Wet snow icing – Analysis of field measurements 1999-2016

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***Abstract*— Wet snow icing accumulation on overhead power lines is rare in most countries. Experience has shown that the frequency and quantity of wet snow accumulation is high in Iceland, but it is very site-dependent and can vary greatly between areas and locations. This paper presents analysis of field measurements of wet snow icing at 10 locations in Iceland from 1999 to 2016. Measurements are made of both operating power lines and specially erected test spans/lines to measure icing. Discussion and classification are made on the main topographical conditions where the most extreme wet snow icing has been occurring. Large-scale effects and the effects of local topography explain the variation. Measurements are presented of accumulation on conductors of different diameters.**

Keywords*— *wet snow accumulation; field measurements; icing measurements, analysis of field measurements; analysis of icing measurements

I. Introduction

Wet snow accretion on overhead power lines can seriously threaten the operational reliability of overhead power lines. Within a few hours, ice accumulation can cause mechanical overloading and lead to failure of the supporting structures (Fig. 1). In the global context, wet snow accretion occurs frequently on overhead power lines in Iceland. It may occur in all regions, but some areas are more exposed than others, and the frequency and amount of accumulation vary greatly between locations (see ref [1]). Historically, wet snow accumulation has led to many severe failures of power lines in Iceland, especially in the 11-33 kV distribution network before 1995.

Fig. 1 Wet snow icing on power line in winter 2012.

Mainly three factors have contributed to fewer failures since 1995: (i) increased knowledge of the most severe icing areas and counter measures, (ii) laying part of the distribution network underground, giving priority to lines in severe icing areas, (iii) changed weather pattern.

Field measurements of icing started in Iceland in 1972, with the erection of test spans. They were specially built and operated to measure icing. Most of the test spans are in areas that are mainly exposed to in-cloud icing. When electronic measurement units were available, in the 1990s, it became possible to identify the icing type and get more reliable data on the accumulation. Field measurements are also made in some operational power lines in areas known to be exposed to wet snow icing.

This paper presents field measurements of wet snow icing accumulation in the period 1999-2016. The measurements are obtained from both operating power lines and test spans. When measurements are made of an operating line, the load cell is installed at the attachment point between insulator and the tower attachment, see Fig. 2. In this case, the measurement therefore contains total loading of ice and wind, so the wind component is subtracted from the measurements from available data. When measurements are made in test spans, the wire tension is measured and ice loading is calculated, based on given assumptions [2].

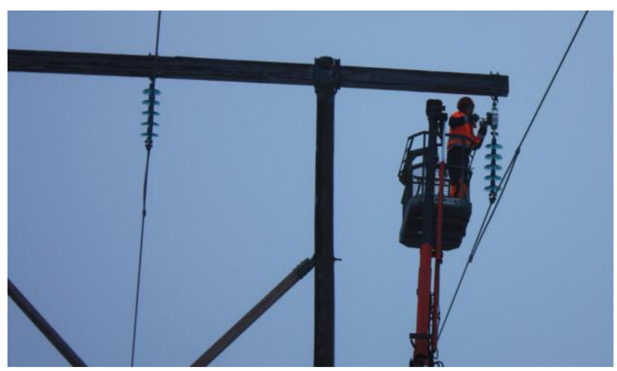

Fig. 2 Load cell in site No. 2 (Kop168), 132 kV power line.

II. Field measurements of wet snow accretion

Field measurements of wet snow icing accumulation from 10 sites are presented. Three of the sites are operating power lines (132 kV), one is from a test line (three towers used from a discontinued 22 kV line), and six sites are specially built test spans. Table 1 shows the sites, including the maximum measured accumulation. The bare diameter of the conductor varies from 12 mm to 28 mm.

All wet snow accumulation events, greater than 10 N/m, measured at the 10 sites are shown in Fig. 3. Most of the events start on bare wire, but in three cases, icing remained from previous accumulation. The most extreme accumulations are marked with an identification number. Some of them have been presented before with more detailed information; event 2, see ref. [3] and [4], event 3-a, see ref. [3] and [4], event 4-a, see ref. [5], event 4-b see ref. [3].

Table 1. Measuring sites used in study.

Site no.	Name	Type	Wire diameter (mm)	Max. meas. wet snow loading (N/m)
1	Kop100	132 kV OHTL	28	28
2	Kop168	132 kV OHTL	28	145
3	Kambur	132 kV OHTL	28	165
4i	Fljotin	Test line	12	70
4ii	Fljotin	Test line	28	90
4iii	Fljotin	Test line	18	80
5	76-1	Test span	28	21
6	82-5	Test span	28	24
7	85-2	Test span	28	70
8	91-1	Test span	18	15
9	05-1	Test span	28	34
10	05-2	Test span	28	21

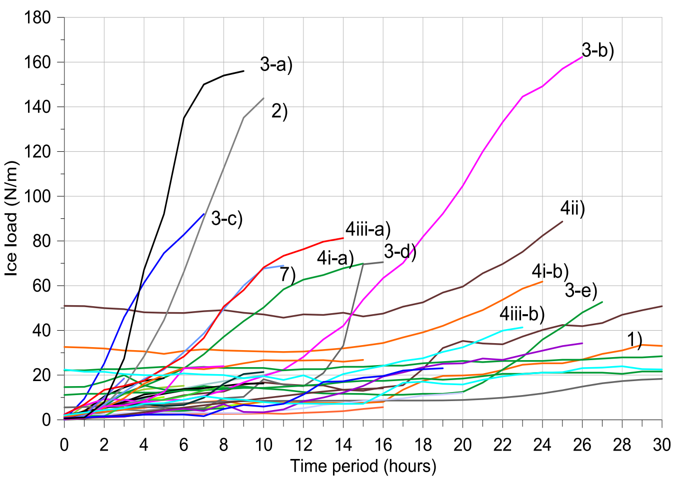

Fig. 3 Wet snow accretion events in field measurements.

The three sites with the highest frequency of accumulation, also have the highest measured loading. Figures 4 - 6 show all measured wet snow accumulation events in each of these sites ranked in size order. It can be observed that wet snow accumulation is a regular event in these locations with more than one event per year on average.

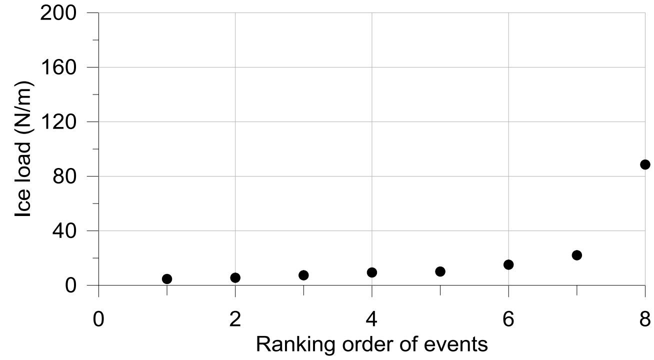

Fig. 4 Site No. 4ii (Fljotin – 28 mm). Maximum wet snow accumulation, 2000-2015.

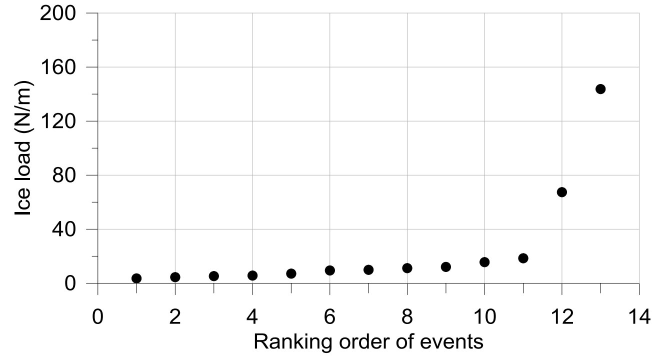

Fig. 5 Site No.2 (Kop168). Maximum wet snow accumulation, 2005-2016.

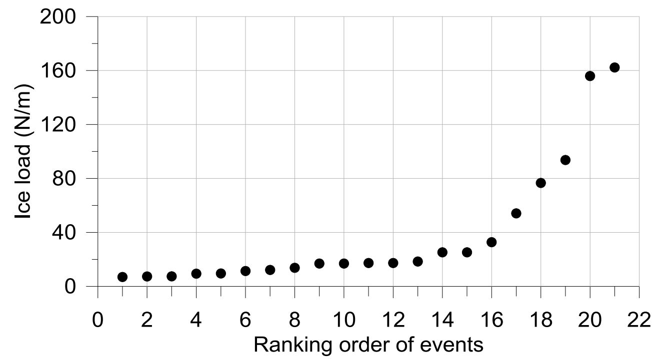

Fig. 6 Site No. 3 (Kambur). Maximum wet snow accumulation, 1999-2016.

Fig. 7 shows more detail for all accumulation events at site No. 3 (Kambur), i.e., the site having the highest frequency of accumulation and the highest overall measured loading.

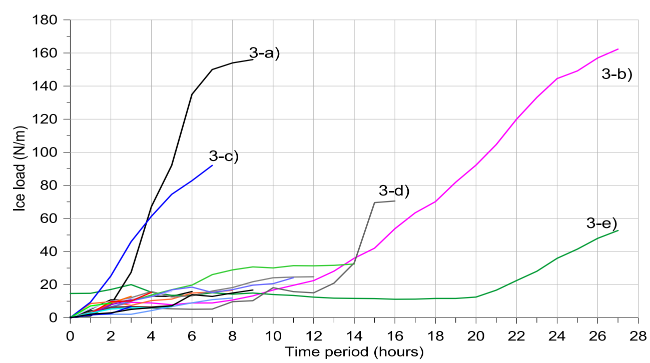

Fig. 7 Site No. 3 (Kambur). All accumulation events in the period 1999-2016.

Fig. 8 Site No. 1 (Kop100). Failure of power line during wet snow icing in 2012, case 3-a).

It can be concluded that the accumulation at the 10 sites varies greatly in size, frequency and accumulation rate.

- The maximum accumulation range is 140-165 N/m for three events (3-a, 3-b and 2). Events 2 and 3-a have been studied in detail in ref [4]. The weather conditions were quite severe, with severe wet snow precipitation combined with wind speed exceeding 20 m/s. The accumulation could have been greater if failure of transmission lines had not occurred. This is an important factor when using measurements to estimate design load or when comparing with simulation.
- The accumulation rate varies greatly in the events. Many events have an icing rate of from 1 to 3 N/m/hour, but in the most extreme case, it reaches 30 N/m/hour.
- The length of accumulation is most often from 6 to 16 hours, but the longest continuous accumulation period is around 30 hours
- The three sites with the largest events have many events with small accumulations. On average, they have more than 1 event per year.
- According to ref [6], extreme wet snow events can last 15 to 24 hours, with ice load of up to 10 kg/m. The maximum ice loads studied in this paper are bigger than what is normally considered extreme. However, the duration is similar.

III. Influence of Topography and Local Conditions

Wet snow accumulation may occur in all regions in Iceland, but some parts are more exposed than others, this and the frequency and the amount vary greatly between locations. Most often the direction of accumulation is from the sea, and the main icing area is generally within 40 km from the ocean. Operational experience from the overhead power lines reveals that accretion depends strongly on predominant icing directions. Power lines oriented favorably with respect to the predominant icing directions often have far less and minimal accretion, compared to nearby lines with a more unfavorable orientation. Discussion of site-dependent icing, with special focus on orography and directional influence can be found in [1]. Following, is a simple explanation of some of the site conditions that often lead to high wet snow icing accumulation. They are linked to the sites in Table 1. Five topographical conditions are presented that have often been exposed to wet snow accumulation.

A. *Icing down-stream of mountains*

Many of the most severe failures related to wet snow icing are down-stream accumulation on the lee side of mountains relatively close to the sea, often in complex orography. Ice accumulation in some areas has ranged from 50-100 N/m every few years. The interaction of atmospheric flow with complex orography may create favorable conditions for wet snow accretion on the lee slopes of high mountains. The three key factors relevant here that influence the accretion rate are: (i) heavy precipitation due to orographic uplift, (ii) gravity (mountain) waves and (iii) adiabatic heating. Further explanation can be found in [1] and [7]. Sites No. 2, No. 3 and No. 4 are of this type.

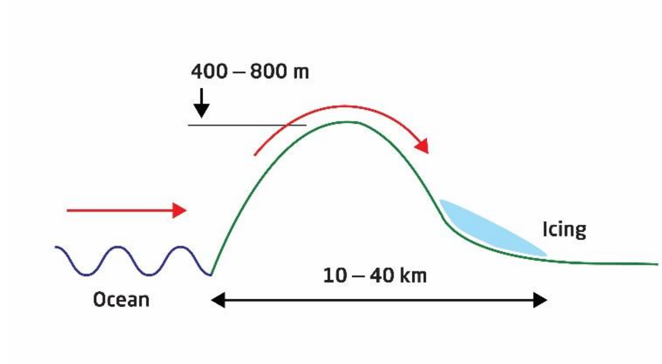

Fig. 9 Wet snow icing, down-stream.

B. *Icing up-stream of mountains*

In some areas, the wet snow accretions up-stream of mountains are significant. The role of the topography in creating favorable icing conditions is at least twofold: (i) it blocks the impinging flow and channels a cold flow ahead of the front, (ii) precipitation increases as the warmer impinging flow is cooled in a forced ascent. Further explanation can be found in [1] and [8]. Site No. 1 is of this type.

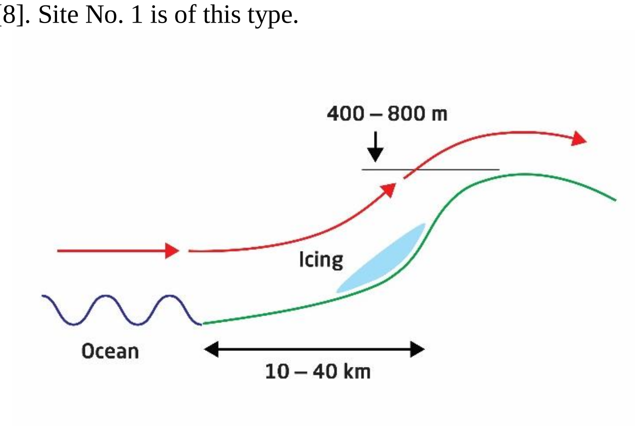

Fig. 10 Wet snow icing, up-stream of mountains.

C. Gently sloping terrain from sea

When the temperature at sea level is only several degrees above freezing, the 0°C isotherm inevitably intersects the topography at some level. Hence, in gently sloping terrain, there will always be a region somewhere inland, where temperatures are favorable for wet snow formation, i.e., in the range of 0.5-2°C. Site No. 6 is of this type.

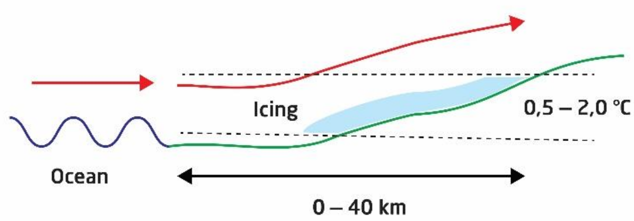

Fig. 11 Wet snow icing, gently upward sloping terrain.

D. Local channeling effects

Channeling effects around mountains and steep topography often lead to increased wind speed and increased wet snow accumulation. The influence can greatly increase accumulation in some cases, especially at the mouths of valleys when wind is blowing down from mountains. Operational experience with the overhead power lines provides some major events of this, for example, in ref [7]. Site No. 7 is of this type.

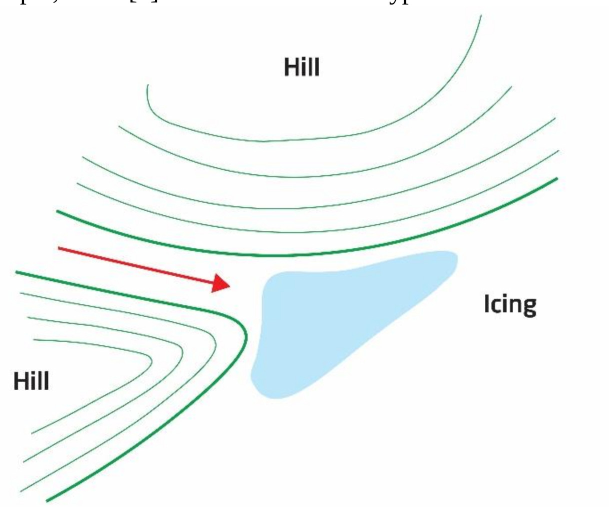

Fig. 12 Wet snow icing, Channeling effects increase wet snow accumulation locally in some cases, especially at the mouths of valleys.

E. Combination of wet snow icing and drifting snow, controlled by local landscape

Some of the most extreme wet snow accumulation in Iceland is related to local landscape conditions which enhance wind speed and precipitation. In special cases a drifting snow controlled by local landscape can accumulate and increase the accumulation significantly. This can for example occur behind small ridges or hills. Fig. 13 shows a typical example of this.

The drifting snow often originates from upper and colder layers and it can accumulate while the icing is still partly wet. The drifting snow adds to the wet snow sleeve. Usually the drifting snow zone reaches only around one meter above the ground or snow surface, but in few special cases, it can reach up to a few meters. The mid span of the conductor can sag down into the drifting snow zone during icing accumulation, where it gets additional accumulation from the drifting snow. (see Fig. 14)

The sites with drifting snow problem are rather few and localized. The total accumulation and the accumulation rate can be some of the greatest observed and are therefore avoided when line routes are selected. Site No. 3 is of this type, it combines the effect of local landscape and icing downstream of mountains, where drifting snow increases the accumulation.

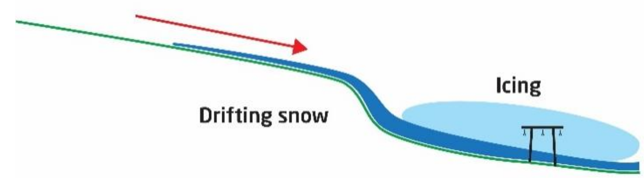

Fig. 13 Wet snow icing, combined with drifting snow controlled by local landscape.

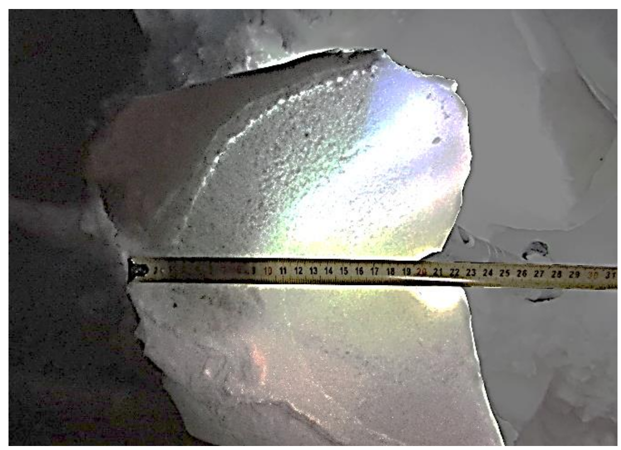

Fig. 14 Wet snow sleeve with additional drift snow, at Site No. 3 (Kambur). Figure show halve icing section with radial thickness > 20cm.

IV. INFLUENCE OF WIRE DIAMETERS ON ACCUMULATION

Measurements presented in Section II include wire diameters in the range of 12-28 mm. It is thus of interest to assess the effect of wire diameter on the accumulation rate. Measuring site No. 4 (Fljotin) has three parallel measuring wires and has for many years been equipped with different conductor diameters (12mm, 18mm and 28mm). All wires are installed with same sag, i.e., different tension. A description of the test site and the two the biggest events are in [5] and [3]. The spacing between the wires is 2m, and the installation has the 12mm wire positioned next to the icing direction, the 28 mm is in the middle and the 18mm wire is farthest away from the icing direction. Some wet snow accumulation events have been observed in the period 1999-2015, and the results give insight into the effect of conductor diameter on the accumulation rate. Two of the events were bigger than 50 N/m and seven were smaller. Only one of the two large events included measurement of the 28mm wire. That event was not typical since the wet snow icing lasted 8 days; there were three main accumulation periods during the event, and some ice reduction took place between the accumulations. The 18mm wire has the lowest accumulation in that event. This is most likely related in part to ice reduction in the event, but another factor can be shielding effects from the other wires.

Figures 15 to 17 show comparison of the accumulation in each event. Each figure shows comparison between two wire diameters. Two load ratios are presented with dotted lines; (i) the ratio of 1:1 and (ii) the ratio of wire diameters. Fig. 15 compares the 12mm and 28mm wires. It shows that there is one large event, and the 28mm wire accumulates more ice weight than the 12mm wire. This event has a load ratio between the ratio 1:1 and the ratio of wire diameters. There are a few smaller cases, and the difference is then higher and close to the ratio of the wire diameters or above. Fig. 16 shows the comparison between 18mm and 28mm wires. It contains one large event where the 28mm wire gets higher loading, and its ends up with a ratio higher than the ratio between the wire diameters. The reason for this is most likely related to ice reduction in the event and shielding effects, see discussion on this event above. The second highest loading results in a load ratio close to the ratio of diameters. The smallest load cases have loading close to or above the ratio of diameters. Fig. 17 shows the comparison between 12mm and 18mm wires. It contains two large events. One of them is the same case as in Fig. 16, and it has the same result, that the loading on the 18mm wire is low. Here its results are considerably lower than those of the 12mm wire. The other case is more regular, and it results in a load ratio between 1:1 and the ratio of wire diameters. There are some smaller cases, and the difference is then greater and close to the ratio of the wire diameters or above.

Based on these measurements of three different diameters, it can be observed that the accumulation is higher for larger diameter. Initially the accumulation is close to or above the ratio of the wires. When accumulation is greater (> 20 N/m), the ratio is linear and between the ratio of 1:1 and the ratio of wire diameters. As an approximation of these wire dimensions (i.e., 12-28 mm), the ratio can be approximated as 60% fixed and 40%, depending on the ratio of wire dimensions.

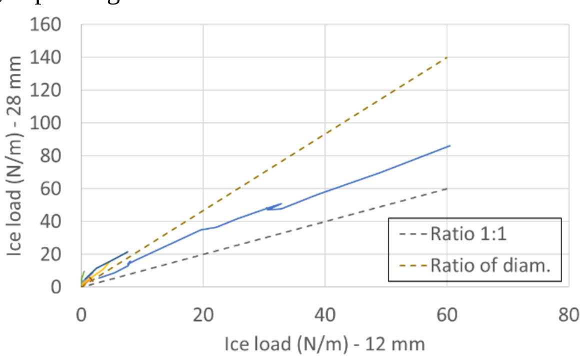

Fig. 15 Comparison of accumulation on 12mm wire and 28mm wire.

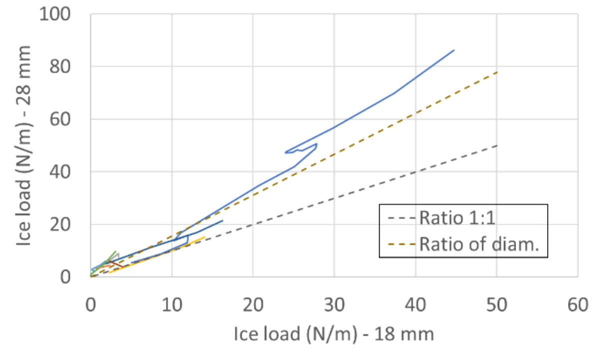

Fig. 16 Comparison of accumulation on 18 mm wire and 28 mm wire.

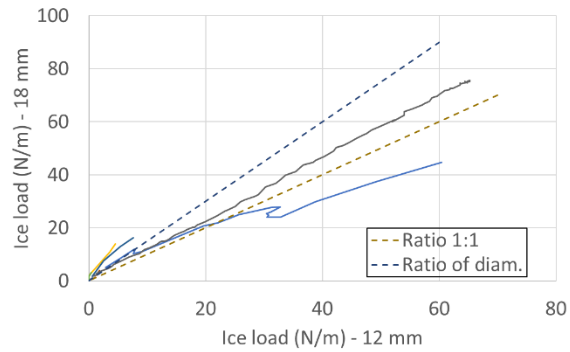

Fig. 17 Comparison of accumulation on 12 mm wire and 18 mm wire.

V. Conclusions

Wet snow icing has historically proposed an operational threat to overhead power lines in Iceland. The condition seems to be somewhat more extreme than in most other countries when comparing frequency and maximum accumulation. An overview of the analysis of field measurements is given for 10 sites, covering 10-17 years of measurements at each site. Most of the events are in the load range of 0-30 N/m, but the most extremes are around 140-165 N/m. The accretion rate varies greatly, many events have icing rates ranging from 1 to 3 N/m/hour, but in the most extreme case, it reaches 30 N/m/hour.

Topography and local conditions play a strong role in the accumulation. Five different situations are specified and the measuring sites related to them.

Discussions are made on the influence of wire diameter on the accumulation rate. The observed accumulation is higher for larger diameters. One finding is that the diameter's influence is closely related to the diameter difference in the initial accumulation. As the accumulation increases, the influences diminish but stays above the 1:1 ratio.

Acknowledgment

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REFERENCES

[1] Á. J. Elíasson, H. Ágústsson and G. M. Hannesson, "Wet snow icing - Comparing simulated accretion with observational experience," in *IWAIS 2015*, Uppsala, 2015.

[2] Á. J. Elíasson, H. Á. E. Thorsteins and Ó. Rögnvaldsson, "Comparison between simulations and measurements of in-cloud icing in test spans," in *Proc. 14th Int. workshop on atmospheric Icing on structures*, China, 2011.

[3] Á. J. Elíasson, H. Ágústsson, G. M. Hannesson and E. Thorsteins, "Modeling wet-snow accretion - Comparison of cylindrical model to field measurements," in *IWAIS 2013*, St.John's. Canada, 2013.

[4] Á. J. Elíasson, H. Ágústsson and G. M. Hannesson, "Wet snow accumulation - A study of two severe events in complex terrain in Iceland," in *IWAIS 2013*, St. John's, 2013.

[5] Á. J. Elíasson and E. Thorsteins, "Field measurements of wet snow icing accumulation," in *IWAIS 2000*, Chester, UK, 2000.

[6] P. Admirat, "Wet snow accretion on overhead lines," in *Atmospheric Icing of Power Network*, M. Farzaneh ed., Springer, 2008, pp. 119-169.

[7] H. Ólafsson, Á. J. Elíasson and E. Thorsteins, "Orographic influence on wet snow icing - Part II: Downstream of mountains," in *IWAIS 2002*, 2002.

[8] H. Ólafsson, Á. J. Elíasson and E. Thorsteins, "Orographic creation of wet snow icing conditions, Part I: Upstream of mountains.," in *IWAIS 2002*, 2002.

[9] Á. J. Elíasson, E. Thorsteins and H. Ólafsson, "Study of wet snow events on the south coast of Iceland," in *IWAIS 2000*, Chester, UK, 2000.

[10] B. E. K. Nygaard, H. Ágústsson and K. Somfalvi-Tóth, "Modeling wet snow accretion on power lines: Improvements to previous methods using 50 years of observations," *Journal of Applied Meteorology and Climatology*, vol. 52, no. 10, pp. 2189-2203, 2013.

[11] Y. Sakamoto, "Snow accretion on overhead wires," *Philosophical Transactions of the Royal Society of London.*, Vols. Series A: Mathematical, Physical and Engineering Sciences 358.1776, pp. 2941-2970, 2000.

[12] B. Dalle and P. Admirat, "Wet snow accretion on overhead lines with French report of experience," *Cold Regions Science and Technology*, p. 43–51, 2011.