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Aero-elastic testing of multi-spanned transmission line subjected to downbursts

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ABSTRACT

This paper reports the first aero-elastic test conducted under a scaled downburst wind field at the WindEEE dome facility at the University of Western Ontario, Canada. The main purpose of the test is to assess the dynamic response of a multi-span transmission line. The study starts by providing a characterization of the downburst wind field produced in WindEEE including a comparison with results of previously conducted numerical simulations. A number of test configurations, involving different locations of the downburst relative to the line, is considered. A decomposition approach is developed to separate between the resonant and the background components of the response. The results are presented in the form of a dynamic magnification factor that relates the peak response including the dynamic effect to the maximum quasi-static response. The test results show that the resonance contribution ranges between 5% and 10% of the peak response for the tower. They also show that the dynamic response of the conductors can reach up to 30% and 12% of the peak response at low and high downburst speeds, respectively.

1. Introduction

Downbursts together with tornadoes are commonly referred to as non-synoptic wind event. In addition, different textbooks and scientific articles use the term High Intensity Wind to refer to both events. In particular, downbursts, which contain masses of convective downdraft air, are usually associated with thunderstorms. Fujita (1985) defined a downburst as a severe descending mass of cold air that impinges on the ground and then transfers horizontally. Different design guidelines such as those of CIGRÉ (2012) and AS/NZS 7000 (2010) have highlighted the fact that downburst and tornado events are the main cause of transmission line failures in various countries. In Canada, many transmission line failures occurred in the past two decades during downburst and tornado events. For example, a chain of transmission towers belonging to the Manitoba Hydro Company failed near Winnipeg during a series of downburst events (McCarthy and Melsness, 1996). Other incidents include the collapse of two 500 kV single circuit guyed towers that failed during a severe thunderstorm in August 2006, and belonged to Hydro One, Ontario, Canada (Hydro One failure report, 2006). The inspection of the line's debris indicated that the anchors and the guy assemblies, were all in a good condition with no failures in the conductors or the insulators. This localized failure, where only two towers failed in different lines passing through the same area, was an indication of a localized downburst or tornado event. This was confirmed by a meteorological analysis, which revealed that a high intensity microburst with wind speeds of approximately 50 m/s caused that particular failure. A picture from the site of one of the failed towers is provided in Fig. 1 Similar transmission line failures have been widely reported in other parts of the world due to non-synoptic winds. For example, in China, Zhang (2006) reported the failure of 18 (500 kV) and 57 (110 kV) transmission line structures in 2005 under downburst and tornado events. Most recently, in September 2016, 23 transmission towers failed during a series of downburst events in South Australia (Australian Wind Alliance, 2016).

Standards and guidelines for designing transmission lines provide detailed information about the loading effect of synoptic winds. However, current codes and standards lack the critical loading information

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List of nomenclature

V_{RD}	radial velocity of the downburst
Running-Mean component	
	Slowly varying mean wind speed of the radial velocity of downbursts
Zone P	Time period when the maximum downburst radial velocity occurs
D	Downburst diameter at WindEEE
H	Height of the test chamber
Z	Elevation of the point of interest
f_{cut}	Cutting frequency of the mean component of the radial velocity
$f_{shedding}$	Shedding frequency of the ring vortices
S_t	Strouhal number

and the necessary guidelines regarding the impact of non-synoptic winds such as downbursts. This lack of information initiated the undertaking of several numerical and experimental studies at The University of Western Ontario, Canada, to investigate the behaviour of transmission line structures when subjected to downburst events. The results of these studies, such as those conducted by Shehata et al. (2005), and Darwish and El Damatty (2011), indicated that the main challenge in analyzing the response of a transmission line under downburst loads is the localized nature of the event. Shehata and El Damatty (2007) showed that the spatial configurations of a downburst (illustrated in Fig. 2) expressed in terms of the distance between the respective centers of the downburst and the tower “R”, the downburst diameter “D”, and the complement of the angle between the line and the radial position of the downburst relative to the tower, “ϴ” have a significant effect on the wind profiles acting on both the tower and its attached conductors. In addition, Shehata and El Damatty (2007) emphasized the dependency of the forces developing in the conductors on the ratio between the line span (L) and the downburst diameter (L/D ratio). The existence of a multitude of parameters that define the downburst loading acting on a transmission line system necessitates the consideration of several analysis cases in order to evaluate the peak internal forces of the tower members resulting from the downburst loads. In addition, the transient characteristics of the downburst's mean velocity further complicates the problem as the mean wind speed changes with time.

The localized nature of downbursts in both time and space made collecting field measurements a hard task to perform and affected the comprehension of the phenomena until the moment. However, there are few successful field measurements available in the literature. For example, Fujita (1985) conducted field measurements through the Northern Illinois Meteorological Research (NIMROD) and the Joint Airport Weather Studies (JAWS) and attempted to characterize event size and intensity. A similar study was conducted by Hjelmfelt (1988) where a summary of the statistics of downbursts measured in Colorado was provided. Later, different field measurement studies such as by Choi and Hidayat (2002), Duranona et al. (2007), Holmes et al. (2008), and Solari et al. (2015b) discussed various decomposition approaches to extract the mean component of the thunderstorm winds. Solari et al. (2015a,b) estimated the possible values of the turbulence intensity of downbursts using the data recorded for more than 90 downburst events as part of the “Wind and Ports” project. Recently, Aboshosha and Mara (2016) developed and validated the first framework to estimate design speeds associated with outflow gust fronts generated by downbursts using historical records and Monte Carlo simulation. This framework has a strong analogy with the method used to analyze hurricanes.

Numerical modeling is an alternative mean to simulate the downburst non-stationarity nature. Different numerical simulation methods have been reported in literature such as the Impinging Jet and the Cooling Source techniques. Kim and Hangan (2007) utilized the Impinging Jet approach to produce a time and space dependent downburst wind field based on the Reynolds Averaged Navier–Stokes (RANS) method. Using a Large Eddy Simulation (LES), Aboshosha et al. (2015) characterized the downburst field under four different exposures based on an Impinging Jet model. Vermeire et al. (2011) conducted a comparison study between the Cooling Source and the Impinging Jet approaches using LES. The study showed that the cooling source and the impinging jet profiles produced serious discrepancies at high elevations.

Other attempts included experimental investigations of the downburst wind field such as the studies conducted by Donaldson and Snedeker (1971), Didden and Ho (1985) and Chay and Letchford (2002) in which downbursts were simulated using an axisymmetric jet impinging on a flat wall. Didden and Ho (1985)'s experiment utilized a jet of a diameter of 3.81 cm and a wall positioned at a distance of 15.24 cm from the jet. Simulating the flow of a reduced-scale downburst of 0.5 m jet diameter against a flat wall located at 0.85 m distance, Chay and Letchford (2002) reported that the maximum wind speed was found at a distance equal to the jet diameter. The study emphasized that the quasi-static simulation was limited in its ability to represent the transient features of the downburst. Xu and Hangan (2008) demonstrated the role of this inflow transient effects and clarified the role of scaling and boundary conditions in impinging jet downburst simulators. Other studies considered simulating downburst-like profiles in conventional boundary layer laboratory, Lin et al. (2012), by simulating the downburst radial velocity profile (but not the resulting vorticity field) adjusting the ratios between the radial velocities along the height of the testing

Fig. 1. Guyed tower failure in Ontario, (Hydro One Report, 2006).

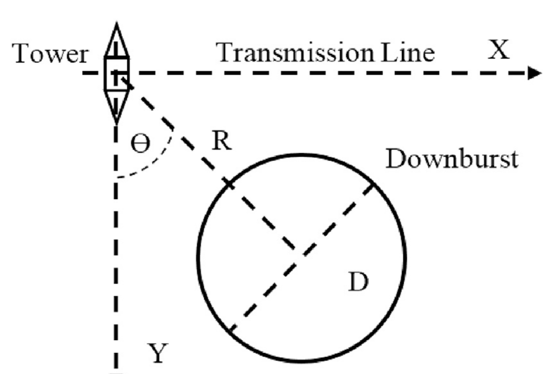

Fig. 2. Downburst characteristic parameters.