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The response of a guyed transmission line system to boundary layer wind

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ABSTRACT

The current study investigates the aeroelastic characteristics and structural response of a multiple-span guyed lattice transmission line system, through a simultaneous testing of four aeroelastic guyed lattice towers and conductors. The transmission line system simulated in the current study is a generic guyed transmission tower used by different hydro companies in North America and in different parts of the world. The aeroelastic model is designed for a geometry scale of 1:50 and tested in the Boundary Layer Wind Tunnel Laboratory at the University of Western Ontario, Canada. The model is tested using an open exposure wind profile. The aeroelastic test is performed for three different wind directions and for two configurations, with and without the transmission lines (conductors and ground-wires). Such aeroelastic model of guyed transmission line system with multiple-spans is not reported in literature. This represent a new contribution to the existing literature of the aeroelastic behaviour of transmission lines under wind actions. The study investigates the aeroelastic model response to boundary layer wind loading under different wind speeds and configurations. For the 37 wind speeds, two configurations, and three angles of attack used in the current aeroelastic test, no instabilities are observed for the tested transmission towers or lines. The measured natural frequencies of the aeroelastic model match those obtained by numerical modelling and those provided in the literature, and are affected by the value of the pretension force applied to the supporting guys. The results indicate that the multiple-span guyed transmission line system aeroelastic model responded in a quasi-static manner to boundary layer wind loads. Resonant dynamic response is less significant and becomes less distinguished by increasing the wind speeds. The results are used to understand the response of guyed transmission line systems to boundary layer wind loads.

1. Introduction

Transmission lines systems are responsible of transferring electricity from the source to the end users. Large transmission line systems such as the 500 kv are responsible for transferring electricity from generation stations to cities and counties, then distribution systems deliver the electricity inside cities. Transmission line systems travel for thousands of kilometers through different topographies and weather conditions. Failure of transmission lines can have significant social and economic impacts. This was clearly demonstrated during the 1998 Montreal snow storm and the 2003 northeast blackout. The Ontario Hydro reported that five out of six weather-related line failures in their territory are due to high intensity wind (HIW), such as tornadoes and downbursts [1]. In the United States, 800–1000 high intensity wind storms occur each year causing extensive damages on transmission structures [1]. The CIGRÉ [2], a multinational committee questionnaire on line failures indicated that 65% of weather-related failure events of transmission lines were caused by high insanity winds in the form of tornadoes. The structural components of a transmission line system are the towers, the conductors, the ground-wires, and the insulator strings, as shown in Figs. 1 and 2. Although the tower's lattice form is favorable, the slenderness and flexibility of the system makes them vulnerable to strong wind loads. The transmission line system's response to wind load is nonlinear and complex due to both the large displacements of the towers and the significant movement of the lines which can reach to same order of

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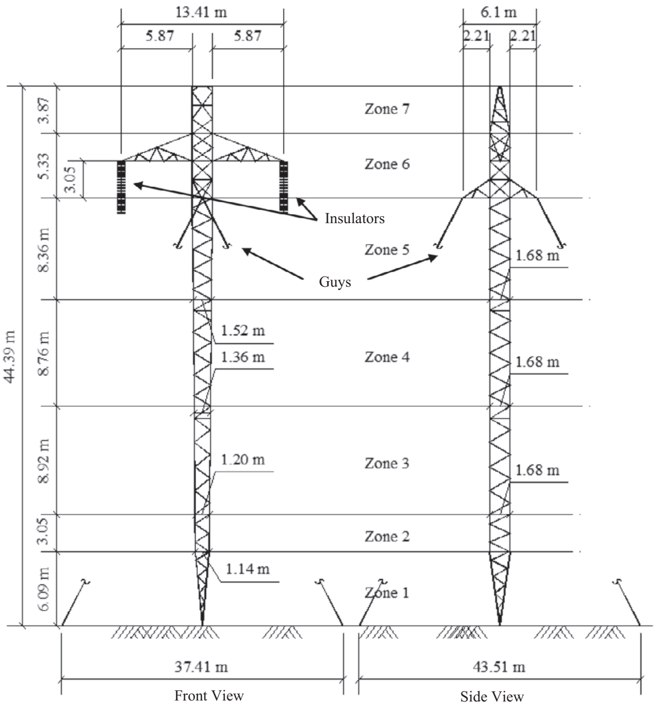

Fig. 1. Schematic of the full-scale guyed transmission tower.

magnitude of the line's sag. In addition, the vertical conductor bundle deflects on an inclined plane under strong wind loads, different from the sagging observed under gravity on vertical planes. This deflection on inclined planes couples the in-plane and out-of-plane lines oscillations [3]. Design codes and manuals of practice also recommend gust response factors to account for load amplification from dynamic response of structural components of a transmission line systems, e.g. towers and lines, to wind gusts. The recommendations include drag coefficients for various solidity ratios and shielding factors [4,5]. Although very useful and pragmatic, these recommendations are primarily derived from two dimensional and three dimensional lattice structure section tests and assume, uniformity of solidity ratio within the tower section and do not consider among other things the following: (i) three dimensionality effects such as end effects, (ii) complex geometric variations with height (tapered towers, variable spacing of members along height and near the cross arms), and (iii) aeroelastic effects. Such complexity in the response of transmission line systems to normal wind requires the use of sophisticated numerical models or aeroelastic testing as performed in the current study.

There are various experimental, numerical and field studies reported in literature. Momomura et al. [6] reported full-scale measurements of wind-induced vibration of a transmission line system in a mountainous area. The data was collected over a two-year period, between 1991 and 1993. It was reported that the vibration characteristics and the total damping of the supporting towers are strongly influenced by the behaviour and the aerodynamic damping (measured up to 8% critical damping) of the conductors. The study also concluded that the vibration mode shapes of the tower with conductors are similar to the mode shape of the tower without conductors. Loredo-Souza and Davenport [7] investigated the effect of wind speeds and line's mass on the aerodynamic damping values of different lines in a boundary layer wind tunnel. The study concluded that the background response was the predominant contribution to the total fluctuation. The resonant component became more significant in the case of low wind speeds and heavier conductors, e.g. higher line mass. Loredo-Souza and Davenport [8] also reported that it is very difficult to verify and measure full-scale aerodynamic behaviour of transmission lines, and wind tunnel testing can be an acceptable alternative. Lin et al. [9] studied a small scale aeroelastic model of a single transmission line span and a guyed transmission tower under boundary layer and downdraft wind. The study was conducted at a length scale of 1:100. The study concluded that the single span transmission line system has a quasi-static response to both boundary layer and downdraft wind. In addition, the resonant dynamic response was found to be less significant in the case of downdraft wind than boundary layer wind.

Extensive numerical studies were performed for transmission line system by [10–19] to assess the structural behaviour under computer simulated wind and HIW events such as downburst and tornadoes. The modelling and assessment of the behaviour of transmission lines under downburst loading was conducted by Shehata et al. [10] and Shehata and El Damatty [11]. In these studies, a three dimensional finite element model simulating the towers and a two-dimensional model simulating the conductors were developed to assess the structural performance of transmission towers under downburst loading. An extensive parametric study was conducted in the same investigations to evaluate the critical downburst loading cases. The studies carried out by Shehata et al. [10] and Shehata and El Damatty [11] was extended by Shehata and El Damatty [12] to investigate the structural performance of the tower under these critical downburst loading cases. In the same study, the failure of a transmission tower during a downburst event, which occurred in Manitoba, Canada in 1996, was assessed. Hamada [13], Hamada et al. [14], and Hamada and El Damatty [15] conducted a comprehensive study to assess the performance of transmission line structures under tornado loading. The transmission line systems were simulated using nonlinear three-dimensional finite element models. The tornado wind fields were obtained from validated computational fluid dynamics simulations. The authors investigated the variation of the tower members' internal forces with the tornado locations relative to the transmission line system. Their studies provided an insight into the structural response of the towers under tornado wind loads. For example, the dynamic effect associated with the translation motion of the tornado was assessed and the results of the parametric study were used to assess the sensitivity of the members' peak forces with the parameters defining the location of the tornado rel-

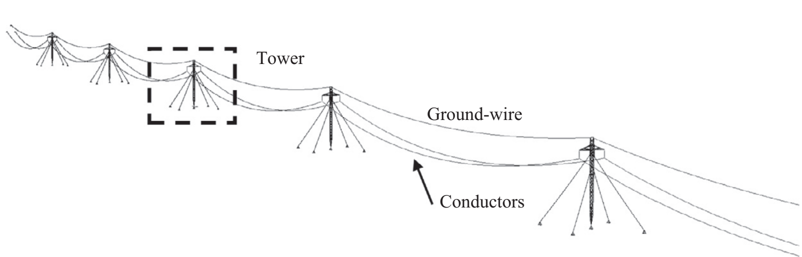

Fig. 2. Schematic view of the three-dimensional finite element model.