Technical Brief

State of the Art Report on Designing Transmission Lines for Wet Snow Accumulation

Transmission Overhead Line Design & Extreme Event Mitigation

Project No. T153733-33/101

Report Background

Wet snow occurs in any region of the world where snow falls at ambient temperatures of around 0ºC. Wet snow may be sticky and easily adhere to exposed objects, such as electric transmission lines. Significant loading on transmission lines may result from wet snow accumulation, especially on conductors and ground wires; therefore, transmission lines must be designed to withstand such loads.

Severe events of wet snow are reported for all continents in the northern hemisphere; several cases have also been registered in New Zealand and South Africa. A wet snow storm in Germany and some neighboring countries that occurred in 2005 made record as the most severe wet snow storm, in terms of total damage and economic consequence. Five 110 kV lines owned by the large utility RWE were damaged, and 83 steel lattice towers failed. This case clearly illustrates that wet snow icing can strike a region suddenly, even in cases where past incidents have been limited.

It has been identified that wet snow accumulation is not sufficiently addressed in the current transmission line design standards. As such, this report aims to identify the gaps that must be closed in order to improve the reliability of modern transmission networks. The objective is to provide a description of state of the art methods for designing transmission lines for wet snow accumulation, and to make recommendations that may improve current industry standards.

Summary

Wet snow accretion occurs when partly melted snowflakes collide with an object and adhere to its surface after collision. Accretion tends to build on the tops and windward surfaces of structures, as well as in the form of cylindrical accretions around high voltage conductors and overhead ground wires. It also forms on trees and can cause them to fall onto distribution lines.

The density of wet snow can vary from 100 - 850 kg/m^3, with the highest density usually relating to high wind speeds that compress the accreted snow layer. A process of cylindrical accretion can lead to very high loads being reached in a matter of hours.

While severe events involving wet snow are reported for all continents in the northern hemisphere, in addition to several cases in New Zealand and South Africa, the wet snow storm in Germany and some neighboring countries in 2005 (fig. 1) was the most severe wet snow storm in terms of total damage and economic consequence. Such failures clearly illustrate the importance of taking wet snow loads properly into account in the design of overhead transmission lines.

Figure 1: Wet snow in Germany, November 2005 (from Cigré TB 344).

In addition to reviewing generally available and relevant information regarding the occurrence of wet snow on transmission lines and failures caused by wet snow events, the scope of the investigation included review, utility design practices, methods and models for predicting anticipated loads caused by wet snow events, as well as a comparison of the ice load requirements between the national and international codes and guides. It also involved the proposal of a methodology to determine the probabilistic wet snow loadings to be considered in the design of transmission lines. Furthermore, methods for the refurbishment of existing installations are discussed, and improved design requirements for new and existing lines are recommended.

The report provides a detailed literature review of the physical phenomenon of "wet snow icing." While aspects of the literature review are devoted to understanding wet snow icing and its relation to meteorological conditions, important methods are described for taking wet snow icing into account in the design of transmission lines. Aspects of the wet snow accretion mechanisms are complex, such that practical models require a combination of theory and empirical relations. Therefore, a variety of models and parameter settings have been proposed in the literature. Based on a review of the literature, the most recently published papers on the respective subject are recommended.

For practical application, examples are provided for modeling wet snow icing, based on:

- Weather station data.
- Data from Numerical Weather Prediction (NWP) models.

Furthermore, the report discusses important aspects of the various statistical methods employed in the calculation of design values.

A questionnaire was distributed to a large number of international utilities in order to obtain a global perspective regarding the occurrence of wet snow accretion on electric overhead line conductors, and to identify variations in design codes and practices for wet snow load assessments. The survey is broken into six parts:

1. Part A: Wet snow loadings as treated in design codes, standards, and operational experience.

2. Part B: Occurrence of wet snow.
3. Part C: Collection of specific data for wet snow load assessments.
4. Part D: Restoration measures.
5. Part E: Electrical failures due to wet snow.
6. Part F: Wet snow Removal.

The report provides a review of how wet snow loads are treated under international industry standards, as well as in some national annexes. The utility survey shows that wet snow loads are considered differently amongst utilities, varying from country to country. In some wet snow prone regions, a map or the tabulated reference values of characteristic wet snow loads are provided according to area and altitude, while in other regions wet snow load is indirectly taken into account through the line design. This section also discuss how the design codes deal with concurrent ice loadings and perpendicular wind speeds

Due to the socio-economic effects resulting from the outages of electric power supply in connection with severe ice accretions on electric overhead lines, there have been many attempts to develop and test various methods and devices for both preventing ice formation on the conductors, and removing ice from the lines whenever excess loads are threatening the safe operation of the line. Such methods can be either mechanical or electrical. A review of such mitigations methods is presented in the report, divided into mitigation measures in the pre-construction phase, as well as the mitigation measures for lines in operation. Examples of recent field experiences including mitigation measures are presented from Norway and Iceland. One of the cases demonstrates how the wet snow design loads were reviewed using a wet snow model forced with data from a numerical weather prediction model.

Conclusions

Over the expected lifetime of a transmission line, the probability of a severe wet snow event remains significant and must be considered in its design, even though other typer of atmospheric icing (such as freezin rain) is much more frequently observed.

Regional or national maps of wet snow occurrence and its extreme value distribution can be made based on a dense network of weather stations and/or hindcast archives from NWP model simulations, as exemplified for Britain in Figure 2. Mapping of wet snow icing should be carried out in all regions where it may occur and affect the reliability of power lines. From the author's point of view, it is necessary to treat the load case of wet snow according to the climatic conditions of the specific region or country, simply because wet snow may vary by an order of magnitude in density, while its frequency, magnitude, and duration is highly variable between different climatic zones. This also affects a combined load case with extreme wind, and the specific reduction factors that should be applied.

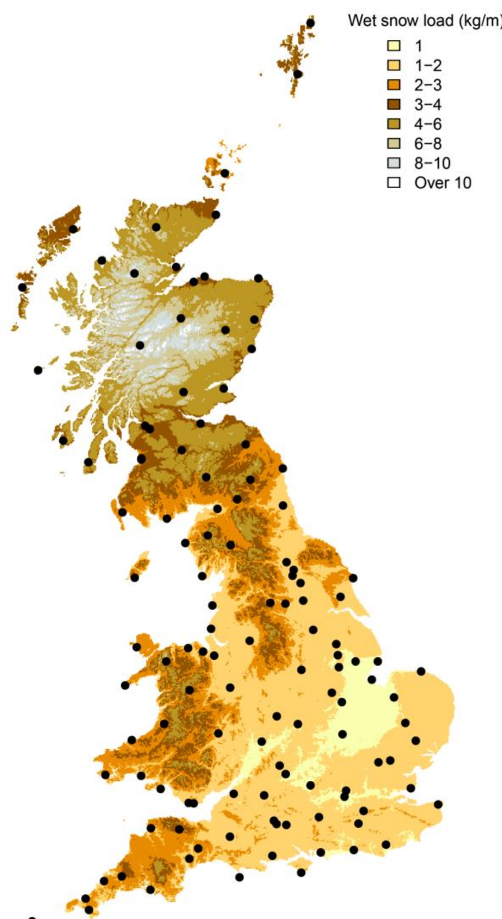

Figure 2: Estimated wet snow load in Britain with 50-year return period interpolated to a regular grid of 500m resolution. Black dots: Locations of the weather stations used in the analysis.

Wet snow loads are mentioned as one possible icing type to consider in international standards, such as IEC 60826 or CENELEC (EN 50341-1). Several European countries treat wet snow specifically in their "National Normative Annex (NNA)," included in EN 50341-1. Wet snow loads are considered differently amongst utilities, varying from country to country. In some wet snow prone regions, a map or the tabulated reference values of characteristic wet snow loads are provided, while in other regions wet snow load is more indirectly taken into account in the line design. The report shows that international standards use significantly different factors for converting the ice loads to return periods different than 50 years.

Regarding the reviewed literature, no fully reliable method for preventing icing on overhead line conductors or for removing formed ice was found. The most effective mitigation method seems to be designing the line according to the expected loadings in the area. This includes determining the configuration and taking into account the topography and the prevailing exposure and wind direction. In critical situations, de-icing measures (such as joule heating or mechanical ice removal) are actively used in various countries.

Recommendations

Since wet snow, freezing rain, and rime ice result from different physical processes, their statistical properties accordingly differ. Extreme values must therefore be calculated individually for each process.

Measurements of wet snow icing can be performed where icing is frequent, preferably through the use of test spans instrumented with load cells and data loggers. The greatest potential for improving the data collection of local wet snow icing conditions is through combining a measurement campaign with a model study, such that a wet snow accretion model is coupled to an NWP model.

A fixed ice density of 900 kg/m3, which is used in many standards for calculating wind pressure on iced conductors, is not applicable for wet snow icing. Wet snow icing normally has a considerably lower density. A site specific value can be calculated from meteorological data.

Joule heating may be effective during the early stage of an icing event in preventing or delaying icing. However, as soon as a cylindrical wet snow sleeve has been formed around the conductor, Joule heating is less efficient as a mitigation method

In case of failure or collapse due to wet snow, it is important to review designs for wet snow loadings in the restoration process. Analyses of design loads should take local conditions into account, including prevailing wind direction during icing, and its normal component to the transmission line. If there is a lack of reliable and representative weather station data, studies using NWP models must be considered.

CEATI International Inc.
1010 Sherbrooke St. West, Suite 2500
Montreal, Quebec, Canada H3A 2R7

Phone +1 (514) 866-5377
Fax +1 (514) 904-5038

www.ceati.com // info@ceati.com

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