Experimental and Numerical Analysis of Overhead Transmission Lines Vibration due to Atmospheric Icing

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***Abstract*—Atmospheric icing is one of the main threats to overhead transmission lines in cold regions. The ice related loads may cause mechanical incidents, such as wire breakage, cable rupture, clamp slipping, cross-arm deformation and even tower collapse. Ice shedding may lead to dramatic vibration of lines and cause flashover or short circuit among ground wires, conductors and the earth. Therefore, to obtain the static and dynamic load characteristics of the overhead electric transmission lines is essential for transmission line design and operation. Also, it provides important information for health evaluation of transmission line components, and prediction of their remaining service life. In present study, a three-span full scale physical model of transmission line was established, with the span length of 50m-150m-50m. Ice shedding was simulated by sudden release of lumped mass. The mid-span jump heights were measured during different ice shedding scenarios, to quantizing the dynamic characteristics of lines. Then, finite element method (FEM) was employed for numerical simulation of ice shedding phenomenon. The comparison of numerical and experimental results confirms the feasibility and efficiency of the numerical simulation method in this paper. This study provides essential experimental data about ice shedding of full scale transmission lines, and is of great help for transmission line design and icing disaster alleviation.**

Keywords—transmission line;dynamic characteristics; finite element method; ice shedding

I. INTRODUCTION

Atmospheric icing of overhead power transmission lines is a common disaster for countries in cold regions, like Russia, Canada, America, Japan, Finland, and Iceland [1]. Among the icing disaster of electric networks, the ice storms hit Canada in January 1998 and 2008 in China are most famous, for the serious destroy and impact. Ice shedding is one of the main destructive dynamic loads on transmission lines during icing events. Ice shedding of conductor and ground wire occurs with proper temperature and certain wind speed, or during mechanical deicing and thermal deicing process, which may cause large amplitude jump of cable and dramatic impact on insulators, fittings and tower structures [2]. The threats of ice shedding can be divided into two aspects. On one hand, it may cause electrical faults, such as flashover and short circuits, due to the insufficient electric clearances among conductors-ground wires, conductors-the earth, and insulators-towers, as a result of vertical jump and transversal movements of conductor and insulators. On the other hand, it may result in mechanical damages, such as uneven icing or unsynchronized ice shedding among adjacent spans, and transient loads on insulators, conductors, fittings and towers, which may further lead to towers collapse.

Therefore, the dynamic characteristics of overhead transmission lines following ice shedding is essential for anti-icing disaster design and structure optimization of electric networks in cold regions. It is also useful for prognostics and health management of towers-lines system structure.

Study on ice shedding of transmission lines dates from 1940s. A series of tests on a five-span line section were carried, where ice loads and ice shedding were modeled by adding and releasing lumped mass [3]. An improved formulate for maximum jump height of conductor was proposed, which fits

This study is supported by Beijing Natural Science Foundation (8174079) and the State of Grid of China's scientific project – the Applicability and Anti-Disaster Ability Improvement of Compact Transmission lines (SGTYHT/14-JS-188).

well with test measurements. With the development of computer science and finite element (FE) technology, Commercial FE analysis software was used to study the dynamic response during ice shedding, focusing on time histories of cable tension and midpoint displacement [4]. The numerical model was validated by reduced scale physical tests on a 3.2 m long span. A series of 21 scenarios of ice shedding phenomenon were simulated, where the influence of multiple factors were studied, like ice thickness, ice shedding amount, span length [5]. In the study, ice shedding was modeled by changing the density of cable in dynamic analysis restarting from static analysis. A new ice shedding model is proposed, by setting an ice element parallel to cable element, which can simulate multiple ice shedding scenarios, especially local or partial ice shedding at prescribed position [6]. Comprehensive study was conducted on the dynamic characteristics of bundled conductor after ice shedding [7, 8]. The analytical formulates for jump height calculation of bundled conductors were deduced, which agree well with the result of numerical simulation [9]. The authors proposed a novel ice shedding simulation method to model the induced ice shedding effects, which is closer to the natural condition [10, 11].

This paper presents the catenary equations of conductor first analytically. Then, a series of ice shedding tests on a three-span full scale line section were carried, which is essential for dynamic analysis of ice shedding phenomenon. Finally, numerical simulation was conducted with FE method, of which the result was compared with physical test for validation. The study in this paper provides helpful information for transmission lines design in cold regions, and for prognostics and health management of towers-lines system structures.

II. Overhead Transmission Line Static Profile

Due to the fact that the magnitude of span length is much greater than that of conductor cross-section, the static profile of transmission line is merely influenced by conductor stiffness. As a result, conductor is assumed that it can stand tensile force only in common practice, rather than bending monument and compressive force. Also, the loads ratio is set to distribute evenly along the whole span. Therefore, the conductor hanging between two towers shows as catenary shape.

The catenary shape of a single span conductor hanged between two suspension points at different elevations is shown in Fig. 1, where A, B are the suspension points.

Then, the equation of the catenary shape can be expressed as (1), where the origin is set at the left suspension point A [12].

$$y=\frac{h}{L_{h=0}}\left[\frac{2\sigma_0}{\gamma}\sinh\frac{\gamma x}{2\sigma_0}\cosh\frac{\gamma(l-x)}{2\sigma_0}\right] - \sqrt{1+\left(\frac{h}{L_{h=0}}\right)^2}\left[\frac{2\sigma_0}{\gamma}\sinh\frac{\gamma x}{2\sigma_0}\sinh\frac{\gamma(l-x)}{2\sigma_0}\right] \quad (1)$$

Where h is the elevation difference of two suspension points, σ_0 is the stress at the minimum sag point ; γ is the vertical load ratio evenly distributed along the span ; l is the level distance between the two suspension points ; $L_{h=0}$ is the conductor length in the span, expressed as (2) [12].

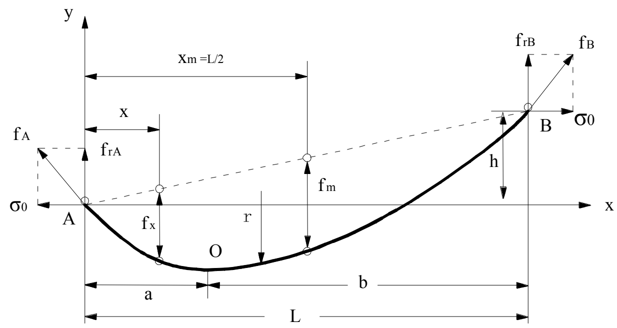

Fig. 1. Catenary shape of the transmission line with unequal suspension points

$$L_{h=0}=\frac{2\sigma_0}{\gamma}\sinh\frac{\gamma l}{2\sigma_0} \quad (2)$$

The correspondence relation of the variables in catenary equation at two different meteorological conditions, like conductor length, sag and stress, may influenced by temperature, ice and wind. Equation (3) shows the correspondence relation of the factors changing from state 1 to state 2 [12]

$$\sigma_{02}-\frac{E\gamma_2^2 l^2\cos^3\beta}{24\sigma_{02}^2}= \sigma_{01}-\frac{E\gamma_1^2 l^2\cos^3\beta}{24\sigma_{01}^2}-\alpha E\cos\beta(t_2-t_1) \quad (3)$$

Where σ_{01}, σ_{02} are the stress at the lowest point of the span, of which the subscripts 01 and 02 are the correspondence value at state 1 and state 2, respectively; γ_1, γ_2 are the load ratio; t_1, t_2 are the temperature; l is the span length; β is the elevation difference angle; α is the temperature expansion coefficient and E is the modulus.

III. Full Scale Ice Shedding Test

Dynamic characteristics of transmission line is impacted by various factors, such as span length, elevation difference of suspension points, insulator length, conductor configuration and damping, as make it very difficult to calculate with analytical analysis. Physical test is the effective way to obtain the dynamic response of transmission line ice shedding, and the experimental results of different scenarios with various ice shedding amount and pattern can be used to revise and validate the numerical model.

A. Test Line Parameter

The test line is located at the Ultra High Voltage Towers Test Base at Bazhou, Hebei province, China. The line section is 250m in total, with the span length from left to right is 50m,