Snow Accretion on Overhead Wires

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Abstract— **This paper describes experience with snow accretion on overhead wires. The first part of the paper refers to the distinctive properties of water, diverse snow accretion mechanisms, difficulty in simulation experiments, difficulty in observing the snow immediately after accretion since it spontaneously drops off or morphosizes, and the test methods of the authors and their drawbacks. It was considered that these issues are key issues when studying snow accretion problems on overhead wires. The second part deals with, in particular, wet snow accretion with respect to the dependency of its characteristics on various parameters. From the results of simulations using wind tunnel tests and observations, the dependence of the density of accreted snow and accretion efficiency on meteorological conditions was inferred to estimate snow accretion loads for the return period. The tendency to spontaneously drop accreted snow is also described. Finally, it was emphasized that collecting field measurement data is required to fill in each matrix with relevant parameters to verify the models that have been proposed from different viewpoints. For this, international cooperation is important and the Guidelines for Field Measurement of Ice Loadings recommended by CIGRE are very useful.**

I. Introduction

It is widely known that snow accretion on overhead wires affects the reliability of transmission lines or distribution lines in various ways in the world. Especially, Canada, France, Norway, Iceland, and the US (Alaska) have experienced various serious accidents due to snow accretion on the wires. Researchers in these countries have made significant efforts on accretion and many papers have been reported to IWAIS.

Japan consists of a group of islands extending along the sub-tropical zone to north latitude 45.5 degrees, located at the boundary of the Pacific Ocean and the Asian Continent. Thus, every winter, snowfalls are experienced under various synoptic meteorological situations and, in particular, power lines suffer many types of faults due to snow at very early stages of commissioning.

Specifically, severe damage to overhead power lines due to snow occurred in the western area of Honshu (main land) in 1970, in Hokkaido (the northernmost of the four major islands) in 1972, in the northeastern area of Honshu in 1980, and in the south central area of Honshu in 1986. Under these circumstances, the authors have conducted many experiments and investigations on snow damage to overhead power lines and have published the results.

Nevertheless research into natural snow accretion on wires after a snow event is not easy, and it is hard to say that the whole picture is fully understood. This paper intends to present the authors' views on why research on snow accretion involves difficulty, point out the dependence of meteorological parameters on the effects of accreted snow on overhead wires that have been recognized from past experience, and make proposals to break through the difficulty bottleneck in this field. The authors would like this paper to be somewhat of a guideline to encourage those who engage in the research of snow accretion, particularly young engineers. The authors believe that this will be a substantial topic of keynote speeches.

This paper is less of a discussion of the results of the authors' research but focuses more on the drawbacks involved in the research. For the research results themselves, please refer to the reports that have been provided to IWAIS and the contribution to Philosophical Transactions of the Royal Society [1].

II. Difficulty Involved in Research On Snow Accreted Overhead Wires

A. Physical Properties of Water

Water (H_2O) is a substance very familiar to human beings, but it has very distinctive properties. Water can exist in three phases, as a gas, liquid and solid, in a temperature environment where human beings normally live. The range of phase change between the three states of water is affected by various causes and is broad. For example, a textbook on rudimentary physics normally discusses water changing from a liquid state to a solid state at freezing, but it is common knowledge for researchers of snow and ice that such a change is hardly a fact. It is also well known that increasing the pressure on the solid ice can cause it to transform to a liquid and that water vapor exists at very low temperatures.

In a study of snow accretion, therefore, it should always be taken into consideration that water normally co-exists in these three states and the phase change occurs between them. The latent heat of water is generally larger than that of other substances of the same kind. This fact makes snow accretion phenomena more complicated. For example, snowflakes produced in an upper atmospheric layer with a temperature below freezing do not melt when they go through a lower atmospheric layer with a temperature above freezing, but are in a mixed state of solid and liquid, because of the large latent heat of melting. Such peculiar properties of water make studies of snow accretion complicated.

B. Rapid Metamorphosis of Snow

As a result of the characteristics mentioned in subsection A, snow, whether it is a form of snow accretion or snow cover, changes its physical properties rapidly due to the effects of ambient temperature, solar radiation and rainfall. This is clearly seen from the fact that the properties of snow differ (particularly in density, ice particle size, and structure) layer by layer when digging into snow cover. Snow accretion is a mixture of water (in the solid and liquid states) and air; and there are a lot of pores in accreted snow, particularly snow with a relatively low density (< 0.5 kg/m^3), where air and liquid-water can pass. This promotes the metamorphosis of snow, which has a complex effect on snow observations.

C. Diversity of Snow Accretion Mechanisms

In order to have snow accretion grow on overhead wires, there must be an adhesive force between the surface of the wire and the snowflake and between the snowflakes themselves. In icing, the adhesive forces mainly come from freezing. On the other hand, in snow accretion, the inferred adhesive mechanisms are many as follows.

(a) Freezing (including pressure melting and re-freezing)
(b) Bonding through freezing of supercooled water droplets existing on the surface of snowflakes
(c) Sintering
(d) Condensation and freezing of vapor in the air
(e) Mechanical intertwining of snowflakes
(f) Capillary action due to liquid-water included
(g) Coherent force between ice particles and water formed through the metamorphosis of snowflakes

Through those mechanisms, snow accretion on overhead wires can be produced over a wide range of air temperatures from +3^{o}C to –7^{o}C. The authors once observed a cylindrical snow-sleeve with a size (diameter) exceeding 50 cm where the air temperature was –7^{o}C and the density of accreted snow was 0.1 kg/m^3. They expected that, when the air temperature is relative low (< 0^{o}C), adhesive mechanisms of (a), (b), (c) and (d) are expected to dominate. On the other hand, in the case of "wet-snow accretion" where the ambient temperature is higher, mechanisms of (f) and (g) are expected to dominate. One of the grounds for this prediction comes from the following observations. Firstly, there is a thin layer of ice at the contact of the snow accretion with the wire when removing the snow accretion on the wire produced under sub-freezing temperatures in natural conditions. Secondly, the snow piled on a thin wire (having a small torsional rigidity) drops off spontaneously due to the eccentric weight of accreted snow caused by wire twisting while the snow piled on a thick wire does not easily drop off but begins to creep in a way to wrap the wire. For the growing process of such accretion, refer to [3].

The cylindrical snow-sleeve under sub-freezing temperatures, mentioned above, has a larger size (diameter) but its load is not so large because of its lower density, and therefore, it seldom causes mechanical damage on modern technology power lines. Thus, this paper will only discuss "wet snow accretion" at temperatures above freezing.

In the case of "dry snow accretion" at such low temperatures, all the accreted snow tends to fall off from the wire easily at the same time by swings due to the wind because the adhesive force is small. The wires then have sleet jump, occasionally causing short circuits between phases. The amount of such a jump is a result of energy conversion, where the energy accumulated in the wire due to the increased tension with the increasing snow load is converted into kinetic energy when the accreted snow drops off. Once a part of the accreted snow starts to fall off, it develops into a total snow drop-off over the span, often causing a large difference in snow load between spans or phases. The difference in sag of each span often causes short circuits between phases of low-voltage power lines. The authors would like to add that pioneer engineers in this field in Japan have developed methods to estimate the range of wire swings or to determine the phase layout.

D. Difficulty of Experiments

Generally, simulation in the laboratory is a good method that allows conducting this type of research efficiently. The authors artificially reproduced snow accretion in a wind tunnel facility, using the snow sampled from natural snow cover, and investigated the effects of various meteorological parameters on the snow accretion.

Nowadays we have technologies to make snow artificially, but, when the authors conducted experiments, it was difficult to make a large amount of snow required for the experiments. Conducting the experiments was limited to winter. Furthermore, even in winter, collecting homogeneous natural snow samples was limited to a very short period because experimental results significantly depend upon the samples used, as mentioned below.

Moreover, as pointed out in the authors' previous report, the relationship between the liquid-water content of the laboratory "wet snowflakes" and the laboratory room temperature is different from that between the liquid-water content of natural snowfall and the outside air temperature. The authors, therefore, could not help having questions about the relationship between the experiment results and natural phenomena. To provide a concrete picture of this problem, experiments by the authors are described briefly along with its grounds in the following. The experiments were carried out as cooperative work with Dr. Admirat, et al., of Electricité de France.

1): Experiment by the Authors

The wind tunnel facility used in the experiment is illustrated in Fig. 1. Before installing this facility, the authors' colleague researchers had done experiments with a facility smaller than this. The experiences with the smaller facility have been introduced into the design of the new one. There are several methods to artificially make "wet snowflakes", including: 1) pouring water on snow samples, 2) heating the snow sample using infrared lamps, 3) injecting a water spray simultaneously with the snow sample into a wind tunnel, and 4) putting snow samples in a room at an air temperature above freezing until the snow partially melts and then injecting it into a wind tunnel. The authors adopted method 4) based on their experiences. The reasons were that either of methods 1) and 2) did not allow making snow samples that contained liquid-water homogeneously, and, for method 3), the microscopic photographs of the snow sample, which was collected using a glass slide at the outlet of the wind tunnel, showed that dry snowflakes and water droplets were blown off separately, but not "wet snowflakes". It was verified that the characteristics of accreted snow made by methods 3) and 4) were also different. Consequently, the wind facility in Fig. 1 was installed in a hut with a heating system where the ambient temperature could be controlled and kept relatively constant.

To study the effect of the rigidity of the wire on the growing process of the snow accretion, a device to change the rotational torque of a wire was also set on both ends of a sample wire.

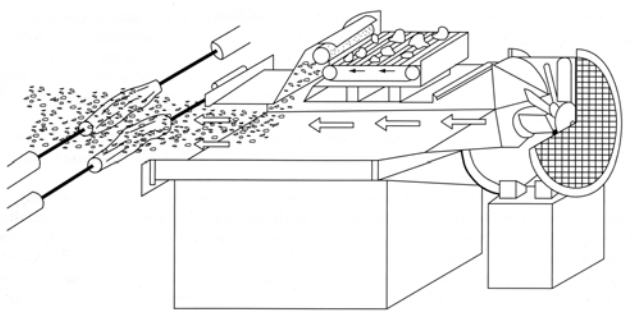

Fig. 1. Wind tunnel facility

Snow samples were taken from the snow cover outside. They were collected only from an upper layer of the snow cover that had not experienced positive air temperature, solar radiation, rain or snowfall after accumulating as snow cover. The authors also conducted experiments using a snow sample taken from a deeper layer. The results of the experiments differed significantly between using fresh and metamorphosed snow.

In bringing the snow sample into the hut to inject it into the wind tunnel, the time the sample stayed in the above-freezing ambient temperature of was five minutes or less, including the time to measure the mass of snow. The snow sample, however, still hardened in such a short time, so the authors attached a rapidly rotating cylinder with many protrusions inside on the lower end of a snow-carrying conveyor to make the hardened snow into flakes, which were then injected into the wind tunnel.

2): Decision of Experimental Conditions

The purpose of the experiment was to examine the dependence of meteorological parameters on snow accretion on overhead wires. Such parameters might be as follows:

(i) Precipitation intensity
(ii) Air temperature
(iii) Wind speed
(iv) Duration time of a wet snow condition
(v) Torsional rigidity of the wire

Considering the heat balance, humidity may affect snow accretion on the wire, but was ignored because of the difficulty in controlling the humidity in the hut. From the growing process of snow accretion, the crystal form of the snowflake may affect it, but was also ignored. Consequently, the schedule of the experiments was designed to cover every matrix of the five parameters above.

3): Parameters Actually Measured in Experiment

In the experiments, the following parameters were actually measured.

(i) Mass of snowflakes passing around the wire per unit time (including distribution)
(ii) Wind speed (including distribution)
(iii) Air temperature
(iv) Relative humidity
(v) Liquid-water content in snow that collided with the wire
(vi) Mass of accreted snow on the wire over its effective length
(vii) Rotating angle of the wire
(viii) Liquid-water content of water in the accreted snow

In addition, the duration of the experiment was recorded, and the surface temperature of the wire was measured when energized.

4): Restriction on, and Review for, the Experiment

The experiments were conducted in Ishiuchi, Niigata Prefecture in Japan, where snow falls for about 50% of the days in winter from the middle of December to early March. However, there were not many days when the experiments could be satisfactorily carried out because of the above restrictions. It was not easy to arrange the experiments to fill in each matrix with conditions of combination.

As a result of the experiments, the dependence of the parameters became quite clear, as discussed below, but there were some questions about the equivalency between the conditions in the artificial experiments and the above natural conditions. Particularly, because filling in the matrices with conditions of combination under the time restriction for the experiments was required, water equivalent precipitation intensity was set greater than expected in the natural conditions and the room temperature was set higher in order to perform the experiment more efficiently. These were drawbacks that considerably lessened the equivalence between the experimental and natural conditions

E. Difficulty of Observation

An ideal method to study the snow accretion on overhead wires is to observe natural snow accretion on wires of a test line with various measuring instruments installed, as is currently conducted in Iceland [4, 5] or as reported previously from France. As mentioned above, however, there would be very little chance of observing accreted wet snow in large quantities at one site, at least in Japan. The northern area of Honshu (the main land of Japan) extending on the side of the Sea of Japan has an enormous snowfall, particularly in the mountainous areas, due to monsoons coming from the Asian Continent. However, most of the snowfalls occur at low temperatures and in weak winds. There are, therefore, few cases of wet snow accretion that may cause a lot of damage to power lines in this heavy snow area.

On the other hand, in areas of Japan on the Pacific Ocean side, an extratropical cyclone that is formed in a boundary between cold air from the North Pole and warm air from the Ocean runs northeastward along Japan, and occasionally causes precipitation with relatively high intensity. This is usually rainfall, but may be an intense fall of wet snow when the cold air from the North Pole comes down at the same time the extratropical cyclone passes across the areas. Such extratropical cyclones typically run fast, so the duration of wet snowfall is short. However, if there is a high pressure air mass in the northern Pacific Ocean when such an extratropical cyclone passes, the extratropical cyclone is blocked and the duration of wet snowfall is longer. Unless several events, each of which is not likely to occur, are combined, wet snow accretion on wires does not develop greatly. This is supported by records of the past half a century that there have been no cases of recurrence of large-scale accidents in a relatively small area.

Accordingly, in Japan, it is not very efficient to install an expensive test line, and if were installed, it would provide little effective data.

Accreted snow metamorphoses rapidly, so it is difficult to observe snow accretion in the "generated state" unless it is monitored on a manned basis.

To counter this, the authors prepared an observation manual for snow accretion and requested all the electric power companies in Japan to observe natural snow accretion on the existing power lines and test lines according to the manual, and obtained a lot of data over seven years. However, most was from the existing lines. The density data were guess values or measurements of the accreted snow, which had dropped off from the wires and, in many cases, had been subjected to metamorphosis. It was often the case that the meteorological parameters were available not from the site, but from a nearest metrological observatory. Wet snow accretion is a phenomenon very sensitive to air temperature, as discussed below, and thus, the absence of temperature measurements at the site was a critical drawback to analyzing the observation results. These are typical reasons for the difficulties encountered in Japan when advancing studies on natural snow accretion on wires in Japan.

III. Relationship Between Characteristics Of Snow Accretion And Meteorological Parameters

As discussed above, it is difficult to observe natural snow accretion, and, in order to design new power lines and to improve the existing lines in a streamlined way, snow loads on wires should be estimated over a long return period (more than 50 years). Just as in the case of the ice load, therefore, it is necessary to establish a technique to estimate snow loads on wires based on meteorological parameters that are available over a long period.

In Japan, about 150 Meteorological Observatories provide data on meteorological parameters over a long period. The Automatic Meteorological Data Acquisition System (AMeDAS) located at about 1,500 sites also provides such data recorded for every hour over the past 30 years or so. Although some of the parameters, such as wind speed and wind directions, are not very reliable because of the locations of the observatories/systems, they are still quite valuable data sources. One of the main purposes of the authors' studies was to develop a model to estimate the snow loads from that data.

The authors conducted wind tunnel experiments, collected the data of natural snow accretion and analyzed the faults encountered. They examined the dependence between the characteristics of snow loads and the parameters that plausibly have significant effects on those loads, and obtained the knowledge about the dependence, although did not attain the goal due to the above restrictions. This chapter briefly discusses the tendency between the characteristics and the parameters.

A. Density of Accreted Snow

From the multiple regression analysis of the results obtained by the wind tunnel experiments, the relationship between the density of accreted snow and the meteorological parameters is given by the following equation:

$$\rho_s = 0.0671V - 0.0102V^{1.1} + 0.0574T - 0.0107P_n - 0.048 \quad (1)$$

where,

ρ_s: density of accreted snow (g/cm^3)

V: wind speed (m/s)

T: air temperature (℃), and

P_n: amount of snow passing around the wire per unit time (g/cm^2.h) = precipitation intensity x [1 + (wind speed/falling speed of snowflakes)^2]$^{1/2}$.

The equation implies that, since the temperature is between 0 and 3°C, wind speed affects the density most significantly. This is quite understandable if we consider that greater snow compaction takes place with the increased wind speed, and that the wind speed positively affects the heat transfer from the air to the accreted snow via sensible heat transfer, resulting in melting the snow. From the equation, it is also noticed that the density of accreted snow decreases with the increase in precipitation intensity, which can be explained from the decrease in the melting factor for snow.

This tendency was clearly recognized in natural snow conditions; however, the authors could not reliably quantify the dependence because the ranges of the parameters obtained from the observation were narrow and because the observation data were not sufficiently reliable.

B. Snow Accretion Efficiency

All snowflakes that pass around a wire do not accrete to the wire or the surface of the snow that has already accreted on the wire. Particularly when the wind speed was above 4-5 m/s, the collision factor was observed as being close to 1. However, snowflakes collide with a wire and this leads to breakage, which results some of them accreting on the wire and the rest are carried away by the wind.

From the results of artificial accretion experiments in which accreted snow takes the shape of a cylindrical sleeve (refer to [1]), efficiency (α) was deduced using the density and the mass of snow accreted per unit length that were measured soon after the experiment finished. Multiple regression techniques were also completed, with the accretion efficiency as the criterion variable and meteorological parameters as functional variables, and the following empirical equation was obtained:

$$\alpha = 0.624\exp\{-0.0865(T-3.27)^2\} \times \exp(0.621V - 0.0744P_n) \quad (2)$$

Here, the same notation is used as in (1).

This equation implies that the snow accretion efficiency has a dependency on air temperature represented as a curve comprised of rising and falling phases with a peak in the midcomprised of rising and falling phases with a peak in the middle, i.e., the efficiency is small at low temperatures, and it increases to a maximum with rising temperatures, then it turns to a decrease. In addition, the wind speed increases the accretion efficiency while the amount of snow passing around the wire decrease the efficiency. However, since the amount of snow that passes around the wire is a function of the wind speed, it is inferred, in a quantitative sense, that the rate of snow load does not keep increasing with the increasing wind speed, but it reaches the maximum at the middle wind speeds (about 7-10 m/s).

A similar analysis was applied to the observation results of natural snow accretion, and a same tendency was confirmed that the accretion efficiency relates to the wind speed and the temperature. However, it was impossible to reliably quantify the dependency of this relationship since the range of parameters in observations was too narrow with not much reliable data.

C. Torsional rigidity of wire

The torsional rigidity of the wire has a large effect on the development of snow accretion growth. As in the case of icing discussed by Poots, et al., [2], the shape of accreted snow/icing on a wire yields along the span when the torsional rigidity of wire is large. The authors mainly used ACSR 410 mm^2, with a diameter of 28.5 mm and a length of 2.5 m as a wire sample. They inserted springs into the wire at the support points on both ends to simulate the torsional rigidity at the center of each wire with a different span length. The results of the experiments showed that, in the case of a span of 350 m, snow accretion developed a cylindrical snow-sleeve growth relatively easily along the wire while, in the case of a span of 125 m, snow accretion did not take a cylindrical shape even in the center even with an extension of time for the experiment. In addition, when snow accretion did not take a cylindrical sleeve shape, the speed of load increase tended to reach a saturation point. This is the reason why counterweights are used in France and Japan to increase the torsional rigidity as a means to reduce the amount of wet snow accretion.

D. Shape of Sample Wire

The snow accretion growth develops in quite different ways between a multiple strand wire and a smooth cylinder wire. In the case of the smooth cylinder, a cylindrical snow-sleeve is formed along a sample wire that is rigidly fixed with no allowance for twisting. Meanwhile, in the case of a multiple stranded wire, with no twisting, no cylindrical snow-sleeve is formed, as mentioned above. Assumedly, this is because the capillary force, which is the main adhesive force for snow accretion in a non-freezing condition, is strong against the tensile stress but weak against the shearing stress, as Colbeck [6] points out. Therefore, the formation of the cylindrical sleeve on a cylinder wire occurs according to the growing process that includes piling of snow on a wire (first stage), sliding of accreted snow on a wire, which is horizontally projected, due to the force of gravitation (second stage), and repletion of the first and second stages. If the cylinder has a slight uneven surface due to deformation, somewhat like a stranded wire, accreted snow does not slide on wire, and follows the same growing process as with the stranded wire.

E. Empirical Model for Estimating Snow Loads Temporarily Used in Japan.

As discussed above, either of the results from the wind tunnel experiments or those from the observations of natural snow accretion provided useful information, but had some drawbacks that prevented the authors from directly applying the results to estimate snow loads for return periods. The density, among others, is the largest problem. Without estimating the density, the accretion efficiency cannot be calculated using the cylindrical sleeve model, even though the amount of accreted snow and the parameters are known. From the relevant literature, the authors found out that Finstead, et al. [7] proposed a model in which the accretion efficiency was inversely proportional to the product of wind speed and diameter of the body exposed to the action of wind. The authors then computed with this model by combining it with the tendency of the snow accretion efficiency obtained in the wind tunnel experiments, and obtained the snow accretion efficiency of the cylindrical snow-sleeve model, which is not significantly dependent on the density. Subsequently, they attempted to find values of the constants by best-fitting data by trial and error and determined the following equation as a temporary empirical model.

$$W = 4.5\,\frac{\exp\left[-6\left\{(T/T_d)-0.32\right\}^2\right]}{V_n^{\,0.2}}\,P_n t \quad (3)$$

where, T_0 is a boundary air temperature that determines whether precipitation is rain or snow. This is introduced because such temperature is different according to the synoptic meteorological conditions in precipitation. Although this equation is now temporarily used, improving it is an important task yet to be solved, as well as the issue of statistical distribution as discussed below. The research is still continuing.

F. Shedding of Accreted Snow

It is important to know the conditions where accreted snow drops off the wire when estimating snow loads and unequal tensile stresses between conductor spans or phases. At the present time, it is impossible to quantitatively determine the conditions for accreted snow to drop off the wire. This subsection briefly discusses the tendency of such conditions from the viewpoint of the experiments and observations so far.

First, there were many cases where a part or all the snow accreted on a wire spontaneously dropped off in the wind tunnel experiments. However, shedding of snow occurred randomly. For example, under the same experimental conditions, accreted snow was formed into a cylindrical snow-sleeve in one experiment. In a second experiment, it was shed off the wire, and in a third experiment, it was but partially shed . The authors attempted to find the difference in the conditions between causing and not causing shedding, but failed to do so. Nonetheless, the following tendencies were found in relation to the parameters.

(a) Accreted snow of smaller density tends to drop off more easily than that of larger density.

(b) When the wind speed is high, the external force, which exerts on accreted snow with the eccentric weight, is greater. Although with the increase in wire twisting, the accreted snow does not tend to drop off easily.

(c) The probability that accreted snow drops off the wire does not significantly depend on the air temperature.

(d) A sample wire with greater torsional rigidity tends to shed the accreted snow more easily than a sample wire with smaller torsional rigidity.

(e) Once accreted snow completely wraps a wire, it is very unlikely to drop off.

It should be pointed out here that, when accreted snow begins to melt because of air temperature rise, solar radiation, energizing the wire, etc., the liquid-water produced by melting flows down to the bottom of the accreted snow due to gravity. This phenomenon is significantly recognizable particularly with accreted snow of a density of less than 0.6 kg/m^3. The authors conducted experiments where the cylindrical snow-sleeve was produced along the wire sample in a wind tunnel facility. Then, as a first case, the accreted snow was melted and shed off by energizing the wire, and, as a second case, it was sprayed with water. Subsequently, they measured the liquid-water content at each level of the accreted snow with a calorimeter method. In both of the cases, water droplets dropped from the bottom-side of the accreted snow, and, even when the bottom-side of the accreted snow became saturated with liquid-water and appeared to be transparent, the liquid-water content in the upper level did not significantly increase. This leads to an assumption that liquid-water moves through the accreted snow in the melting process.

These tendencies mean that, once snow accretion has been formed into a cylindrical sleeve, it hardly drops off spontaneously until the melting substantially progresses. This suggests that inhibiting the formation of a cylindrical snow-sleeve may be one way of reducing the load of accreted snow.

However, it needs to be noted that the shape of accreted snow, then, tends to be the same over a span, and galloping is more likely to occur there.

G. Topography of the area where wet snow accretion occurred

In Japan where large wet snow accretion occurred, the topography was flat. For example, Sendai, where heavy damage occurred on power lines due to wet snow accretion in 1980, is located in a flat plain near the Pacific Ocean. Meanwhile, a recent study in Iceland [8, 9] reports cases of significant snow accretion observed on the windward or leeward of a mountain, which is attracting concern. Also in Japan, there have been snow accretion events that are inferred as being affected by meso-scale or macro-scale meteorological disturbances, too. This may be a target of future research.

IV. Statistical Distribution For The Occurrence Probability Of Snow Load On Overhead Wires

Although the phenomenon of snow accretion is rare in Japan, it is a big issue in areas where, once the snow accretion occurs, it is likely to produce heavy loads on the wire. The authors assume that areas in Japan on the Pacific Ocean side fall just within such areas of concern, and that the areas in France near the Mediterranean Sea about which Pezart [10] reports might be similar to them. In fact, the authors attempted to estimate the loads of snow accretion in areas on the Pacific Ocean side using the meteorological records of the past, and found that, in many of the areas, the mean value of the snow load is very small with its standard deviation several times the mean value. For example, this is clearly represented by the fact that there was no snow cover in the winters of 2002-2003 and 2003-2004 in Tokyo.

On the other hand, areas on the Sea of Japan side more frequently encounter snow accretion events, and the mean value of the snow load is larger with its smaller standard deviation. The distribution tolerably fits the Extreme Value Distribution (type I).

IEC 60826 [11] recommends using a gamma distribution in such cases, but it is not easy to determine the distribution parameters because observation is difficult in the areas as described above.

The authors consider that one method is to conduct a probabilistic study of combinations and statistical analysis based on the statistical methods and correlations between data by focusing on the parameters for snow accretion, i.e., as is clear from the above, (a) precipitation intensity, (b) duration of precipitation, (c) air temperature, and (d) wind speed and wind direction in relation to the wire. This is an important issue yet to be studied.

V. Concluding Remarks

This paper mainly describes the authors' views centered on their studies of wet-snow accretion on overhead wires. As pointed out here and there, wet snow accretion occasionally causes heavy damage to overhead wires, and there are still many issues remaining for future study because of many difficulties involved.

One way to solve them is, in the authors' opinion, for the engineers and researchers who are facing these issues in the world come to have a common recognition of such issues and their solutions, and internationally cooperate with one another to collect relevant data. Specifically, creating formats to collect necessary information will lead to promoting data collection according to each matrix of relevant parameters, as is being conducted in CIGRE. From this viewpoint, the Guidelines for Field Measurement of Ice Loadings [12] recommended by CIGRE are very useful.

Many alternative measures on power lines, including prevention of snow accretion, failure prediction and prevention of cascade faults, have been targeted, at least, for areas such as those on the Pacific Ocean side in Japan, where heavy snowfall is rare but if it does occur the result is wet snow accretion with large loads, In that respect, the studies conducted in WISMIG are of great concern.

This paper highlights the issues yet to be solved based on information obtained from the studies by the authors and many papers available mainly through IWAIS. The authors collected and read so many papers that they could not list all of them in the references. The authors are very grateful to the authors of the papers that could not be listed, and apologize to them.

Finally, the authors expect steady efforts and early solutions for this complicated issue of wet snow accretion.

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[12] *Guidelines for field measurement of ice loadings on overhead power line conductors*, CIGRE Task Force 22.06.01,CIGRE, Technical Brochure 179, 2001.