Modeling Snow and Wind-on-Snow Loads in Southern Alberta

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***Abstract*—Experience with the transmission system in Southern Alberta has shown that snow and wind on snow loads should be considered in the design of transmission and distribution lines. AltaLink, Ltd is proposing to build a new 500 kV line between Edmonton and Calgary. A new revision of the Finstad snow accretion model based on recent research and experience was used to predict snow loads in the area. This paper describes the model and its development. A companion paper describes the model results and their analysis.**

I. Introduction

The first version of this model was developed to investigate the trajectories of cloud droplets during in-cloud icing and predict the accretion of rime ice on a cylinder [1-3]. The model was then modified and extended to include accretion of glaze ice due to freezing rain and snow accretion [4-7]. The snow model was updated in 1996 during a study done in Southeastern Alaska [8]. This version of the model benefited by comparison of modeled snow amounts with amounts recorded by a snow load monitoring system [9]. Further development took place during studies in the American mid-west [10]. The current model includes a number of changes and improvements to the previous versions of the snow model.

The principal features of a transmission line snow model include identifying snowstorms, determining the amount of snow which strikes the conductor during the storm, calculating the fraction of striking snow which accrete and its distribution around the conductor, determining the response of the conductor to the additional load added by the snow, and verifying the results against other information from the area being modeled.

II. SNOW STORM IDENTIFICATION

The data used by the model includes the station latitude, longitude and elevation, the hourly wind direction and speed, the peak gust wind direction and speed, the temperature, atmospheric pressure, relative humidity, precipitation (water equivalent), visibility and present weather code.

Historical meteorological data was obtained from Environment Canada for all weather stations in the area having the required information. The data was reformatted for each station to combine all data for each hour onto one line. The wind speed data was corrected for anemometer height based on the anemometer history of the station. Accumulated daily precipitation data was merged with the hourly data at the time the accumulated precipitation was measured.

The data for each station was examined for gaps in the data. Stations used in the study were chosen based on their location and completeness of record. Often, a single hour would have data missing that was required for the model input. The missing hours would be filled by interpolating the data. The present weather codes for intensity of rain, freezing rain, snow, etc. were kept the same as the preceding hour. The hourly wind velocity and direction and the temperature, barometric pressure, visibility and relative humidity were set to the average of the values for the preceding and succeeding hours.

The data for each snow storm event was then extracted from the meteorological data files and written to a new file for use by the modeling program. Each snow storm event has two phases. In the first phase, the snow phase, snow may be accreted on the line. In the second "post snow tracking" phase, snow has stopped accreting but is assumed to remain on the line. During the second phase, wind speed and direction information is tracked to determine the maximum wind speed to use for calculating the transverse wind on snow load.

Within the snow phase, there may be lulls in snow fall of up to three hours with either no snow falling, or snow falling when the temperature is less than -5°C. During lulls, the wind speed, direction and total time are tracked. In both lulls and the post snow phase, the wind speed and direction that have the largest component in a direction perpendicular to the line are reported.

A new event begins when the temperature is greater than or equal to -5 °C and one of the data elements in Table I indicating snow is greater than 0 (indicating the presence and intensity). The snow phase begins even if there is snow mixed with rain or freezing rain of any intensity.

TABLE I
DATA ELEMENTS TO BEGIN SNOWSTORM

Data Element	Abbreviation	Description
091	S	Snow
092	SG	Snow grains
096	SW	Snow showers
097	SP	Snow pellets

The snow phase ends and the post snow tracking phase begins when there have been four hours in a row with either no snow (all data elements in Table 1 = 0) or a temperature below -5°C (whether it is snowing or not).

The post snow tracking phase continues until one of the following occurs:

- A new event begins as defined above, i.e. it begins snowing again with a temperature greater than or equal to -5°C.
- The air temperature is greater than 1°C.
- Any of the rain elements in Table II has been greater than 0 for three consecutive hours without any snow.
- The total time elapsed since the snow stopped is greater than 72 hours

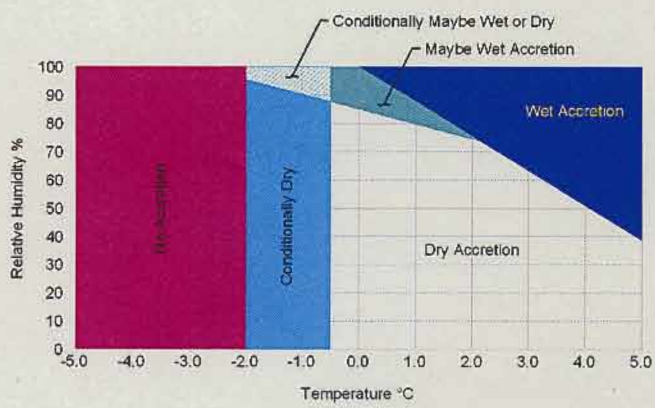
TABLE II
RAIN DATA ELEMENTS THAT END THE EVENT

Data Element	Abbreviation	Description
086	R	Rain
087	RW	Rain Showers
088	L	Drizzle
089	ZR	Freezing Rain
090	ZL	Freezing Drizzle

The event is complete when the post snow tracking phase ends.

III. SNOW STRIKING THE CONDUCTOR

The snow which sweeps past the conductor (liquid water content of the air) may be determined using the visibility, the precipitation or a combination of the two. In this case the visibility was used to determine the liquid water content. The precipitation on the ground was also calculated and compared with the precipitation data. The snow was classified based on the temperature and relative humidity as shown in Fig. 1.



The fall speed and air liquid water content are based on the work of Rasmussen et al. (1999). The fall speed of wet snow is taken as 2 m/s. The air liquid water content is calculated using (1).

$$\text{Wet} \quad lwc = \frac{0.5}{V}$$
$$\text{Maybe Wet} \quad lwc = \frac{0.25}{V} \qquad (1)$$
$$\text{Dry} \quad lwc = \frac{0.1}{V}$$

Where:

lwc = liquid water content in $\frac{kg}{m^3}$

V = visibility in m

Rasmusssen et al. [11] report that visibility at night is roughly twice as far for the same snowfall rate as it is during the day. To account for this, the liquid water content is doubled at night. The approximate sunrise and sunset times are calculated based on the date and station latitude. The coefficients in the numerators in (1) have been tweaked to better fit field observations of accretion events in Alberta (which include recorded precipitation amounts) while still fitting within the theoretical range of coefficients from dry to wet snow. The relationships in (1) are applied only to visibilities greater than 100 m. When the reported visibility is less than 100 m, 100 m is is used. The liquid water content is limited to a maximum of 0.55 g/m3 which corresponds to a precipitation rate of 4 mm/hr at a snowflake fall speed of 2 m/sec.

Equation (2) gives the snow speed normal to the conductor.

$$U = \sqrt{U_f^2 + (U_w Sin\theta)^2} \qquad (2)$$

Where:

U = impact speed normal to the conductor

U_f = fall speed

U_w = wind speed

θ = angle between wind and centerline of line

Equation (3) gives the volume of snow which strikes the snow covered conductor.

$$Vol = \frac{\Delta T\ lwc\ A\ U}{\rho} \qquad (3)$$

Where:

Vol = snow volume

ΔT = time interval

A = projected area of snow covered conductor

ρ = snow density

The snow density is given in Equation 4.

$$\text{Wet} \quad \rho = 55\,U$$
$$\text{Maybe Wet} \quad \rho = 45\,U \qquad (4)$$
$$\text{Dry} \quad \rho = 35\,U$$

Where:

U = speed in m/s

ρ = density in kg/m^3

Density is limited to a maximum of 850 kg/m^3, and a minimum of 50 kg/m^3, although the effective minimum density is 70 kg/m^3 with the minimum fall speed of 2 m/s.

A. Snow Fraction Accreting on the Conductor

Snow is assumed to accrete (See Fig. 1) when snow or snow showers of any intensity are present with following limitations:

- Snow concentration is halved when fog is present with snow, or when only snow grains are present.
- The duration of accretion is halved when only snow showers are present.
- Snow pellets are not allowed to accrete.
- Dry snow is allowed to accrete when the wind speed is below 2 m/s and the temperature is above -2°C.

The volume of snow accreted is the product of the volume swept past the conductor and the sticking efficiency which is given in (5).

$$S = \frac{T+2}{U} \text{ if } U \geq T = 2 \text{ otherwise } S = 1 \quad (5)$$

Where:

S = sticking efficiency

T = temperature °C

B. Accretion Distribution and Conductor Response

The snow for each time period is assumed to accrete in layers distributed on the half of the conductor centered in the direction of the snowfall. As each layer accretes, the conductor is rotated to balance the twisting moment due to the eccentricity of the deposit with the torsional resistance of the conductor.

IV. VERIFYING THE RESULTS

Table III shows a comparison between the model results and several storms for which field information was available.

TABLE III
COMPARISON OF MODEL AND FIELD RESULTS

Parameter	Brooks 933/934L	Brooks 504L	Haynes 912L	Mossleigh 924L	Sylvan 717L	Lethbridge 1967	Lethbridge 1968
Observed Accretion							
Mass kg/m	Unknown	Unknown	Unknown	Unknown	~ 2 or less	Unknown	Unknown
Max Diameter cm	7.5	5 to 8	10	15	7 (mean)	Unknown	Unknown
Modeled Accretion							
Mass kg/m	1.4	0.9	6.0	5.3	.9	12.2	25.5
Max Diameter cm	6.2	5.0	13	12	5.1	21	24
Average Density kg/m^3	514	495	496	507	554	376	561
Reported Snow Depth, local	12 to 17 cm	12 to 17 cm	30 to 40 cm	22 to 45 cm			
Reported Liquid Equivalent Precipitation at nearest station	28 mm	28 mm	41 mm	28 mm	20 mm	87 mm	80 mm
Modeled Liquid Equivalent Precipitation	32 mm	32 mm	82 mm	88 mm	33 mm	141 mm	149 mm

V. Acknowledgments

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