conclusion

Finite element model of six tower and five span tower line system is established in this paper, dynamic response research of every component in the tower line system is carried out when galloping phenomenon occurs in the overhead conductor of the power transmission line under action of ice and wind load. Following conclusions are obtained through comparison calculation, which provides reference for design and construction of the power transmission line tower system and modification of relevant specification.

(1) Most vibration modes of the tower line system take induction mode of the conductor as primary and take induction mode of the power transmission tower and coupling mode of the tower line as auxiliary.

(2) Because the tower line system includes 15 pieces quality equivalent single conductors and 10 pieces quality equivalent grounding lines and six power transmission towers, several vibration at some order can occur in some power transmission section in the tower line coupling system, vibration frequency is different when its vibration mode is different.

(3) Obvious change may occur in power characteristic of the power transmission tower in the tower line system; its low frequency characteristic will be activated. For example, first order coupling frequency out of the power transmission tower in the tower line system is far lower than self-vibration frequency of the same order vibration model in the single tower. The plane vibration model of the power transmission tower in the tower line system and vibration coupling frequency of the conductor are slightly higher than vibration model coupling frequency out of the plane, but its coupling frequency is also far lower than self-vibration frequency of the same order vibration model of the single tower.

(4) Torsion vibration mode of the power transmission tower in the tower line system seldom appears.

(5) Every span of the conductor in the tower line coupling system can gallop at same time under same external wind load and icing type. Because span is different, order of every span of galloping is also different. Even vertical galloping amplitude increases following increasing of the span, but it is not increased linearly because of influence of galloping order.

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