Snow Accretion Properties of Various Insulators Exposed to an Artificial Wet Snow Accretion Test

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***Abstract* - Artificial snow accretion tests were carried out with various types of insulators, including porcelain long rod, cap & pin, and polymeric insulators. A wind tunnel was used to deposit snow particles onto the insulators using snow taken from outside of the facility. Temperature of the wind tunnel and liquid water content of the snow was controlled to maintain desired moisture levels. Wind velocity was varied from 5 to 15 m/sec. Snow accretion properties of the insulators were evaluated by observation of the accreted snow shape and the time to bridging between the insulator sheds. The cap & pin insulator showed superior performance under conditions of wet snow accretion as compared with the long rod and polymeric insulators, as a result of their large shed spacing. Continuous observation of snow accretion on various types of insulators under natural conditions was performed in parallel. The observation system, which employs CCD cameras and inter-net terminals, was installed on an existing transmission tower in Niigata, Japan. During the winter of 2009, snow accretion on the insulators was observed on several occasions, which allowed us to confirm that snow accretion on the insulators during the artificial tests was very similar to that under natural conditions.**

I. Introduction

On 22 Dec. 2005, a severe wet snowstorm caused a large blackout in the Niigata Kaetsu area of Japan [1]. About 650 thousand households were affected, and the maximum duration of the blackout was 31 hours. This blackout was induced by the wet snow mixed with sea-salt which packed the sheds of a number of the 154 kV and 66 kV porcelain long-rod insulators. Conductor galloping of 275 kV transmission lines also contributed to the outage. In this event, large amounts of wet snow accreted on the insulators and filled the gaps between the sheds. The large amounts of sea salt reduced the insulation strength of the insulator strings that caused flashovers. This flashover phenomenon was quite different from well known phenomena caused by ice accretion or snow cover on the insulator strings.

While large amounts of research has been performed on ice accretion and snow cover on insulators [2-7], knowledge related to the effect of salt-containing wet snow is very limited, as these conditions are quite rare.

The Central Research Institute of Electrical Power Industry, CRIEPI, started comprehensive research project, “The Research of Wet Snow Related Failures on Overhead Transmission Lines” in July 2007 as a result of the outage. As a part of the project research, a Task Force on failures caused by wet snow packed with sea-salt on insulator strings deals with clarifying the mechanism of failure and establishing effective countermeasures. The authors have reported the phenomenon of wet snow packed with sea-salt on insulator strings and qualitative properties of wet snow accretion of various types of insulators in artificial wet snow accretion tests [10]. This paper provides a brief overview of the wet snowstorm in Niigata Kaetsu area and presents the results of quantitative analysis of the basic properties of wet snow accretion on insulator strings based on the artificial wet snow accretion tests.

II. Blackout in Niigata Kaetsu Area

A strong low pressure system in Pacific Ocean moved from south to north along the east coast of Japan’s Main Island, and another low pressure system in the Sea of Japan moved across the island on 22 Dec. 2005. The ambient temperature in Niigata Kaetsu area, which is located in the north west of the Japan Main Island facing the Sea of Japan, stabilized in the range of 0 to +2 degree Celsius on 22 Dec. with heavy precipitation and wind [1].

The cascading electrical failures on 154 kV and 66 kV transmission lines started at just before 9:00 morning and resulted in numerous tripped lines. At about the same time, a couple of 275 kV transmission lines also tripped as a result of conductor galloping. A total of 30 transmission lines with 49 circuits tripped and induced a blackout over a large area.

Many porcelain long rod insulator strings at 154 kV and 66 kV transmission lines were packed with wet snow as shown in Fig. 1. The shapes of packed snow on insulators were cylindrical or eccentric pennant into the wind direction. The volume density of the snow ranged from 0.54 to 0.94 g/cm^3, and the maximum conductivity was approximately 0.2 mS/cm.

III. Artificial Wet Snow Accretion Tests

Artificial wet snow accretion tests were carried out using a wind tunnel test facility of a cable manufacture, J-Power Systems Corporation, at Echigo-Yuzawa, Niigata. Snow accretion properties of various insulators were evaluated with a range of shed profiles.

Fig.1 Example of packed snow on horizontally mounted long rod insulator strings.

Fig. 2 is a photo of the wind tunnel and the test set-up. A wind generator, the size of 1,500 × 500 mm, is located in the center of the tunnel, and temperature inside the wind tunnel can be controlled over the range of -5 to +5 degree Celsius. Wind velocity can be increased up to 20 m/sec.

Natural snow kept in a freezer and exposed to the ambient temperature around +2 degree Celsius for a while before the test, to control the liquid water content (LWC) of the snow. Then, the snow particles were drop into the front of the wind generator through a mesh by hand. The snow particles were flowed towards the insulators by wind.

Table I shows the test conditions. Wet snow that contained about 5 to 8% liquid water was used for the tests, because dry snow, 0% of LWC, never accreted on the insulator surface. Conductivity of the snow was about 0.05 mS/cm.

Table II shows the specifications of the test insulators. 66 kV porcelain long rod, cap & pin, and polymeric insulators arranged horizontally and vertically were tested, and the snow accretion properties were compared.

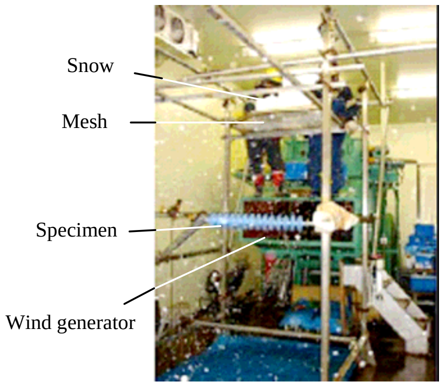


Fig. 2 Artificial wet snow accretion test set-up.

IV. Snow Accretion Properties of Various Insulators

A. Long Rod Insulator, Horizontal Set-up

Snow easily accreted on the windward side of insulator surface (Fig. 3(a)). After a while, the snow slid gradually downward along the insulator surface due to its own weight and the wind pressure, followed by moving further to the leeward side of the insulator. Finally, the snow became packed and grew to a cylindrical shape. For the case of high wind velocity, snow accretion was slowed comparing with the low wind velocity.

TABLE I Test Conditions

Items	Values
Volume density of snow	0.2-0.3 g/cm^3
Water content of snow	5-8%
Temperature inside wind generator	Around 2 degree Celsius
Wind velocity	5, 10, 15 m/sec
Precipitation	Approx. 5 mm/h

TABLE II Specifications of Test Insulators

Items	Long rod 8A	Cap & Pin 250 mm×6	Polymeric
Total length (mm)	1,175	876	1,200
Creepage distance (mm)	2,470	1,680	2,640
Shed diameter (mm)	160	254	135
Core-rod diameter (mm)	80	-	30
Shed spacing (mm)	40	170	65

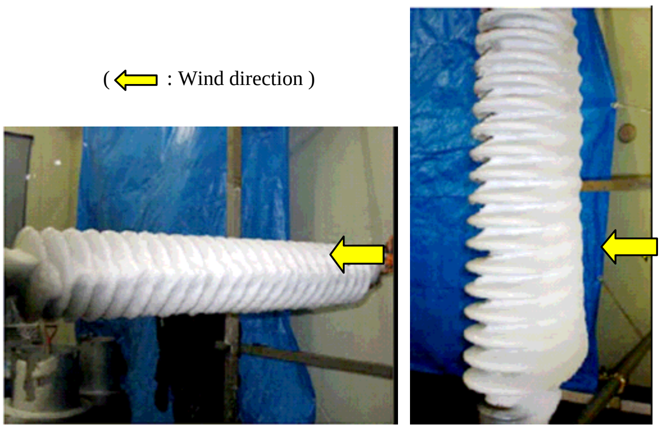
In the snowstorms in Niigata Kaetsu area and Okhotsk area, cylinder like shapes of packed snow were observed on some long rod and line post insulators, as see in Fig. 1. The shape of packed snow seems to be relatively similar with the artificially packed snow.

The water in the packed snow tends to move downward and accumulate at the bottom part of the insulator. The LWC of the pack snow near the bottom becomes larger than that the other areas. This migration of moisture possibly plays an important role for the flashover phenomena.

B. Long Rod Insulator, Vertical Set-up

The snow accreted on the windward side of the sheds and bridged between the sheds within a short time. Eventually a large amount of packed snow was formed on the windward side, especially in the case of low wind velocity. The shape of accreted snow was not cylinder like, but like eccentric pennants into the wind direction. Fig. 3(b) shows the snow accretion after the test.

Time to bridge between the sheds for the vertically mounted insulator was shorter than that of the horizontal one. In the vertical arrangement, the upper parts of the sheds are easily covered with snow, and thus the sheds are easily bridged. The movement of water to the bottom part of packed snow was seen as same as horizontal set-up.



(a) Horizontal set-up (b) Vertical set-up

Fig. 3 Snow accretion on long rod insulator.

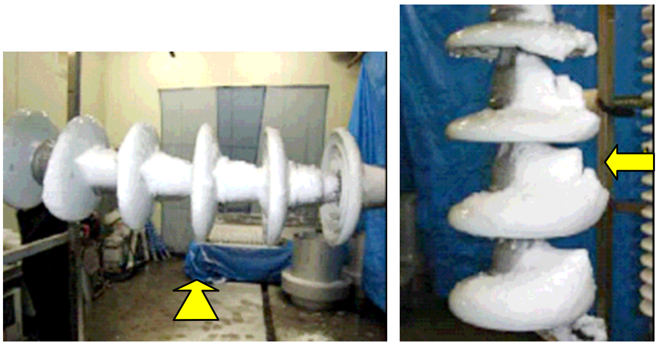
In the vertical set-up, cylinder like snow accretion was also reproduced by swing the wind direction about 30 degrees periodically. Accreted snow on the shed surface slid to the leeward side gradually and consecutive snow accretion on the windward shed surface formed a cylindrical shape finally.

C. Cap & Pin Insulator, Horizontal Set-up

Snow accreted on the cap parts firstly, but it tended to be removed easily by its weight and never grew to bridge between the sheds. Fig. 4(a) shows the snow accretion after the test. As cap & pin insulator had a large shed diameter and large shed spacing, snow accretion could not grow to bridge between sheds and tended to be removed by its weight.

D. Cap & Pin Insulator, Vertical Set-up

Snow accreted on the upper part of the sheds and finally bridged between the sheds in a packed condition. Fig. 4(b) shows the snow accretion just before bridging, and it shows the comparison between the cap & pin insulators and the long rod insulator. As the shed spacing of the cap and pin type was much larger than that of the long rod type, the time to bridge of the cap & pin insulators was about 5 times longer than that of the long rod insulator.



(a) Horizontal set-up (b) Vertical set-up

Fig. 4 Snow accretion on Cap & Pin insulators.

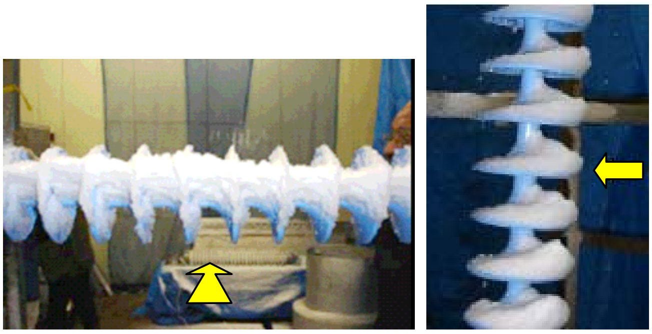
E. Polymeric Insulator, Horizontal Set-up

Snow accreted on the core rod at first and then gradually packed, followed by bridging between the sheds. Fig. 5(a) shows the snow accretion after the test. The shape of packed snow was like eccentric pennants into the wind. The snow tended to be blown off easily by wind in comparison with the porcelain long rod insulator. This might be the result of smaller core diameter of the polymeric insulator in comparison with the long rod insulator, which result in a smaller contact area between the surface and snow particles. The shape of the accreted snow was not cylinder like but eccentric perpendicular into wind.

F. Polymeric Insulator, Vertical Set-up

Snow accreted on the upper part of the sheds at first, and finally bridged and packed between the sheds as shown in Fig. 5(b). The time needed to bridge of the polymeric insulator was about two or three times longer than the long-rod insulator. As the shed spacing of the polymeric insulator was larger than that of the long rod, the time to bridge of the polymeric insulator was longer than that of the long rod insulator.

The polymeric insulator maintained hydrophobic surface during the test, but the hydrophobicity seemed to have little effect on snow accretion. The shed profiles appear to be more important than the shed materials.



(a) Horizontal set-up (b) Vertical set-up

Fig. 5 Snow accretion on Polymeric insulator.

G. Comparison of Time to Bridge between the Insulator Sheds

For the evaluation of the time to bridge between the insulator sheds, electrical measurements were employed to detect the bridging as a decrease in insulating strength. Electrodes were attached at the edge of insulator sheds at an interval and leakage resistance between the electrodes was measured continuously.

Fig. 6 shows a comparison of the time to bridge between the insulator sheds. Relation between the wind velocity and the time to bridge of various insulators are plotted. Results of the polymeric insulators having different sheds profiles, standard type of 65 mm shed spacing and alternating shed type of 70 mm shed spacing, are shown in fig. 6.

All insulators showed that increase of the time to bridge with increase of the wind velocity. Also, the larger shed spacing resulted increase of the time to bridge and less possibility of the bridging. It was clearly confirmed that the shed profiles affected the wet snow accretion properties.

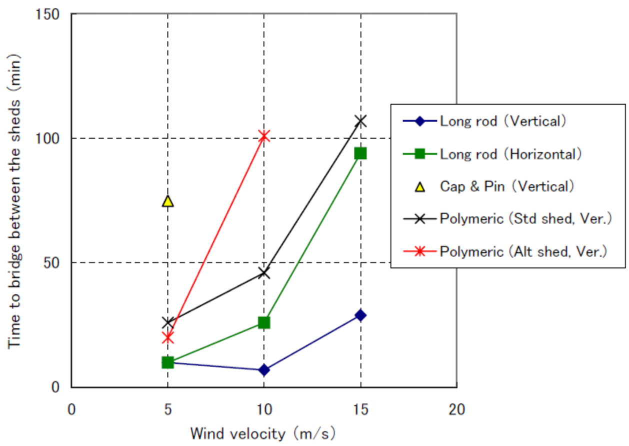
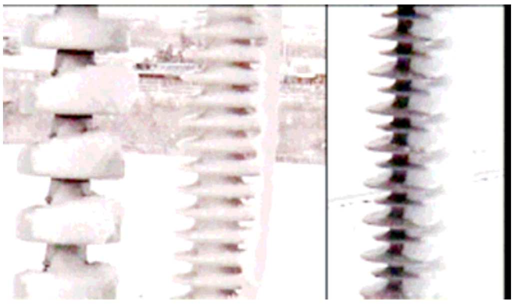


Fig. 6 Relation between the wind velocity and the time to bridge of various insulators.

V. Observation of Snow Accretion on Various Insulators under Natural Conditions

Continuous observation of snow accretion on various types of insulators under natural conditions was performed at the Niigata area, in parallel with the artificial snow accretion tests. The observation system, which employed CCD cameras and inter-net terminals, was installed on an existing transmission tower. Long rod, cap & pin, and polymeric insulators were mounted in the middle section of the tower without voltage application. Photos of the target insulators and the climate condition were recorded every 10 minutes.

During the winter of 2009, snow accretion on the insulators was observed on several occasions. Although the wind velocity was lower than 5 m/sec in the most occasions, aspects of the snow accretion and bridging between the sheds were observed as shown in Fig. 7. It looked to be similar with the artificial tests and confirmed that larger shed diameter and the larger shad spacing resulted in smaller amounts of snow accretion and the less possibility of bridging. Which allowed us to confirm that snow accretion on the insulators during the artificial tests could reproduce that under natural conditions.



Left to right: Cap & Pin, long rod, polymeric insulators, vertical set-up

Long rod insulator, horizontal set-up

Fig. 7 Snow accretion on various insulators under natural conditions.

VI. Conclusions

Artificial snow accretion tests were carried out with various types of insulators. Snow accretion properties of the insulators were evaluated by observation of the accreted snow shape and the time to bridge between the insulator sheds. Continuous observation of snow accretion on various types of insulators under natural conditions was also performed in parallel. The results were summarized as follows.

(1) Shed profiles affected the wet snow accretion properties. Larger shed diameter and larger shad spacing result in smaller amounts of snow accretion and less possibility of bridging between the sheds. Thus, the cap & pin insulators performed the best, the polymeric insulators were the second, and the long rod insulator was the most vulnerable to the packed snow.

(2) Bridging between the sheds can be easily formed for the vertically mounted long rod insulator rather than the horizontally mounted one.

(3) Water inside the packed snow tends to move downward and accumulate near the bottom of the insulator. LWC of the bottom part of packed snow become larger than that of the other parts. Water migration possibly plays an important role in the flashover mechanism.

(4) As the results of comparison between the artificial tests and the field observation, it was confirm that snow accretion on the insulators during the artificial tests could reproduce that under natural conditions.

VII. Acknowledgement

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