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INFLUENCE OF TRANSMISSION-LINE PARAMETERS ON HIGH-AMPLITUDE VIBRATION OF CONDUCTOR BUNDLES

L. E. Kollár[1], M. Farzaneh[1]

[1]NSERC/Hydro-Québec/UQAC Industrial Chair on Atmospheric Icing of Power Network Equipment (CIGELE) and Canada Research Chair on Atmospheric Icing Engineering of Power Networks (INGIVRE), University of Québec at Chicoutimi (UQAC)

Abstract. *The influence of transmission-line parameters on high-amplitude cable vibration was studied numerically on a bundle of two conductors. Such line parameters as span length, number of spacers in a span, and suspension length were varied, because they have great influence on the severity of vibration. The high-amplitude vibration was initiated by load removal simulating ice shedding from an entire span of a transmission line, and the severity of vibration was evaluated by determining conductor rebound height and angle of bundle rotation. The numerical model was developed using the commercial finite element analysis software ADINA. Results show that when the initial horizontal tension is kept constant, the conductor jump increases with span length for the shortest spans, and it varies in a limited interval for the longest spans. When the sag-to-span ratio is kept constant, the conductor jump increases with span length even for the longest spans considered. The bundle rotation may increase considerably with span length; however, if the number of spacers is great enough, then the span length may not affect the bundle rotation significantly. The bundle rotation is independent of the suspension length even when only one spacer is applied in the entire span, but the conductor jump increases considerably with suspension length.*

Keywords: *Cable vibration, Conductor bundle, Numerical modeling, Transmission line*

1. INTRODUCTION

The severity of vibration of conductor bundles depends on several transmission-line parameters. Some of these parameters have particularly important effects when the conductor vibrates with high amplitude as is the case in different processes occurring occasionally in cold regions, e.g. during galloping, after ice shedding, after the application of a shock load for ice removal, or following conductor breakage. These line parameters include span length, number of spacers in a span, and suspension length; and they influence significantly the vibration amplitude, or the conductor rebound height, and the angle of bundle rotation. The prediction of these parameters is particularly important for avoiding flashover, bundle collapse, and further related problems in the transmission line. A review of ice-related dynamic problems on overhead lines, including ice shedding and bundle rolling is provided in [3]. These problems justify the particular interest in cold climate regions to predict the parameters mentioned above in transmission lines where line parameters vary in a wide range.

High-amplitude vibration of transmission line conductors has been modeled in a vast number of publications. The present research focuses on the influence of line parameters on conductor dynamics, rather than studying the different sources leading to high-amplitude conductor vibration. In particular, a numerical model developed formerly to simulate ice shedding is applied for a twin bundle of conductors with various line parameters. Ice shedding was simulated numerically on a single conductor in [5] and [10], and on conductor bundles in [6] and [7]. The numerical model of [5] was validated by small-scale experiments; whereas full-scale experiments were carried out in [8] to simulate sudden ice shedding, and in [11] to simulate propagating ice shedding. The effects of such line parameters as span length, difference in elevation between end and suspension points, unequal spans, and number of spans per line section were studied in [10] in a line section with single conductors. The dependence of conductor jump height on length of ice-shedding span and elevation difference was computed in [12]. The vertical vibration of bundled conductors was simulated in [6] for different subspan lengths. Bundle rotation was also considered in [7], but the effects of different line parameters on both of vibration and rotation of the conductor bundle have not been investigated in the literature. The goal of this paper is to consider line parameters which have great influence on the severity of vibration, namely span length, number of spacers in a span, and suspension length, and establish how conductor rebound height and bundle rotation depend on these parameters after the application of such sudden load on the line as ice shedding from a conductor.

2. NUMERICAL MODEL

This section describes the numerical model briefly with particular attention to the parameters varied in the simulations. First, modeling of the transmission line elements is presented including cable model with various lengths, suspension string model with different lengths and fixations, and spacer model. Then, the model for ice load and ice shedding is summarized. The simulation is carried out using the finite element analysis software ADINA [1].

Models for the cable and the suspension strings are based on former recommendations [5, 10]. The cable is modeled by two-node isoparametric truss elements with large kinematics. The initial condition for cable elements include a constant initial pre-strain that is obtained from the static equilibrium of the catenary [4]. The material properties of the cable are accounted for by a nonlinear elastic material model, not allowing compression and assuming Hookian small-strain behaviour in tension. The cable damping is considered as Rayleigh damping as proposed in [9]. When varying span length, the cable length and the catenary profile are modified by keeping either the sag-to-span ratio or the initial horizontal tension constant.

Cables are suspended via insulator strings modelled by beam elements and by isotropic linear elastic material properties with constant cross-section. Suspensions with two different lengths were considered, and additionally, the extreme case with zero suspension length was also modeled by fixing the cable end directly to the tower. The suspension was either fixed to the tower or hinged to it allowing rotation around a horizontal axis. The tower was not modeled meaning that the suspension or cable was connected to a perfectly rigid wall.

Spacers are considered as simple rods clamped to a conductor at each end as was proposed for twin bundles in [6]. They are modeled by two-node truss elements and are associated with an isotropic linear elastic material. The structural damping of spacers is considered by a nonlinear spring element. Spacer properties were not changed throughout the simulations, only their number was varied along a span.

Ice load is modeled by several concentrated loads acting at constant distances along the loaded span. Although ice usually appears on conductors as a distributed load, concentrated loads can be applied on truss elements unlike distributed loads; furthermore, the applicability of this approach was shown in [7]. Thus, in the static analysis concentrated loads are applied along the span at constant distances. Then, these loads are removed from one subconductor at the beginning of the dynamic analysis simulating ice shedding.

3. SIMULATION OF BUNDLE VIBRATION AND ROTATION FOLLOWING ICE SHEDDING

3.1. Configurations of simulated line sections

The subject of the basic case in the present study is a twin bundle of Bersfort ACSR conductors where the subconductors are connected to each other horizontally by a spacer damper. The geometrical and material data of the conductor are as follows: its diameter is 35.6 mm, its cross-sectional area is 747.1 mm^2, the mass per unit length is 2.37 kg/m, and its Young's modulus is 67.6 GPa. The span length is 200 m, the sag is 6 m, and the horizontal component of conductor tension in this case is 19.5 kN. Translational degrees of freedom are fixed at the suspension, but rotation is allowed around the axis perpendicular to the vertical plane of conductor. The applied load corresponds to a load due to 50-mm-thick glaze ice whose density is $900\,kg/m^3$. In each simulated case, one subconductor sheds completely and the other subconductor remains loaded. The damping ratio of the spacer is set at 0.2 in correspondence with [2].

Each conductor is simulated by 100 elements, and concentrated loads are applied at every fourth points. It was verified that further increasing the number of loads while keeping the total load on the span constant did not cause considerable difference in the results. When loads were applied at every fourth or at every fifth point on a single conductor, the difference in the conductor rebound height was 7%. When loads were applied at each point, it caused a less than 2% change as compared to loads at every fourth point.

The influence of three parameters is of greatest interest: span length, number of spacers along the span (or sub-span length), and length and fixation of suspension. The span length was varied from 50 to 1200 m keeping the horizontal component of tension constant, and from 50 to 400 m when the sag-to-span ratio was kept constant. Increasing span length to 800 m with constant sag-to-span ratio and applying the same ice load leaded to conductor tension exceeding its tensile strength; thus, the maximum span length considered in this case

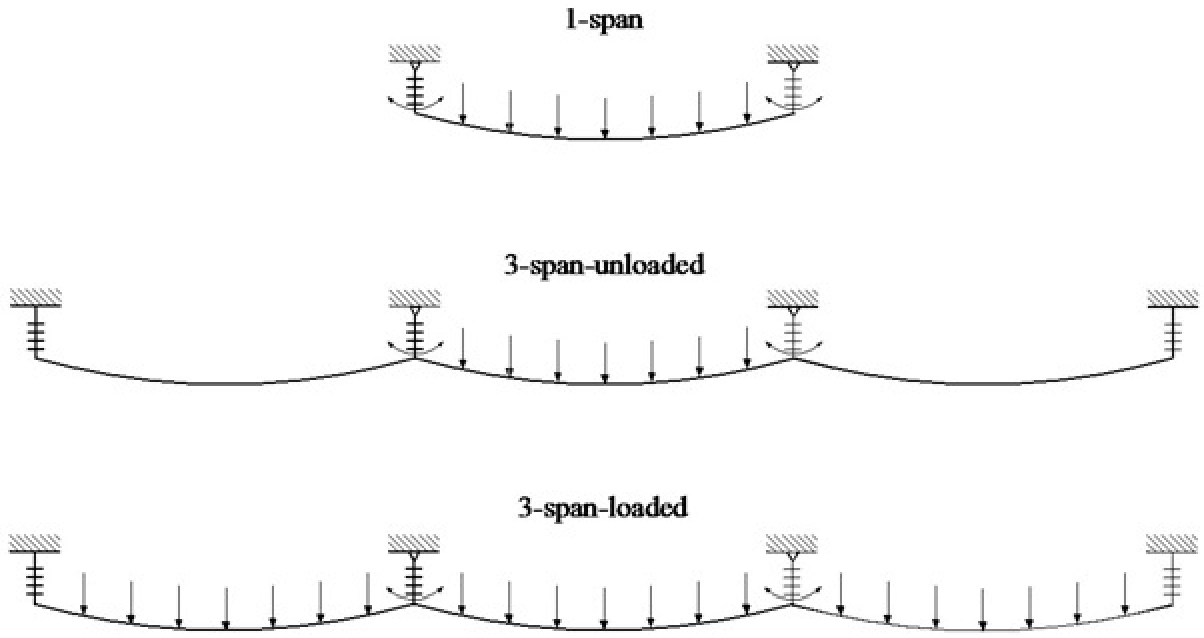
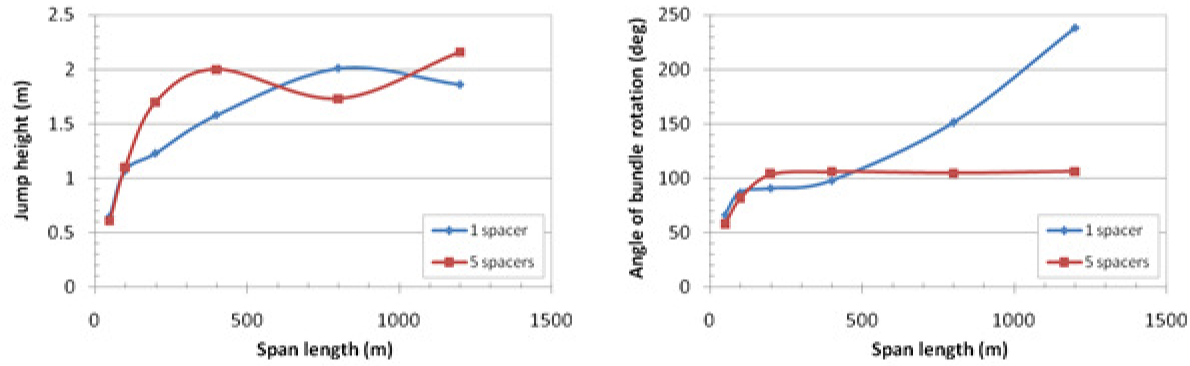


Figure 1. Three configurations considered in the simulations with different suspensions (each span includes a horizontal bundle of two conductors)

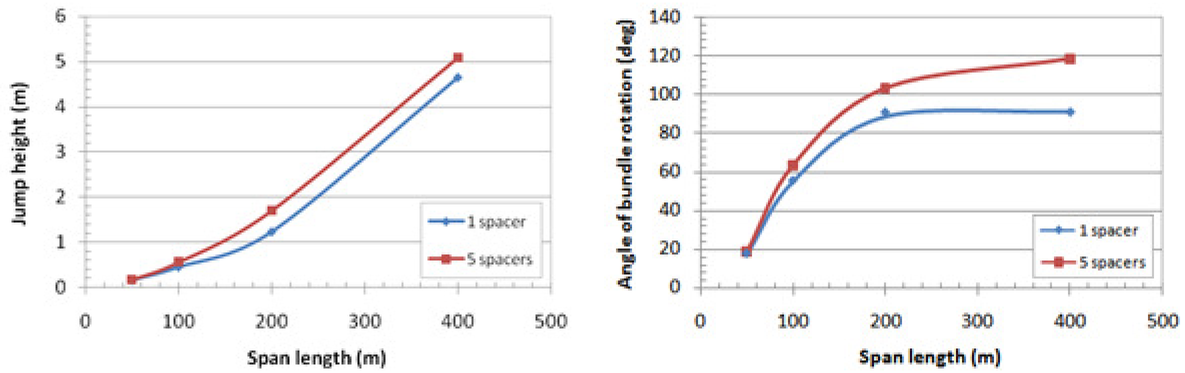
was 400 m. The number of elements in each cable was changed so that the length of an element was kept constant (2 m), except for the 50-m-long span when 50 elements were used. Loads were applied at every fourth point except for the cases with 50 elements per conductor (i.e. span lengths of 50 m and 100 m) when loads were applied at every second point. The effects of number of spacers were already studied in [7]. It was concluded that jump height may be reduced significantly by increasing the number spacers along the span; however, bundle rotation rather increased than decreased when the number of spacers was increased from 1 to 3 or 5. Thus, these simulations are not repeated here, but the study with varying span lengths was carried out with 1 and 5 spacers.

The suspension was not modeled in the simulations with varying span lengths, but the cable was hinged to the rigid tower allowing rotation around the horizontal axis perpendicular to the vertical plane of conductor. Therefore, further simulations were carried out considering suspensions with lengths of 0.9 m and 1.8 m, which was hinged to the tower at one end and the conductor was connected to the other end allowing rotation around the axis mentioned above. This configuration will be called the “1-span” model. The influence of suspension was also studied on 3-span sections where the suspensions at the two ends were fixed to the tower, whereas those on the two sides of the middle span were allowed to rotate. The middle span was loaded, whereas the left and right spans were unloaded in simulations with the model called “3-spans-unloaded” and they were loaded in simulations with the model called “3-spans-loaded”. The schema of these configurations is shown in Fig. 1. Only 1 spacer at mid-span was assumed in all of these simulations.



(a) (b)

Figure 2. Bundle dynamics for different span lengths and constant initial horizontal tension, (a) conductor jump height, (b) angle of bundle rotation



(a) (b)

Figure 3. Bundle dynamics for different span lengths and constant sag-to-span ratio, (a) conductor jump height, (b) angle of bundle rotation

3.2. Influence of line parameters on bundle vibration and rotation

The first set of simulations was carried out by varying the span length and keeping the initial horizontal tension in the conductor constant. In this case, the sag-to-span ratio varied from 0.7 % for span length of 50 m to 18.6 % for span length of 1200 m, which values are quite low and quite high, respectively, as compared to reality. However, these were considered as extreme cases, and sag-to-span ratios for the other span lengths examined fell in between. When 1 spacer was applied along the span, then the jump height increased with span length except for the longest spans when it remained around 2 m. When 5 spacers were applied, then the increase was faster, but it also remained in a similar range for the longest spans (see Fig. 2a). It should be noted that higher jump heights may be obtained at mid-span if 2 or 4 spacers are applied along the span, because in that case there is no spacer at mid-span [7]. The rotation of bundle with 1 spacer increased even for the longest spans making the risk of bundle collapse very high (Fig. 2b). However, increasing the number of spacers up to 5 reduced bundle rotation significantly for the longest spans. It was concluded in [7] that the bundle rotation may be a bit higher when the number of spacers increases, which holds for a 200-m-long span that was considered in that study. For longer spans, however, the bundle rotation

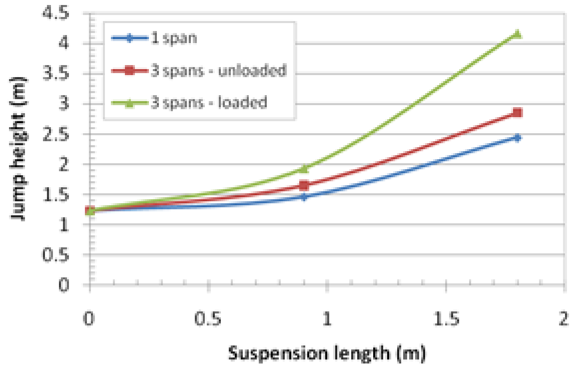


Figure 4. Conductor jump height for different configurations and suspension lengths

Table 1. Angle of bundle rotation for different configurations and suspension lengths

Model	Suspension length (m)	Angle (deg)
1-span	0	90.9
1-span	0.9	91.2
1-span	1.8	91.4
3-span-unloaded	0.9	91.1
3-span-unloaded	1.8	91.0
3-span-loaded	0.9	91.0
3-span-loaded	1.8	90.4

increases significantly with 1 spacer, but it does not change considerably with 5 spacers (Fig. 2b).

The span length was also varied keeping the sag-to-span ratio constant, because the dynamic behaviour of conductor was different (cf. Figs. 2 and 3). In these cases, the initial tension varied from 5 kN (50-m-span) to 39 kN (400-m-span). The conductor jump increased with span length to much higher values; it was more than double for the 400-m-span than with constant horizontal tension. This can be explained by the very taut cable with high tension in this case. However, the bundle rotation did not increase considerably when the span length was changed from 200 m to 400 m as shown in Fig. 3b. Also, the difference between the cases with 1 and 5 spacers is much less than for constant horizontal tension; and the conclusion of [7], i.e. the little higher bundle rotation for higher number of spacers, holds for all of the span lengths considered.

The influence of suspension length is presented in Fig. 4 and Table 1. The three curves in Fig. 4 show the effects of increasing suspension length on conductor jump height for different configurations. The suspension length 0 means in each curve the basic configuration, i.e. a single span when the cable is hinged to the rigid tower allowing rotation around the axis perpendicular to the vertical plane of conductor. Increasing suspension length always increases jump height, but the degree of increase is greater for the 3-span-sections, especially when the left and right spans are loaded. An important factor is that the suspensions near the middle span may rotate in these cases, which allows more severe movement of the conductors. According to Fig. 4, the jump height may be doubled or tripled by allowing more and more movement of cable end-points; however, this factor does not influence the angle of bundle rotation. As Table 1 shows, this angle varies in a very narrow interval, i.e. between 90.4 and 91.4 degrees, and this interval is the same for the 1-span section and the 3-span-sections.

4. CONCLUSIONS

The influence of transmission-line parameters, in particular the span length, number of spacers in a span, and suspension length, on cable vibration and bundle rotation has been studied numerically using a model implemented in the finite element analysis software ADINA. Ice shedding from one subconductor in a twin bundle was simulated, and the model provided conductor rebound height as well as the angle of bundle rotation. Observations may be summarized as follows:

- When the initial horizontal tension is kept constant, the conductor jump increases with span length for the shortest spans, and it varies in a limited interval for the longest spans. The angle of bundle rotation increases with span length when 1 spacer is applied, and it also increases for the shortest spans when 5 spacers are applied; it remains constant, however, for the longest spans. The higher number of spacers along a span reduces significantly the bundle rotation for long spans.
- When the sag-to-span ratio is kept constant, the conductor jump increases with span length even for the longest spans considered. The angle of bundle rotation increases quickly with short span lengths, but it does not increase considerably with the longest spans. The bundle rotation is a bit higher when the number of spacers along the span is greater.

The conductor jump increases with suspension length, particularly in the 3-span-sections where more movement of cable end-points is allowed; however, the suspension does not influence the angle of bundle rotation.

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