Cold Regions Science and Technology 153 (2018) 120–129

Contents lists available at ScienceDirect

Cold Regions Science and Technology

journal homepage: www.elsevier.com/locate/coldregions

Ice loads on overhead lines due to freezing radiation fog events in plains

H. Ducloux[a,*], B.E.K. Nygaard[b]

[a] *Réseau de Transport d'Electricité, Versailles, France*
[b] *Kjeller Vindteknikk, Kjeller, Norway*

ARTICLE INFO

Keywords:
Freezing radiation fog
Overhead line
Ice load
Rime deposit

ABSTRACT

The paper discusses specific ice accretion events that may occur in plains, i.e. freezing radiation fog events, whose worst cases can damage transmission overhead lines. A simple model is proposed able to estimate ice loads due to such events, based on standard meteorological observational data. The simple model has been validated by comparing ice loads estimated by the model with historical input data and ice loads estimated based on historical damages to overhead lines. It has been shown that its most promising application can be obtained by replacing the observed meteorological input data with similar parameters from an operational numerical weather prediction model. Such icing forecasts can be used to generate alarms to anticipate potential damage to overhead lines. This application was successfully tested on a significant freezing radiation fog event that took place in the northern half of France in the very beginning of 2017, using data issued from the French convective-scale numerical weather prediction model AROME (Application of Research to Operations at MEsoscale).

1. Introduction

Significant ice loads on overhead power lines are usually due to freezing rain, wet-snow, or in-cloud icing events (Makkonen, 2000; Fikke et al., 2016). In-cloud icing events occur where the cloud bases are located lower than the terrain height, which is very common in mountainous areas. Icing events are usually combined with strong winds, therefore the ice loads can pose real issues for the overhead lines built on such areas (Nygaard et al., 2011).

At the very beginning of 2017, another kind of icing event took place in the northern half of France: freezing radiation fog. The fog appeared during the night between the 28th and 29th of December 2016 and lasted several days. The event was responsible for more than 150 insulation faults, 40 of them permanent. 10 of the permanent faults were caused by damaged or broken conductors and earth-wires, as well as broken concrete poles. The wind speed during the event was very low, therefore models for in-cloud icing, as described in Makkonen (2000) or Finstad et al. (1988), are inadequate in order to directly estimating the ice loads causing the damages.

The objective of the paper is to propose a simple model able to estimate ice loads due to such freezing radiation fog events, based on standard meteorological observational data.

One particular freezing fog event that occurred in the beginning of 2017 in the area of Beauvais (a small city situated 50 km north-west of Paris) was used to compare the thickness of the rime deposit estimated by the simple model to real observations. The area of Chartres (another small city situated 75 km south-west of Paris) was disturbed by the 2017 event as well as another severe freezing radiation fog event in the beginning of 1990. The surface meteorological records of the local weather station were used to optimize the model with respect to the threshold for relative humidity.

The most promising application of the simple model can be obtained by replacing the observed meteorological input data with similar parameters from an operational numerical weather prediction model. Such icing forecasts can be used to generate alarms to anticipate potential damage to overhead lines. This application, as presented at the end of the paper, was successfully tested on the freezing radiation fog event of the beginning of 2017 using data issued from the French convective-scale numerical weather prediction model AROME (Application of Research to Operations at MEsoscale).

2. Development of a simple model dedicated to freezing radiation fog events

The objective is to develop a simple model that uses standard meteorological data as input, i.e. air temperature, dew point temperature or relative humidity, wind velocity, and precipitation intensity. Data used in the different studies presented in the paper come from either the Integrated Surface Database (Smith et al., 2011) or the AROME-France Convective-Scale Operational Model (Seity et al., 2011), both available in open data format.

The simple model is composed of three distinct parts:

* Corresponding author.
E-mail address: herve.ducloux@rte-france.com (H. Ducloux).

https://doi.org/10.1016/j.coldregions.2018.04.018
Received 19 December 2017; Received in revised form 26 March 2018; Accepted 28 April 2018

✓ Detection of weather conditions favourable to ice accretion
✓ Increase of the ice load based on a cylindrical accretion model
✓ End of the freezing fog event (shedding)

2.1. Conditions favourable to rime accretion on overhead lines

Tardif and Rasmussen (2007) provide a list of different types of fog, their definition and the morphology of their formation. A low wind speed, i.e. below 2,5 m/s, is typical for radiation fog, which is generated by radiative cooling over land.

Conditions favourable to radiation fog over the French plains have also been recently studied by Guidard and Tzanos (2007) as well as Menut et al. (2014). It appears that conditions on relative humidity RH, wind velocity V, precipitation P and air temperature T can be used to generate a single binary variable BV able to identify if the meteorological conditions are favourable to freezing radiation fog. In these papers, a low wind speed is also a key factor for the detection of radiation fog, although thresholds greater than 2,5 m/s are used.

The four weather conditions favourable to rime accretion used in the simple model are given hereafter:

RH Air must be saturated with water vapour to allow liquid water droplets to be produced by cooling, and consequently to let radiation fog occur

RH ≥ 90% according to Guidard and Tzanos (2007) as well as Menut et al. (2014).

V Radiation fog does not occur at high wind speeds

V ≤ 7 m/s according to Guidard and Tzanos (2007).

V ≤ 3 m/s according to Menut et al. (2014).

P Radiation fog is associated with no or very light precipitation

$P \leq 0{,}2$ mm/h according to Guidard and Tzanos (2007).

T Fog droplets must be super cooled water droplets to be sticky

$T \leq 0$ °C.

They are used to generate the binary variable BV, which is set to 1 if the above four conditions are met and set to 0 if at least one condition is not met.

If not directly given, the relative humidity RH can be calculated from air temperature T and dew point temperature Td, according to the formulae proposed by the World Meteorological Organization (Chapter 4 of the Guide to Meteorological Instruments and Methods of Observation, WMO-No. 8, 2008).

Cloud types (Guidard and Tzanos, 2007) or net infrared flux (Menut et al., 2014) could also be used to improve the binary variable BV. Unfortunately, those meteorological variables are usually not available from regular weather stations.

The effectiveness of BV can be assessed, according to the present weather observation codes recorded at some weather stations such as Lille-Lesquin station in the north of France. That specific plain area is occasionally affected by significant events of dense radiation fog (Guedalia and Bergot, 1994). Codes corresponding to rime deposit are 48 (Fog, depositing rime, sky visible) and 49 (Fog, depositing rime, sky invisible). Contingency tables can be generated to study BV with different thresholds for RH and V. Those tables, as well as definitions of Potential of detection (POD) and False alarm ratio (FAR), are designed according to Table 1 (Guidard and Tzanos, 2007). POD is h/(h + m) and FAR is fa/(h + fa).

From 2000/01/01 to 2017/03/08, 146279 hourly records are available at Lille-Lesquin station, which means that less than 3% of all possible records are missing due to maintenance or breakdowns. 91187 present weather observation codes are recorded. Only 429 hourly records include codes 48 or 49, which means that freezing fog events are rare in that area. In that case, (h + m) is equal to 429 and (h + m + fa + cr) is equal to 91187. The first step to find the best adjustment for BV, i.e. very high POD, is to set the threshold for RH to 90% and to try values varying from 3 to 7 m/s as thresholds for V.

Table 1
Contingency table design.

	Code 48 or 49	No code 48 or 49
BV = 1	Hits (h)	False alarm (fa)
BV = 0	Misses (m)	Correct rejection (cr)

The optimal wind velocity threshold appears to be 5 m/s. POD of fog depositing rime is about 99%, while FAR still remains smaller compared to velocity threshold of 6 or 7 m/s (Fig. 1).

Afterwards, the threshold for V is set to 5 m/s and the threshold for RH is tested with values from 90 to 98% (Fig. 2). With a value of 90%, almost all fog events depositing rime are detected but the FAR is about 83%. With the threshold set to 94%, about 92% of fog events deposing rime are still detected, which is an acceptable POD. Unfortunately, the FAR is still quite large (76%), which means that BV set with those two thresholds is quite conservative. For selected thresholds V ≤ 5 m/s and RH ≥ 94%, the contingency table for Lille-Lesquin station is filled in Table 2.

According to contingency tables such as Table 2, it is also possible to calculate skill scores, e.g. Critical Success Index (CSI) or Equitable Threat Score (ETS), to find the optimal wind speed and relative humidity thresholds. Unfortunately, the base rate p = (h + m) / (h + m + fa + cr) is very low in the typical case of the Lille-Lesquin weather station, i.e. $p = 429/91187 = 0{,}0047$. According to Stephenson et al. (2008), a low base rate (rare events) means that commonly used skill scores such as ETS or CSI tend towards zero, giving the impression that the rare events cannot be skilfully forecasted. Thus, it was decided to use the POD and FAR for optimizing the simple model.

To conclude, in the proposed simple model, BV is conservatively set to 1 when RH ≥ 94%, V ≤ 5 m/s, $P \leq 0{,}2$ mm/h and $T < 0$ °C.

2.2. Increase of the ice load based on a cylindrical accretion model

When conditions are favourable to freezing radiation fog, rime ice can accrete on cables. The simple model proposed in the paper is based on the following general equation described in Makkonen (2000):

$$dM/dt = \alpha_1 \cdot \alpha_2 \cdot \alpha_3 \cdot w \cdot V \cdot A \quad \text{(E1)}$$

with

M the mass of accreted ice per meter of cable [kg/m]

A the surface area per meter of cable exposed to the flux of droplets [m^2/m]

w the mass concentration of water droplets in the atmosphere [kg/m^3]

V the velocity of the droplets relative to the conductor [m/s]

α_1 the collision efficiency

α_2 the sticking efficiency

α_3 the accretion efficiency

Considering that the shape of the ice deposit is a perfect cylinder, the mass M of accreted ice per meter of cable is linked to the outer diameter D of the ice deposit by the following equation:

$$M = \pi \cdot \rho \cdot (D^2 - D_0^2)/4 \quad \text{(E2)}$$

Or

$$D = [(4 \cdot M)/(\pi \cdot \rho) + D_0^2]^{0,5}.$$

With

D_0 the diameter of the cable without rime [m], here set to 0,03

ρ the density of the accreted rime [kg/m^3]

The cylindrical approximation is applied since the cable can be considered as free in rotation for the main central parts of the overhead spans.

In Macklin (1962) or Jones (1990), three parameters are necessary to estimate rime density, i.e. the temperature of the cylinder Ts, the velocity of impact of the droplets v_0 and the median volume diameter of the droplets d_m. Unfortunately, those parameters are not recorded and