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Review article

Review on dynamic and quasi-static buffeting response of transmission lines under synoptic and non-synoptic winds

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ABSTRACT

This study reviews the literature on the dynamic response of a Transmission Line (TL) system under synoptic wind (conventional atmospheric boundary layer) as well as non-synoptic wind loading (downbursts). Gust-induced response for the conductors and the towers are covered and the limitations in the current structural design codes for wind loading are identified. Three main sections are considered in this study covering synoptic wind loading, downburst, and main conclusions and recommendations. For the case of synoptic wind events, four design codes (ASCE 74 2010, AS/NZS 2010, BS 2001, IEC 2003) specialized in TLs are considered for comparison. Using the ASCE 74 as a datum for normalization, a code ratio (*CR*) is evaluated for various parameters to assess the discrepancy between the codes. The code ratio for conductor forces CR_{Fc} is found to be ranging between 0.81 and 1.44. For tower forces code ratio CR_{Ft}, a discrepancy range of 0.68 and 1.85 is noticed. The study highlights the main reasons behind these discrepancies. For the case of downbursts, the study reveals that the event's size and its relative location to the tower lead to a number of critical load cases that need to be considered. The study provides important design considerations for both synoptic and non-synoptic winds. At the end of the study, a list of the main gaps existing in current design codes and recommendations to fill out these gaps is provided.

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1. Introduction

Electricity is carried by Transmission Lines (TLs) from the source of power generation to the distribution system. Overhead transmission lines consist mainly of support towers, conductors, insulators and ground wires. Conductors are responsible for transmitting the electricity and they are attached to the towers using insulators. Ground wires protect the line from lightning strike. Optimal TL design is particularly important when the site of power generation is geographically remote from population centers, such as in the case of many hydroelectric dams in North America. The ubiquity and full integration of electronics into modern life means that power outages due to TL failure are unacceptable from the standpoint of both social and economic losses. Past reports of TL failure due to weather conditions [37,79], including High Intensity Wind (HIW) events (downbursts and Tornadoes), emphasize the importance of accurate design wind loads.

The current study summarizes the previously conducted work related to the buffeting dynamic behavior of TL under synoptic and non-synoptic winds in order to identify the limitations and gaps in the current codes and to suggest how these gaps can be closed. The study is structured in the form of three main sections. Dynamic response of transmission line structures under synoptic winds is discussed in Section 2. In this section, four design codes [12,13,20,69] specialized in TLs are considered to compare between the approaches utilized to estimate the forces acting on the conductors and the towers under synoptic winds. This comparison is provided in a tabulated format. For each quantity, a code ratio (*CR*) is obtained by normalizing the values predicted from the three codes [13,20,69] by the value obtained from ASCE 74 [12]. Section 3 covers the response of TL structures under downburst winds. This section provides a description of the downburst wind field and a literature review showing previous field measurements and numerical modeling of downbursts. The last section (Section 4) identifies gaps in design codes and recommendations to fill out these gaps for both synoptic and non-synoptic wind cases studied in Sections 2 and 3. This section starts by presenting the gaps existing in the current design codes related to the gust response of TLs under synoptic wind and recommendation for filling these gaps. The second part of Section 4 provides the main conclusions and recommendations for the downburst case.

2. Dynamic and quasi-static responses of TLs under synoptic winds

This section discusses the response of TLs to fluctuating synoptic winds and is divided into two main parts. In the first part (Section 2.1), a literature review on the buffeting dynamic behavior of TLs is presented emphasizing the main parameters affecting the response. In addition, a literature review on field tests conducted during the last few decades to measure loads on conductors and towers has been provided. In the second part (Section 2.2), the quasi-static method used by design codes to account for the dynamic behavior of TLs is discussed in detail. The procedures used by four major design codes to obtain the design forces on the conductors and the towers are compared to identify the sources of discrepancy between different codes' approaches.

2.1. Literature on the dynamic buffeting response of transmission lines

Dynamic responses of transmission lines can be classified into the following groups: (i) buffeting due to the incoming turbulence, (ii) vortex shedding and (iii) galloping. The current study focuses on the dynamic buffeting response of transmission lines which affects both the lines and the towers. Vortex shedding and galloping affect mainly the lines and can lead to adverse effects such as clashing of wires, excessive conductor sags, wire fatigue, and generally collapse of line components. For deeper explanation of such phenomena, authors recommend reading studies by Den Hartog [40], Davison et al. [36], Havard and Pohlman [59], Rawlins [109] and more recent studies such as Macdonald et al. [90], Ohkuma and Marukawa [107], Gurunga et al. [54], Chabart and Lilien [24], Dyke and Laneville [44], Boddy and Rice [21], Jones [72], Lilien et al. [89], Yan et al. [142], and Ma et al. [91].

Buffeting dynamic response of the conductors is governed by the fluctuating incoming wind speeds and the properties of the conductors including their damping. Damping of the conductors results from a structural contribution and an aerodynamic contribution. Structural contribution of the damping is typically minor in the order of 0.05% as indicated by Bachmann et al. [15] and thus can be neglected. Aerodynamic contribution to damping, which is typically referred to as aerodynamic damping ζ_a, is usually dominant and can be calculated using the expression proposed by Davenport [31] and is shown in Eq. (1) [101].

$$\zeta_a = \frac{\pi C_d}{4}\frac{\rho D^2}{m}\frac{\bar{V}}{f\cdot D} \tag{1}$$

where C_d is the drag coefficient of the conductor and can be taken equal to 1.0 according to the ASCE 74 [12] and AS/NZS [13]; ρ: air density; m: mass per unit length; D: Conductor diameter; $\bar{V}$: mean wind velocity; f: conductor frequency.

As indicated from the equation above, the aerodynamic damping, ζ_a, is directly proportional to the mean wind velocity, $\bar{V}$, and is inversely proportional to the line mass, m. This contribution can rise up to 60% of the critical damping according to Loredo-Souza and Davenport [83] for light weight conductors subjected to high velocities (i.e. a critically damped system returns to its equilibrium position without oscillating).

The study conducted by Loredo-Souza and Davenport [83] concluded that the background response is, indeed, the main contributor to the total fluctuating response. However, the resonant component can be also important if the line characteristics and wind velocities lessen the aerodynamic damping. There were only minor resonant effects for the cases of high aerodynamic damping. For low aerodynamic damping, dynamic effects should be considered but confirmation of a threshold value of aerodynamic