A COMPARISON OF WIND AND ICE LOADS FOR THE DESIGN OF TRANSMISSION LINES

Seyedeh Nasim Rezaei and Luc Chouinard*
Department of Civil Engineering and Applied Mechanics, McGill University (Canada)
Frédéric Légeron
Département de génie civil, Université De Sherbrooke (Canada)
*Email: Luc.chouinard@mcgill.ca

Abstract: The main objective of this paper is to study and compare various reliability based criteria for weather events proposed by current codes such as ASCE74, CSA/CAN, IEC and CENELEC and to discuss their impact on overall line reliability. For demonstration purposes, climatic loads imposed to a specific transmission lines situated in Boston are calculated for different return periods.

1. INTRODUCTION

Recent failures in overhead transmission lines caused by atmospheric hazards have indicated that weather related loads are the most important and frequently critical factors in designing criteria especially in cold climates.

Over the past years many reliability based standards such as ASCE74, CSA/CAN, IEC and CENELEC have been published for the development of loading criteria for these structures. However, there are some differences when dealing with the wind speed time averaging period, the reliability levels and the application of different combinations of statics on wind and ice to assess the combined wind on ice loads [1, 2, 3, 4].

The main objective of the current study is to provide a brief review on the differences between the aforementioned codes and to discuss on overall line reliability proposed by each code.

2. RESULTS AND DISCUSSION

Transverse wind loads on bare and ice covered conductors and vertical loads due to ice accumulations for a typical transmission line with 450 meters wind span and 540 meters weight span at an effective height of 10 meters in several cities of America are calculated based on data provided by ASCE maps. The conductor diameter is assumed to be 30 (mm) and the coincident temperature for calculating wind loads on bare and ice covered wires are 15°C and -5°C, respectively. The drag coefficient is set equal to "1.0" and the values of span factor, gust response factor and adjusting load factor can be estimated according to each standard.

Fig.1 indicates the comparison of transverse wind loads (kN) on bare conductors for Boston with a 3 second gust speed equal to 47.4 (m/s). It is inferred that CSA has the most conservative trend while ASCE has the least. Fig.2 displays all the combinations of wind speed and ice thickness that contributes to proposed wind on ice loads by different design guidelines. The highlighted points on the curves correspond to wind and ice combinations recommended by each code.

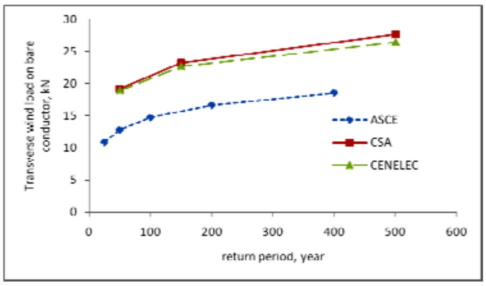

Figure 1: Comparison of transverse wind loads (kN) on bare conductors for selected return periods according to different codes.

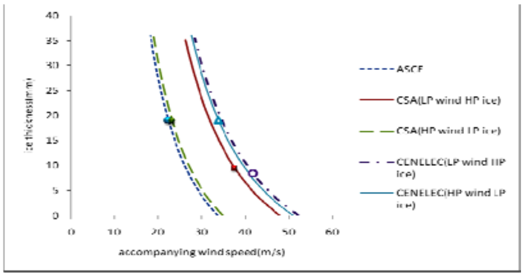

Figure 2: Boston 50 year return period wind on ice load (kN) as a function of wind speed (m/s) and ice thickness(mm).

3. CONCLUSION

The paper presents a summary of the results of a study that compares design criteria for electric transmission lines for several cities across North America using four different codes, The results indicate that there are significant differences in the load levels obtained with different codes and that this can translate into different levels of reliability for transmission lines.

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Seyedeh Nasim Rezaei and Luc Chouinard
Department of Civil Engineering and Applied Mechanics
McGill University
Montreal, Quebec, Canada
Seyedeh.rezaei@mail.mcgill.ca
Luc.chouinard@mcgill.ca

Frédéric Légeron
Département de génie civil
Université de Sherbrooke
Sherbrooke, Quebec, Canada
Frederic.Legeron@usherbrooke.ca

***Abstract*— This paper deals with reliability based criteria for the design of overhead electric transmission lines relative to atmospheric hazards. The main objective of this paper is to study and compare various approaches and criteria for atmospheric hazards which are used in current codes such as ASCE74, CSA/CAN, IEC and CENELEC and to discuss their impact on overall line reliability.**

Keywords-transmission lines; reliability; wind; ice

I. Introduction

Operational experience with electric transmission lines in harsh climates indicates that one of the principal causes of structural failures is weather events which generate loads that exceed the structural loading design criteria. In recent years, many examples of long return period (low probability) wind and ice storms have been reported such as the ice storm in Montreal, New York, New England areas in 1998 which had a return period of approximately 200 to 500 years [1]; and the wind storm in France in 1999. The interruption in the delivery of electric power caused by structural failures during these storms had a significant impact on local economy.

Over the past several years, professional societies and standard writing organizations such as ASCE, CSA, IEC and CENELEC have published guidelines for the development of loading criteria for overhead transmission lines. All the aforementioned standards apply reliability concepts and probabilistic methods to provide design criteria; however they differ in some aspects such as the wind speed time averaging period, the reliability levels and the application of different combinations of wind and ice to assess the combined wind on ice loads. The main purpose of the present study is to review the statistical methods proposed by each code and to compare their influence on overall line reliability.

II. Brief Review of the Codes

A. Selection of reliability levels

Transmission lines can be designed for different reliability levels depending on the line importance within a supply network.

CSA, IEC and CENELEC guidelines generally propose three reliability levels which are characterized by return periods of 50, 150 and 500 years for the climatic limit loads, while ASCE specifies six reliability levels in accordance with load return periods of 25, 50, 100, 200, 400 and 800 years. In all cases, the electric transmission lines have loads specified for a return period of 50 years with adjustment factors to climatic loads for return periods other than 50 years [2, 3, 4, 5].

B. Climatic loads

Weather related loads that are considered in this article are wind alone, ice (or snow) and ice (or snow) with accompanying wind. ASCE also considers high intensity winds such as tornados, microbursts and downburst but these are beyond the scope of the paper.

1) Wind and associated temperature:

The load (F in Newtons) due to the effect of the wind pressure upon a wind span length of (L) and acting at a right angle with the conductors is given by the following expression.

$$F = 0.5\, \gamma_w\, \rho\, C_D K_Z G_C G_L V^2 D\, L \qquad (1)$$

where

γ_w = the load factor to adjust the force, F, to the desired return period

ρ = the air mass per unit volume equal to 1.225 kg/m^3 at a temperature of 15 °C and an atmospheric pressure of 101.3 kPa at sea level

C_D = the drag (or pressure) coefficient depending on the shape and surface properties of the element being considered

K_Z = the velocity pressure exposure coefficient, which modifies the basic wind speed for various heights above ground and for different exposure categories

G_C = the gust response factor

G_L = span factor

D = diameter of the conductor (m)

L = the wind span of the supports (m)

V = the reference wind speed (m/s) corresponding to a return period T

The proposed values for the mentioned parameters are different in the codes. A numerical case study is carried out in this paper which illustrates the different trends of the codes in considering these variables.

Regarding the reference wind speed, ASCE suggests using a 3 second gust at 10 meters above ground and in flat and open country terrain (exposure C) and associated with a 50 year return period, while CSA and IEC use wind speeds with an averaging period of 10 minutes, and CENELEC enables the designers to use either a 2 second gust or an average 10 minute wind as the reference wind speed.

2) Ice without Wind:

Four categories of atmospheric icing are considered in design guidelines (freezing rain, in-cloud-icing and wet and dry snow). Ice data is usually expressed as a uniform radial thickness around the conductor t (mm), or as the weight per unit length of the conductor, g (N/m). Equation (2) defines the relationship between g and t.

$$g = 9.82 \times 10^{-3}\, \delta\, \pi\, t\, (D + t/1000) \qquad (2)$$

where

δ = the ice density (kg/m^3)
D = the conductor diameter (m)

In order to adjust the ice load to the desired return period, the codes propose different load factors to apply on the weight or the thickness of the ice [2, 3, 4, 5].

3) Combined wind and ice loadings:

The force (F) in Newton due to wind pressure on an ice covered conductor is defined by Equation (3).

$$F = 0.5\, \gamma_w\, \rho\, C_D K_Z G_C G_L V^2 (D+2t/1000)\, L \qquad (3)$$

Where

t = the uniform radial ice thickness (mm)

Although there has been several developments in statistical analysis of extreme wind and icing over the past several years, and that several national and international standards have provided designers with 50 year return period extreme wind speed and ice thickness maps [2, 3], there are significant gaps in the assessment of combined wind and ice loads.

Considering that there is a small probability for extreme winds and extreme ice to occur simultaneously, it is reasonable to reduce both wind speeds and ice thickness to establish realistic combined loads for design purposes.

All the codes reviewed in this paper agree that the most accurate way to assess combined wind and ice loads is using statistical analysis of wind and ice data during storms. Following this approach, a subcommittee of ANSI/ASCE7 compiled the 50 year return period extreme radial ice thicknesses combined with 3 second gust velocities map for the USA [2]. In cases where direct measurements of wind speeds during ice storms are not available, codes recommend to combine these variables such that the return period of the combined event is appropriate for each reliability level.

At least three variables are involved in calculating loads due to wind on ice covered conductors: wind speeds accompanying the icing phenomenon, ice weight and ice shape (the effect of drag coefficient). CSA, IEC and CENELEC assume that maximum loads are most likely related to combinations involving a low probability value of one variable (associated with a return period of T) combined with high probability values of other variables (with reduced return periods). As the marginal distributions for wind speed and ice thickness are not readily available, high probability events are assumed to be equal to the corresponding extreme values multiplied by a reduction factor. Following this description, CENELEC takes into account two main combinations [5]:

- An extreme ice load with a return period of T combined with a moderate wind load with a reduction factor equal to 0.4 which corresponds to a moderate wind speed taken as 0.55 to 0.65 times the extreme wind speed depending on the type of ice.
- A high wind speed corresponding to 0.7 to 0.85 times the extreme wind speed combined with a moderate ice load with a reduction factor equal to 0.35.

The temperature to be considered for calculating the combined wind and ice loads is 0°C.

CSA and IEC also consider the same two scenarios but with different factors [3, 4]:

- A low ice probability (return period T) associated with the average of yearly maximum winds during icing presence which is assumed to be equal to 0.4 to 0.5 times the extreme wind speed.
- A low probability wind during icing (return period T) which is assumed to be equal to 0.6 to 0.85 times the extreme wind speed combined with 0.4 times the extreme ice load that corresponds to the average of the yearly maximum icing.

The coincident temperature is taken equal to -5°C.

III. NUMERICAL COMPARISON

Transverse wind loads on bare and ice covered conductors and vertical loads due to ice accumulations for a typical transmission line with 450 meters wind span and 540 meters weight span at an effective height of 25 meters in several cities of America are calculated based on data provided by ASCE maps. The conductor diameter is assumed to be 30 (mm) and the coincident temperature for calculating wind loads on bare and ice covered wires are 15°C and -5°C, respectively. The meteorological data are measured at stations located in flat and open terrain which corresponds to exposure category "II" in CENELEC, "C" in ASCE and "B" in CSA. The drag coefficient is set equal to "1.0" when in reality this coefficient is highly variable depending on the form of ice accumulation and wind speed. The climatic loads are assessed for all four standards mentioned before and for their suggested return periods using Equations (1), (2), and (3). The values of span factor, gust response factor and adjusting load factor can be estimated according to each standard.

Figure 1 indicates the comparison of transverse wind loads (kN) on bare conductors for Boston with a 3 second gust speed equal to 47.4 (m/s). It is inferred that CSA has the most conservative trend while ASCE is the least conservative. The comparison of vertical loads due to ice accumulation and transverse wind loads on ice covered conductors are respectively illustrated in Figures 2 and Figure 3, ASCE proposes a 50 year return period ice thickness equal to 19 (mm), and a coincident 3 second gust speed of 22.4 (m/s) for Boston. Figure 2 suggest that ASCE is very conservative relative to vertical loads for large return periods, while CSA and CENELEC result in similar load levels. In Figure 3 "load case 1" and "load case 2" correspond to a low probability wind accompanying a high probability ice and a high probability wind coincident with a low probability ice, respectively

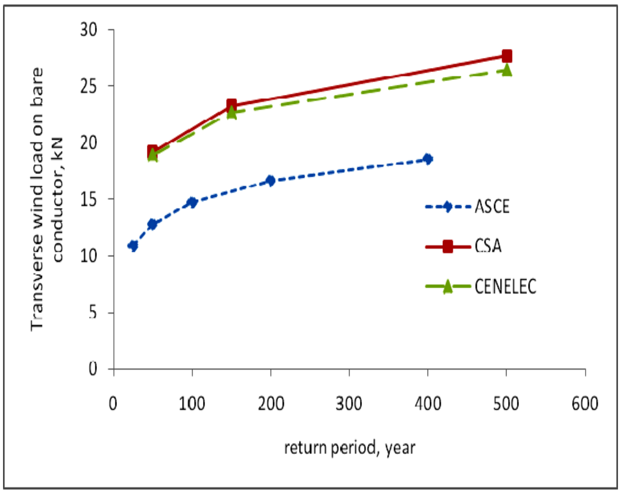

Figure 1: Comparison of transverse wind loads (kN) on bare conductors for selected return periods according to different codes.

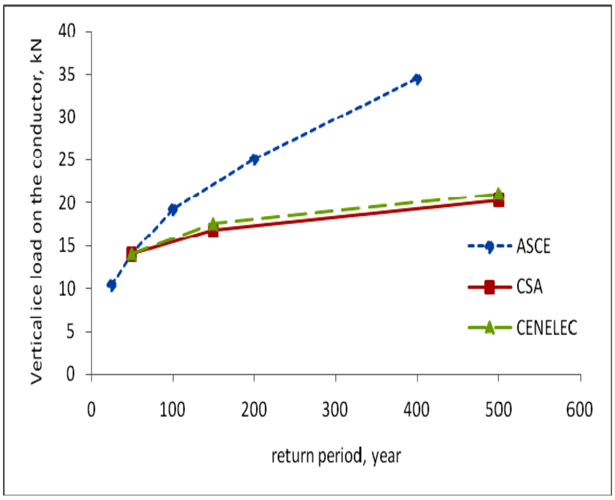

Figure 2: Comparison of vertical ice loads (kN) on conductors for selected return periods according to different codes.

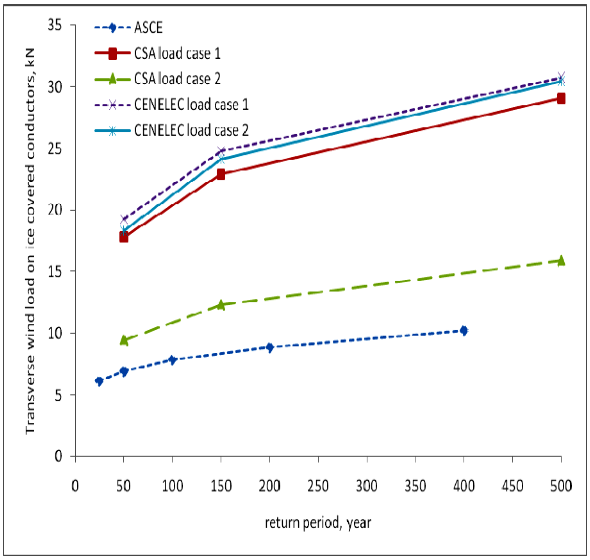

Figure 3: Comparison of transverse wind loads (kN) on ice covered conductors for selected return periods according to different codes.

. Figure 3 indicates that ASCE provides for much smaller values for wind on ice and that CENELEC and CSA have similar load levels (load case 2).

Figure 4 shows the combinations of wind speed and ice thickness according to the different codes for a return period of 50 years. Also shown are the lines corresponding to all possible combinations of wind and ice that result in the same load level. This figure indicates that the two load cases of CENELEC are very consistent in terms of load levels. The CSA load cases on the other hand have similar return periods for the combination of wind and ice events but correspond to load levels with different return periods.

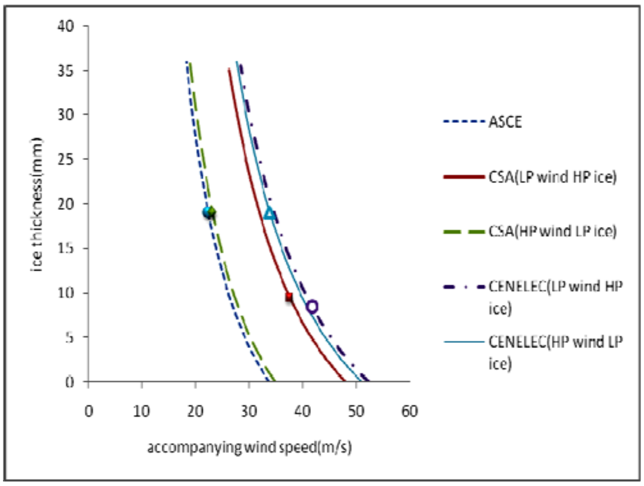

Figure 4: Boston 50 year return period wind on ice load (kN) as a function of wind speed (m/s) and ice thickness (mm).

The load case 1 of CSA provides for similar load levels to ASCE.

IV. Conclusions

The paper presents a summary of the results of a study that compares design criteria for electric transmission lines for several cities across North America using four different codes, The results indicate that there are significant differences in the load levels obtained with different codes and that this can translate into different levels of reliability for transmission lines. Other design factors in design that can affect the level of reliability of transmission lines will be investigated in the next phase of the project.

Acknowledgements

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