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Oscillation of conductors following ice-shedding on UHV transmission lines

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ABSTRACT

Ice-shedding on a UHV overhead transmission line was simulated by releasing lumped loads from it. The resulting oscillations were compared with those from a simulation program for a multi-span line. The damping parameter in the simulation program was adjusted until the jump heights and oscillation attenuation obtained from the program and the physical test agreed. Using this damping parameter, the behavior of a UHV transmission line was evaluated by the program for various values of span length, number of spans per line section, insulator length as well as the effect of the 'unzipping' mode of ice shedding.

1. Introduction

Ice accumulating on conductors is a serious problem frequently arising on overhead transmission lines in cold regions. Ice-shedding happens when the ice formed on conductors suddenly drops off under particular temperature and wind conditions or man-made shocks. This will cause high-amplitude oscillations of the conductors and large transient forces on the suspension insulators and towers. Flashover between adjacent conductors may well be caused by these conductor oscillations, and the transient forces may damage the insulators and, in extreme cases, the towers. To evaluate these potential electrical and mechanical problems, the maximum conductor jump heights and tensions need to be determined.

Numerical simulation models using nonlinear finite element analysis have been used to study the dynamic effects of ice-shedding on overhead transmission lines [1–3]. Most were developed using the ADINA finite-element analysis software [1,4]. In a later study, the dynamic effects of ice-shedding were simulated on a two-span section using a numerical model, varying several of the span parameters [2]. More recently a finite-element model for bundled conductors was constructed using ADINA, followed by a parametric study where the ice-shedding parameters were varied [3]. In all of these, the value of the damping parameter was selected on the basis of reasonable, but not proven, assumptions.

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The selection of a damping parameter for this case is complex, but is a critical aspect of the analysis of the dynamics of overhead transmission line conductors. Values can be obtained from tests [5–9], but most of these have not been on full-scale spans.

In the authors' previous work [10], the dynamic response of conductors to ice-shedding – the variation of conductor displacement and tension with time – were determined in physical tests in which the natural ice formed on conductors was simulated by 10 or more lumped loads hanging from the conductors. Full-size multi-span configurations on overhead transmission lines were used. A dynamic model of ice-shedding on these multi-span lines was developed to compare with the measured dynamic responses. The results of the numerical computations and the physical tests were compared in respect of the vertical movement and tension of the conductor, and the tension and swing angle of the suspension insulator. Good agreement between test and numerical computation was obtained in each case, giving confidence in accuracy of the computation program to study the dynamic characteristics of ice-shedding on overhead transmission lines, both existing and planned. Some of the parameters influencing the effect of ice-shedding were studied in short line section: the ice thickness, the percentage of ice shed and the non-uniformity of the ice-shedding.

In the present paper details are given of the method by which the damping parameter used in the previous work was determined. This was achieved by comparing the results of physical tests on the actual transmission line with numerical computations using various trial values of the damping coefficient, and finding the appropriate value by trial and error. The acquisition of the damping parameter is clearly crucial to studying the ice-shedding behavior of UHV overhead transmission lines by numerical computation. In addition, studies of the parameters influencing ice-shedding, that is, span length, multi-span configuration, number of spans per line section, insulator length and the 'unzipping' ice-shedding mode, using the simulation program, are reported.

2. Numerical simulation model of ice-shedding

2.1. Catenary form of conductor

The stiffness of the conductor has little effect on the shape of a cable hung between two suspension points. The conductor of an overhead transmission line can therefore be assumed to act like a soft chain. The conductor is assumed to be uniform along its length and therefore to take up a catenary shape [11]:

$$y=\frac{T}{q}\cosh\left[\frac{q}{T}(x-x_0)\right]+y_0 \tag{1}$$

where T is the horizontal tension of the conductor and q is the load on unit length of the conductor. The horizontal tension and the line load of unit length of conductor may be replaced by the horizontal stress and the linear density, respectively: $\sigma_0=T/A$ and $g=q/A$ (where A is the cross-sectional area of the conductor). The catenary formula of an overhead transmission line may then be re-written as follows:

$$y=\frac{\sigma_0}{g}\left[\cosh\frac{g}{\sigma_0}(x-x_0)\right]+y_0 \tag{2}$$

2.2. Computation of conductor tension

The state equation when the suspension points are at the same elevation is as follows, where the conductor length has been converted to that under zero loading and standard temperature [11]:

$$s-\frac{\sigma}{E}L-\alpha\theta=L+\frac{g^2L^3}{24\sigma^2}-\frac{\sigma}{E}L-L\alpha\theta=s_0 \tag{3}$$

so that,

$$\sigma-\frac{EL^2g^2}{24\sigma^2}+\alpha E\theta=C \tag{4}$$

where E is Young's modulus of the conductor in MPa, θ the temperature in °C and L the length of the span in m. The state equation under different conditions, A and B, may be re-written as follows:

$$\sigma_A-\frac{EL^2g_A^2}{24\sigma_A^2}+\alpha E\theta_A=\sigma_B-\frac{EL^2g_B^2}{24\sigma_B^2}+\alpha E\theta_B \tag{5}$$

Each conductor type has a maximum allowable tension and it is essential that this should not be reached, even under the severest anticipated weather conditions for the particular location of the UHV overhead transmission line. This may be checked by substitution in Eq. (5) of the severest anticipated weather conditions, both the low temperature and heavy ice accretion (the linear density being increased by the accretion of ice) for a particular overhead transmission line, thus deriving the conductor tension under those weather conditions.