Analysis of Influencing Factors of the Ice Shedding Vibration on Iced Transmission Lines

Long Zhang¹, Yi You¹, *, Zhitao Yan², Xiaochun Nie², Feng Wang³

¹State Grid Xinjiang Company Limited Electric Power Research Institute, Urumqi 830011, China
²School of Civil Engineering and Architecture, Chongqing University of Science and Technology, Chongqing 401331, China
³China Electric Power Research Institute, Beijing 100192, China

*Corresponding author email: yiyou@sgcc.com.cn

Abstract. In order to study influencing factors of the ice shedding vibration on iced transmission lines. Based on the principle of nonlinear finite element analysis, the influences of the modal of conductors, the quality of the ice on ice shedding vibration response of transmission lines was analyzed by means of changing the density of transmission lines. The results show that the simulation method is reasonable and accurate. The worst condition of ice shedding on transmission lines depends on its basic vertical vibration mode. the relationship of the vibration displacement with the mass ratio of iced transmission lines both present the nonlinear proportional law.

Keywords: iced transmission lines; vibration of ice shedding; vibration mode; the mass ratio; the sag-span ratio.

1. Introduction

The ice covering on the transmission line falls off, which leads to the jump of ice shedding on the transmission line. The phenomenon is common in cold regions of the high latitude. After ice shedding, the balanced state of conductor will be changed. It will lead to the severe vibration on conductor, and lead to accidents such as the short circuit in line, flashover and even the cascade damage occurring like lines broken, towers collapsed and so on. It greatly threatens the operational security of the transmission tower line system.

The ice shedding vibration on transmission lines is a strong nonlinear structural problem. It needs to consider the coupling effect in the process of vibrating. In recent years, many scholars have conducted a great deal of researches on the jumping vibration of ice shedding on iced transmission lines by means of the computer nonlinear finite element numerical simulation technology. Nonlinear finite element analysis first was applied in simulating the ice shedding on transmission lines by Jamaluddin [1]. Based on the ADINA, the jumping vibration of ice shedding on conductors was simulated by means of applying the additional force on iced conductors. It proved the feasibility of non-linear finite element analysis. McClure [2] accomplished the simulated analysis for ice shedding on iced conductors by means of changing the density and killing or activating elements [3]. The vibration response of conductors was obtained and influences induced by the ice shedding on
conductors on the tower line system were analyzed [4-6]. Kalman [7] used the finite element simulation software to analyze the ice shedding response of iced conductors under different shock loads. László E. Kollár and Masoud Farzana [8-9] established a numerical simulation model and detaily analyzed influences induced by the rotation of divided conductors, the spread of ice shedding and the phase-to-phase spacer on the ice shedding response of conductors.

Based on the method of nonlinear finite element analysis, the ice shedding on iced conductors was simulated by means of changing the density of conductors in this paper. The influence factors of ice shedding on iced conductors were analyzed. It provides a theoretical basis for researches on the iced transmission lines and the anti-icing design for tower line system.

2. Simulation ice shedding vibration

2.1. Analytical method

The behavior of ice shedding on conductors can be simulated by means of changing the density of conductor before and after ice shedding [10]. The method can be precise to simulate the vibration behavior of ice shedding on conductors.

Before using the method of changing the density, the initial configuration of conductors must be found first. The initial equilibrium state is used to be obtained by iteration considering the nonlinear characters. The ice shedding on conductors starts with the ice. When ice is shedding, the tension of conductors remains unchanged, and the quality is changing. So, the original equilibrium state is broken and the conductor starts to vibrate. The parameters of the conductor such as the displacement, the dynamic tension are obtained. The vibration will gradually decay due to the damping of the structure.

2.2. Model validation

The numerical simulation is conducted to compare with the experiment of Chen Yong [11]. The experiment belongs to the prototype test, and its data is accurate and reliable. To ensure the accuracy of the calculation in the model, the cycle of all models firstly was calculated. The interval time for calculating is $\Delta t = T / 30$. The overhead line is simulated by means of the LINK10 Element. In contrast to the test, the result is shown in Fig.1.

![Figure 1. Comparison of single span simulation](image)

Fig.1 shows that the simulated result is very close to the experimental result. There is a slight error in the average displacement of midspan. In midspan, the average displacement of the test result is 2.07m, while the average displacement of the numerical simulation result is 1.97m. The error is 4.8%. Therefore, it is considered that the numerical simulation analysis for ice shedding vibration on conductors meets the research precision requirements by using the above model.
3. Influencing factors

3.1. Vibration mode

Because the transmission line is a strongly nonlinear structure, the vibration mode of conductor has a great influence on its dynamic characteristics. Different vibration mode of conductor significantly influences on the ice shedding height of transmission lines and the tension of conductors. The relationship between the vibration mode of conductor and the tension of conductor is shown as follows:

\[ H = \frac{mg^2}{gd} \]  \hfill (1)

\[ \lambda^2 = \frac{(mg/H)^2 l/(HL_E/E)} \]  \hfill (2)

Where, \( H \) is the tension of the conductor, \( m \) is the quality of the conductor per meter, \( d \) is the sag of the conductor, \( l \) is the horizontal length of the conductor, \( \lambda^2 \) is the dimensionless parameter that reflects the sag-span ratio and \( L_E \) is the original length of the conductor.

The vibration mode of conductor includes the symmetric vibration mode and the anti-symmetric vibration mode. When \( \lambda^2 \) is small, the symmetric vibration mode is the basic vibration mode. With increasing of the sag, \( \lambda^2 \) becomes large gradually, the anti-symmetric vibration mode becomes the basic vibration mode.

Therefore, The cases in different sags of the conductor were analyzed and contrasted. The conductor are the 4×JLHA1/G1A-575/40-45/7 ACSR. The safety factor is 3.0. The maximum design stress is \( \sigma_m = 119 \) MPa. The span is 550m, the ice thickness is 30mm. The calculation method for ice shedding adopts the full span ice shedding and the half span ice shedding. The specific cases are shown in Table 1. The analysis results are shown in Fig. 2.

| Model | Sag(m) | 1st mode shape | 2nd mode shape | Ice shedding span |
|-------|--------|----------------|----------------|-------------------|
| MX-1  | 12.835 | Symmetric      | Asymmetric     | Full Span         |
|       |        |                |                | Half span         |
| MX-2  | 30     | Asymmetric     | Symmetric      | Full Span         |
|       |        |                |                | Half span         |
Figure 2. Comparison between the full span ice shedding and the half span ice shedding of the two models

Figs. 2(a) and 2(c) show that the response of the full span ice shedding is larger to the half span ice shedding for the case MX-1 which the low order mode is the symmetrical mode. Figs. 2(b) and 2(d) show that the response of the half span ice shedding is larger to the full span ice shedding for the case MX-2 which the low order mode is the anti-symmetrical mode. In conclusion, the vibration mode of the transmission line has a significant influence on the vibration response of ice shedding on the conductor.

3.2. Ice quality
In order to study the influence of ice thickness on the transmission line, the ice quality of the transmission line is described by using the mass ratio $m_1/m_0$ of ice shedding. The $m_1$ is the ice shedding quality and the $m_0$ is the quality of the transmission line. The calculated cases are shown in Table 2.
Table 2. Computation cases

| cases | \( m_1/m_0 \) |
|-------|---------------|
| FB-1  | 0             |
| FB-2  | 0.46          |
| FB-3  | 0.92          |
| FB-4  | 1.38          |
| FB-5  | 1.84          |
| FB-6  | 2.30          |
| FB-7  | 2.76          |
| FB-8  | 3.22          |

Fig. 3(a) shows that the sag of the conductor is proportional with the ice quality. With the ice quality of the conductor increasing to 3.22, the sag of the iced conductor reaches up to 22m from 12.8m. Fig. 3(b) shows that the tension of both the conductor and the insulator present the increase of an exponential rule with the mass ratio rising. When the mass ratio rises to 3.22, the tensions of the conductor, the fixed insulator and the suspension insulator are 2.68, 2.58 and 2.71 times higher respectively.

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(a) Inference of the mass ratio on the sag (b) Inference of the mass ratio on the tension

Figure 3. The influence of different mass ratio on configuration

Fig. 4(a) shows that the displacement amplitude of midspan on the ice shedding span is linear proportional with the mass ratio when the jump amplitude of midspan increases from 4.22m to 31.02m.

Figure 4. Influence of the mass ratio on the ice shedding vibration
On the same case, the jump amplitude of midspan on the side-span decreases from -1.67m to -7.64m with the mass ratio of ice shedding rising. In general, the displacement amplitude of midspan on the ice shedding span is linear proportional with the mass ratio, the jump amplitude of midspan on the side span is nonlinear to the mass ratio.

Fig. 4(b) show that the tension of the fixed insulator, the suspension insulator, the ice shedding span and the conductor of the side-span increase with the mass ratio of ice shedding on the conductor rising, which generally presents a weak nonlinear proportional relationship. The tension amplitude of the fixed insulator increases from 69.384kN to 194.44kN with the mass ratio rising from 0.46 to 3.22. The conductor tension of the ice shedding span increases from 67.04kN to 178.04kN. The change is generally same to the change of the strain insulator. The conductor tension of the side span increases from 67.63kN to 188.90kN with the mass ratio rising from 0.46 to 3.22.

4. Conclusions

The ice shedding on conductors can lead to the severe vibration of conductors. There is no mature theoretical calculation for the vibration of ice shedding. Based on the method of the nonlinear finite element, the analysis for the ice shedding vibration on conductors by means of changing the density were conducted. the accuracy of computation through a calculation example was verified. Through the analysis for the dynamic response of ice shedding under multiple cases, some conclusions were made as follows:

(1) The vibration mode of transmission line has a significant influence on the vibration response of ice shedding on the conductor. Normally, the vibration mode of structure will not change materially. The full span ice shedding is the most unfavorable condition.

(2) The displacement amplitude at the mid-point of the ice shedding span and the side span increases with the rising mass ratio of iced conductor. The ice shedding response at ice shedding span present a linear law, and the response at side span presents a nonlinear law.

(3) The tension of the fixed insulator, the suspension insulator, the ice shedding span, and the conductor of the side-span increase with the mass ratio of ice shedding on the conductor rising, which generally presents a weak nonlinear proportional relationship. The tension of the fixed insulator increase faster with the mass ratio.

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