A UK PROBABILISTIC WIND/ICE MAP

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Abstract:
Currently UK electricity utilities have to build new lines to BSEN50341 and 50423 standards using either the 'general' a pproach to line design (BS8100) or the deterministic 'empiri cal' approach using fixed wind/ice parameters. Currently UK medium voltage lines use a deterministic approach. CENELEC standards allow alternative line designs if evidence can be given of wind/ice loads for the UK. The European Union COST727 project provided the modelling tools necessary to develop a wind/ice map of the UK which will relate weathe r data to conductor ice loads. EA Technology Ltd, UK, has started a Strategic Technology Programme project using these tools to develop such a map. This will allow return periods of wind/ice loads to be evalua ted on a geographical basis. Future UK line design can follo w these new wind/ice loads which are expected to be less onerous than those predicted by the current UK building sta ndard BS8100. The WRF-based icing model developed at the Norway Meteorological Institute under the COST progra mme will be applied to the UK OHL network with the aid of Svein Fikke, a consultant meteorologist who has worked on ice load predictions for Norway and Greenland for many years. The project is currently in the second of three stages . It uses UK meteorological office historical data as well as historical and current data from an EA Technology test site at Deadwater Fell on the English/Scottish Border in the UK. To date preliminary predictions of past events using the WR F model and the Makonnen and Admirat models have proved accurate. The recent severe winter in the UK has also prov ided data from the Deadwater site which monitors ice loads on conductors on a 190m span as well as full meteorological data and video camera coverage.

1. INTRODUCTION

Within the CENELEC standards EN50341 and 50423, the UK must apply wind/ice loads to its overhead line network according to either probabilistic or deterministic principles. Previously, the UK approach had been based on a semi-probabilistic approach from initial deterministic values. Using these principles, UK transmission lines have survived up to 70 years with virtually no problems with wind/ice loads. The distribution network built to 1947 deterministic principles had suffered problems but lines designed since 1988 to the semi-probabilistic method had proved resilient. However, the necessity to build all new lines to the current CENELEC standard meant using the weather loads under BS8100 which entailed much heavier weather loads. Due to the consistent performance of UK lines to the previous standard and the much higher cost of building to BS8100, it was decided to start a project to investigate probabilistic wind/ice loads for the UK based on historical data and snow/ice accretion models developed under the European Project COST727. The procedure to combine modern weather forecasting models with detailed topography and conventional ice accretion models for overhead line design purposes was suggested by Fikke. This paper describes a current project run under a Strategic Technology Programme (STP) by EA Technology Ltd, where this procedure is being used to revise wind and ice loading maps for UK

This paper covers the current position of this project which is intended to form a revision of the current UK wind and ice loads.

2. TASKS

The project was divided into 3 stages with an optional fourth stage intended to embed the project data into design software. The stages are:

1. Project strategy and related interfaces
2. Analyse model performance and develop procedures
3. Production of a conductor load wind/ice map of the UK
4. Embed wind/ice loads into design software

Currently the project is part way through its second stage.

3. CONCLUSION

This paper describes the first stage of a large project run under a Strategic Technology Programme (STP) by EA Technology Ltd of UK, which may form a revision of the current UK OHL conductor wind and ice loads. Details of major wind/ice incidents dating back to 1870 have been located and, along with UK and Norwegian Met Offices and Deadwater Fell data have been used in developing rime ice and wet snow models. Specific historical wet snow and rime ice incidents have been modelled in detail. Data on extreme winds in the UK have also been obtained. The final outcome of this work is to develop new wind/ice loads which are expected to be less onerous than those predicted by BS 8100 and further can be used to update BS EN 50341 and BS EN 50423 standards.

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Abstract—
Currently UK electricity utilities have to build new lines to BSEN50341 and 50423 standards using either the ‘general’ approach to line design (BS8100) or the deterministic ‘empirical’ approach using fixed wind/ice parameters. Currently UK medium voltage lines use a deterministic approach. CENELEC standards allow alternative line designs if evidence can be given of wind/ice loads for the UK. The European Union COST727 project provided the modelling tools necessary to develop a wind/ice map of the UK which will relate weather data to conductor ice loads. EA Technology Ltd, UK, has started a Strategic Technology Programme project using these tools to develop such a map. This will allow return periods of wind/ice loads to be evaluated on a geographical basis. Future UK line design can follow these new wind/ice loads which are expected to be less onerous than those predicted by the current UK building standard BS8100. The WRF-based icing model developed at the Norway Meteorological Institute under the COST programme will be applied to the UK OHL network with the aid of Svein Fikke, a consultant meteorologist who has worked on ice load predictions for Norway and Greenland for many years. The project is currently in the second of three stages. It uses UK meteorological office historical data as well as historical and current data from an EA Technology test site at Deadwater Fell on the English/Scottish Border in the UK.To date preliminary predictions of past events using the WRF model and the Makonnen and Admirat models have proved accurate. The recent severe winter in the UK has also provided data from the Deadwater site which monitors ice loads on conductors on a 190m span as well as full meteorological data and video camera coverage.

Keywords-component; modeling, snow/ice loads, validation, tests site data

I. Introduction

Following the CENELEC standards EN50341 and EN50423, the UK must apply wind/ice loads to its overhead line (OHL) network according to either probabilistic or deterministic principles. Previously, the UK approach had been based on a semi-probabilistic approach from initial deterministic values. Using these principles, UK transmission lines have survived up to 70 years with virtually no problems with wind/ice loads. The distribution network built to 1947 deterministic principles had suffered problems but lines designed since 1988 to the semi-probabilistic method had proved resilient. However, the necessity to build all new lines to the current CENELEC standard meant using the weather loads under BS8100 which entailed much heavier weather loads. Due to the consistent performance of UK lines to the previous standard and the much higher cost of building to BS8100, it was decided to start a project to investigate probabilistic wind/ice loads for the UK based on historical data and snow/ice accretion models developed under the European Project COST727.

The procedure to combine modern weather forecasting models with detailed topography and conventional ice accretion models for overhead line design purposes was suggested by Fikke in [1]. This paper describes a current project run under a Strategic Technology Programme (STP) by EA Technology Ltd, where this procedure is being used to revise wind and ice loading maps for UK. The STP is a partnership between EA Technology and the UK Utilities (Members of the STP) which consists of Scottish & Southern Energy, Electricity North West Ltd ……….etc . Mr John Baker from Scottish and Southern Energy is the Project Champion representing the STP Members. Other members of the working group are Mr Antony Veal, UK Met Office, Mr Bjørn Egil Nygaard and Ivar Seierstad of the Nowegian Met Office etc. Mr David Horsman, EA Technology is the Project Leader for the work.

This paper covers the current position of this project which is intended to form a revision of the current UK wind and ice loads.

II. Project Status

A. Stages

The project was started in October, 2009, and was divided into 3 stages with an optional fourth stage intended to embed the project data into design software. The stages are:

1. Project strategy and related interfaces
2. Analyse model performance and develop procedures
3. Production of a conductor load wind/ice map of the UK
4. Embed wind/ice loads into design software

Currently the project is part way through its second stage.

B. Tasks

The main tasks under the first stage of the project were:

1. Obtain specific requirements of UK OHL engineers with regard to conductor wind/ice loads and form of final 'atlas'.
2. Cooperate with UK Distribution Network Operators (DNOs) and the Norwegian and UK Met Offices to determine project strategy and availability of data required.
3. Develop strategy for development of atlas and possible associated software
4. Develop Stage 2 strategy.

This stage was completed by July, 2010, and the Stage 2 strategy was laid out according to the following tasks:

1. Define structure for the Weather Research and Forecasting (WRF) model for Stage 3 processing.
2. Selection of wet snow models based on Stage 1 input
3. Set-up and tests of final wet snow model tools at UK Met Office.
4. Presentation of extreme winds based on UK input.
5. Procedure for selecting combined wind/ice loads. This will be determined by investigating the methods used in UK standards ET111 and ENATS 43-40 and CENELEC standards EN 50341/EN50423 as well as in other countries.
6. Discussion of preliminary results, related to current design practices. The results will be applied to specific areas and compared with ENA TS 43-40 and BS8100 data.
7. Presentations to UK STP Members to keep them updated with progress and how the wind/ice loads determined by the project affect their areas.
8. Detailing Stage 3 work plan. This will be based on the Stage 2 progress and output and input from UK DNOs.

In Stage 1, data was located on UK wind/ice events that affected overhead lines since 1870 as well as detailed meteorological data and conductor wind/ice loads from the EA Technology Deadwater Fell Test site (Figure 1). This data was used to validate the snow/ice models and test their ability to take the current weather data and predict the ice loads on the conductors. The Deadwater Fell severe weather test site is described in another paper at this and a previous IWAIS [2, 3].

Figure 1 The EA Technology Deadwater Fell Site

III. Modelling Results

A. Wet snow modelling

Two versions of a simple wet snow model have been coded and tested on three different UK incidents where snow and ice loadings have been reasonably well documented in old reports. The three incidents covered the periods December 1981 – January 1982, January 1984 and December 1990 as well as data from selected weather stations in the affected regions which have been provided by the UK Met Office. The data include the following parameters:

- Temperature;
- wind direction;
- wind speed;
- precipitation amount;
- relative humidity;
- visibility;
- sea level pressure;
- present weather code and past weather code.

The above data was necessary to drive the wet snow models.

The two models used are referred to as the Admirat and the Makkonen models, both of which are fully described in Cigré Technical Brochure 291 [4]. The Admirat model was first presented at the 4th International Workshop on Atmospheric Icing of Structures in Paris 1988 by Pierre Admirat [5] but is also explained in [6]. It is a simple cylindrical accretion model that gives the accumulated snow load on a horizontal cylinder/conductor based on information about wind speed, temperature, humidity and precipitation amount. The latter is used to estimate the snow content in the air during the accretion period. Collection efficiency is assumed to be inversely related to wind speed by $\beta=1/U$, and the density as a function of the wind speed by $\rho=200+20U$.

One example of preliminary results is given in Figures 2 and 3. The two models have been tested on the January

1984 incident when overhead lines suffered extensive damages on several occasions. In this period there were two storms which caused major system emergencies, those of 2-3 January and of 21-22 January, as well as a period of relatively minor storms in the period 11 - 17 January. As seen from the figures both models pick out the three main periods of wet snow accretion during January 1984 quite well. There is however a difference in iceload between the two models of almost a factor of three. This difference is probably caused by different criteria used to identify wet snow in the current set up of the models. There is no precise criterion defined in the literature, but Makkonen argues that one necessary but not sufficient criterion is that T_w (Wet bulb temperature) is positive. For a conservative model he uses $T_w > -0.2$ ºC. In the current setup of the Admirat model the wet snow criteria are defined as -0.2 ºC $< T_w < 2.5$ ºC and $P > 0.1$ mm per hour. In the Makkonen model $T_w > -0.2$ ºC and snow or sleet observed at the observation time.

Another sensitive part of the model is the process of ice shedding/melting. In the current set up the ice is assumed to shed from the conductor immediately when $T_w > 3$ ºC. An allowed persistence time is also included for the ice deposit. In the examples given here the maximum persistence time is set to 24 hours. In Figure 4 the persistence time is set to infinity, which means that snow is removed only when $T_w > 3$ ºC.

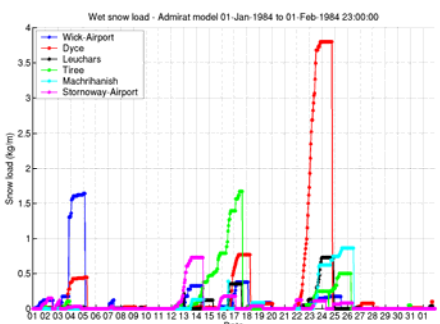

Figure 2 Admirat model

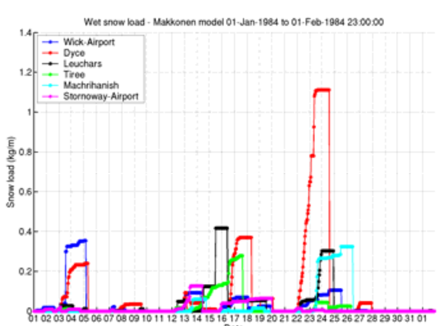

Figure 3 Makkonen model

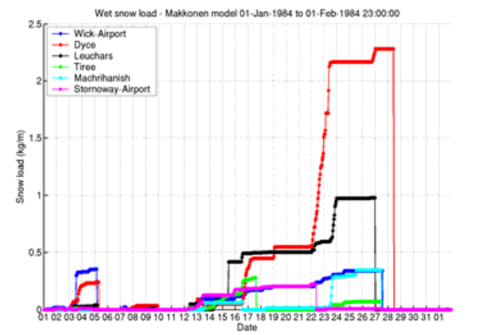

Figure 4 As figure 3 but now without any restriction to persistence time.

Similar results have also been produced for the snow storms in December 1981 and in December 1990. In the next step the main focus was to optimise the models with respect to criteria for wet snow, temperature limits and persistence time to match the observed features of the three storms more closely.

B. Rime ice modelling using WRF

The latest available version of the WRF modelling system, WRF-ARW version 3.2, has been set up over the British Isles as shown in Figure 5. The model is configured with a triple nested model domain, indicated with the blue, green and red squares. The area inside the red square is divided into 581x709 grid boxes with 1.5 km grid spacing, and the atmosphere is divided into 32 vertical levels. A horizontal grid spacing equal to 1.5 km is considered as a very high resolution, and requires extensive computational power, but it is required in order to resolve the local terrain induced vertical motions that cause in-cloud icing.

The model is also set up with the Thompson cloud microphysics scheme which has shown to be very well suited for icing application through tests performed within the framework of the COST-727work.

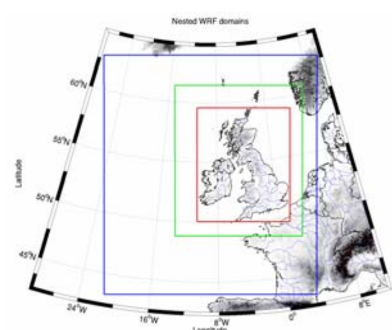

Figure 5 Nested WRF domain over the British Isles

In-cloud icing (rime icing) is a very local phenomenon which is often observed, but rarely measured at ground level, and cannot easily be parameterized based on routinely measured meteorological data. It was therefore decided to apply the WRF model as a tool to predict this type of icing. The main idea of the simulations is to identify which areas that are exposed to in-cloud icing and also try to identify to what extent in-cloud icing is the dominant icing process for those areas. Line design is based on maximum loads over a certain return period and it is necessary to determine whether this load will be due to wet snow or rime icing according to the particular areas considered. Data from the test site at Deadwater Fell will be used to identify the icing episodes that will be subject for model simulations, and the load measurements at the site will be used to validate and calibrate the post processing of the model results

Based on the data from Deadwater Fell from the winter season 2009/2010 one first test case was selected: 11-14 of January 2010. A preliminary result from this test simulation is displayed in Figure 6. Icing severity is divided into three levels; light, medium and high, based on the accumulated iceloads calculated by the post processing algorithm (based on the Makkonen rime icing model).

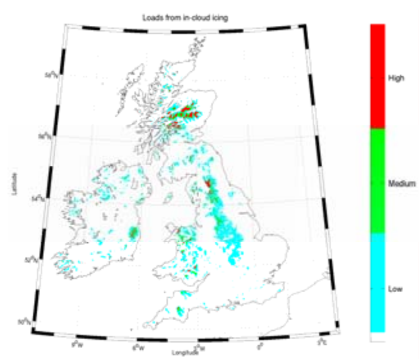

Figure 6 Preliminary results based on a simulation for January 11th to January 14th 2010.

In the next stage of the project, more icing events will be selected from the Deadwater Fell data and simulated with the same model setup. A compilation of all the cases will form a basis for estimating a climatological map of in-cloud icing severity.

C. Data for Extreme Wind Speeds

It had been assumed that the main source of data on UK wind speeds would be the UK Met Office. However, this was found not to be the case. As a result, the UK wind loading standard for buildings (BS 6399-2) was investigated. This used the wind code CP 3-V-2 up to its withdrawal in 2001. A revised version of BS 6399 was then issued in 2002 [Superseded by Loading for Buildings CoP: BS EN 1991-1-4:2005.]. This included a data base of wind speeds and direction throughout England, Wales and Scotland but did not include Northern Ireland. A software package BREVe3 was based on this and delivers effective wind speeds and dynamic pressure to a resolution of 1km for the whole of the UK. The software includes the Ordnance survey database of ground roughness and topography. Data is obtained by inputting the UK grid reference.

IV. UK Conductor Weather Loads

Conductor weather loads in the UK are historically based on a wind/ice load. Utilities are also interested in wind only loads. Wet snow has normally been taken as the source of the heaviest loads that a line will suffer over a 50 year period. However, in-cloud or rime icing is more common at higher altitudes and may even provide the greatest loads there. This project looks at all ice types, including glaze icing which is relatively rare in the UK but can provide severe loads.

Atmospheric icing: BS8100 gives weather data based on wind and ice only and wind & ice combined. The project has focussed initially on the icing conditions in the UK in collaboration with UK Met Office.

Wind: BS6399-2 and the associated Breve3 software will be investigated along with Eurocode BSEN 1991-1-4:2005 which gives the methods applied.

Combined wind and ice loads: This will be evaluated after separate assessments of extreme values of wind loads and ice loads. By ‘extreme values’ is meant the major snow and ice events which have caused major disruption i.e. ‘normal’ snow and ice events will not be considered as they have no effect on OHL design.

Icing types: Historically the main problems to the UK OHL network come from wet snow and occasionally glaze ice with rime ice possibly a major problem above certain altitudes.

The main data analyses will be performed by the UK Met Office using selected model studies, mainly the WRF model.

V. Methodology

A. General

The following methodology will be carried out but this is open to amendment and adjustment as the project progresses.

B. Wet Snow

The first step was to identify severe wet snow episodes from EA Technology reports and Deadwater Fell test station data. Different approaches were also used, based on the models of Admirat [6], Makkonen and Wichura [5]. These have been tested on specific wet snow cases.

A further approach was based on determining the snow loads directly from a numerical weather prediction (NWP) model. To model the wet snow accretion on power lines the parameters normally required are temperature, wind speed, precipitation rate, wet bulb temperature (or alternatively pressure and relative or specific humidity) and visibility (if available). In the first stage of the project these variables were taken from representative weather stations. The UK Met Office has several different data sources available for this project. These enabled interpolated data to be used in grid points covering the whole of UK, as well as regular observations from a dense network of weather stations. If any of the high resolution dataset is suitable, the wet snow model driven by the NWP output will be used and compared with the wet snow model from observations.

C. *In-cloud icing*

The procedure to study in-cloud icing further is to:

1. Use the reference station Deadwater Fell for case studies;
2. Investigate a selection of weather situations;
3. Perform WRF simulations of selected episodes to gain knowledge about in-cloud icing incidents, preferably from widely spread geographical locations in the UK. This will help to identify critical land heights in-cloud icing.

D. *Extreme values and loads*

Line design is determined by the worst cases over an expected lifetime (or return period (RP)) of weather loads. These high load values (extreme values) will be analysed:

1. Wet snow: Calculate frequency of wet snow incidents from observations and/or high resolution model data. These wet snow incidents will be identified from the wet bulb temperature and precipitation rate. The snow load in these incidents will then be estimated based on the various accretion models.
2. Expected return values over the 50 year RP can then be calculated based on this extreme value analysis of the major annual wet snow loads. At this stage it is not decided whether to use weather station data or an analysed hindcast dataset for this purpose. This will depend on the availability of suitable time series data from the UK Met Office.
3. A selection of averages of these “wet snow” extremes (RP = 50 years) for the UK will then be related to known general patterns and wet snow levels in Europe.
4. In-cloud icing: WRF simulations may contribute to risk and exposure maps. Mapping of in-cloud icing risk (probability that the design load will be exceeded) will invariably involve a high degree of subjective expert knowledge.
5. Possible reduction factors due to wind direction will also be considered.

E. *Combined wind and ice load maps*

Combined wind/ice loads are the basis of UK line design. To obtain these from the separate snow/rime ice and wind data, the appropriate recommendations from IEC 60826 Ed 3:2003 [Design Criteria for Overhead Transmission Lines]will be used. This standard is currently under revision for this part, partly by Cigré SCB2 WG28 entitled “Meteorological data for assessing climatic loads” which includes the authors of this paper. The needs and input from the UK DNOs will be very important before settling this part.

VI. SUMMARY

This paper describes the first stage of a large project run under a Strategic Technology Programme (STP) by EA Technology Ltd of UK, which may form a revision of the current UK OHL conductor wind and ice loads. Details of major wind/ice incidents dating back to 1870 have been located and, along with UK and Norwegian Met Offices and Deadwater Fell data have been used in developing rime ice and wet snow models. Specific historical wet snow and rime ice incidents have been modelled in detail. Data on extreme winds in the UK have also been obtained. The final outcome of this work is to develop new wind/ice loads which are expected to be less onerous than those predicted by BS 8100 and further can be used to update BS EN 50341 and BS EN 50423 standards.

VII. ACKNOWLEDGMENT

The authors acknowledge the contributions of Ivar Seierstad and Bjorn Egil Nygaard of the Norwegian Met Office, Anthony Veal of the UK Met Office and David Horsman of EA Technology who is in charge of this project. The authors also acknowledge the permission of the EA Technology STP Members to produce this paper.

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