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Electrical Properties of Snow

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Abstract: This paper reviews the parameters that affect the electrical properties of snow. All the parameters listed are important, but some have a special merit for the characterization of the electrical properties of snow. The most important are volume conductivity and density, followed by the liquid water content and conductivity of water melted from snow. The dc conductivity and liquid water content as a function of snow density and temperature were measured and the relationships between them were determined.

Introduction

When designing insulation coordination of transmission lines and substations, emphasis is placed on the environmental and meteorological conditions of the routes or sites. The insulation design for a contaminated area is based on the contamination withstand-voltage characteristics under the operating voltage. In Nordic regions, yearly snowfall is between 70 and 300 inches [1-3]. Besides mechanical damages, the accretion of ice and wet snow on outdoor insulators causes a considerable reduction in their electrical performance [1-3]. Especially in heavy snowfall areas, sometimes wet snow and superimposed contamination cause flashover faults on insulators [2, 4-7]. Actually, flashover faults of snow-covered insulator strings, due to switching surges or ac operating voltage, have been experienced in Japan, Canada, and other cold-climate countries [2, 4-7]. Such problems generally appear on tension insulator assemblies, and rarely on suspension assemblies, since tension assemblies are more prone to large amounts of snow accumulation [2]. In order to understand the flashover processes of snow-covered insulators, and to establish design criteria for outdoor insulators, the electrical characteristics of natural snow should first be investigated.

Although the determination of those parameters is amongst the most important, to the best of our knowledge, very few studies have been carried out on this aspect. Therefore, this paper reviews the major parameters affecting the electrical properties of snow, such as temperature, contamination, volume conductivity and density, liquid water content, and conductivity of water melted from snow [2]. The liquid water content and dc conductivity were measured as a function of volume density and temperature for a large number of snow samples, in order to establish whether any relation exists between them.

Review of parameters affecting electrical properties of snow

Dry snow behaves like an insulating material made of air and ice [9], that is to say, it is a two-component system. Considerable air is trapped in miniscule pockets among the individual ice crystals comprising the snow cover. When wet, the snow becomes a three-component system composed of air, ice, and water. Wet snow is treated as a three-phase mixture, considering the ice and water particles as inclusions embedded in air, which is the background material.

There is a fundamental difference between wet and dry snow since liquid water causes major reconfigurations of both grains and bonds [8, 9]. Within the wet and dry snow categories there are also two important divisions: wet snow at low and high liquid contents, and dry snow at low and high growth rates. Wet snow is less cohesive and slushy at high liquid contents because the grain boundaries are unstable against pressure melting [9].

However, wet snow is well-bonded at low liquid contents, where ice-bonded clusters form. A transitional form of snow, melt–freeze grains, can be either wet or dry. These amorphous, multi crystalline particles arise from melt–freeze cycles. They are solid within and well-bonded to their neighbors.

The electrical properties of snow are altered according to the content of ice within it, that is, according to its density. The parameters characterising the electrical properties of snow are its volume conductivity, dielectric constant, salt content, water content, volume density, crystal structure and size, impurities, as well as the electric field and frequency to which it is submitted [8]. These properties also depend on geometric factors and contact of the electrodes with snow. However, it has been acknowledged that among these, the volume conductivity is the major parameter which affects the insulation characteristics of snow [2]. The volume conductivity is largely affected by its volume, density, and salt content [2], and thus, chemical analysis of snow collected from various places has shown that the conductivity of water melted from snow is due mainly to NaCl [10]. The salt content of snow is expressed by the conductivity of water melted from snow, which is corrected to the value at 20°C.

Results and discussions

For all the measurements carried out and reported here, samples of natural snow stored in a freezer at –20°C after collection were used.

Liquid water content: The free water content is defined as the ratio of the amount of water contained to the total weight of the wet snow. The free water content, LWC, is determined by separating the water from the snow, by putting the wet snow into a graduated test-tube (Figure 1) in a motor-driven centrifuge with a rotation speed of 1,700 rpm. The time of rotation was half a minute, to prevent the snow from melting during the operation.

Two test-tubes containing filters were especially designed for this purpose. These filters separate dry snow from the liquid water contained in the snow sample, as depicted in Fig. 1. Three wires are attached to the filter, which makes it possible to remove it from the tubes after each test. The amount water separated from the snow is then measured using the graduated scale.

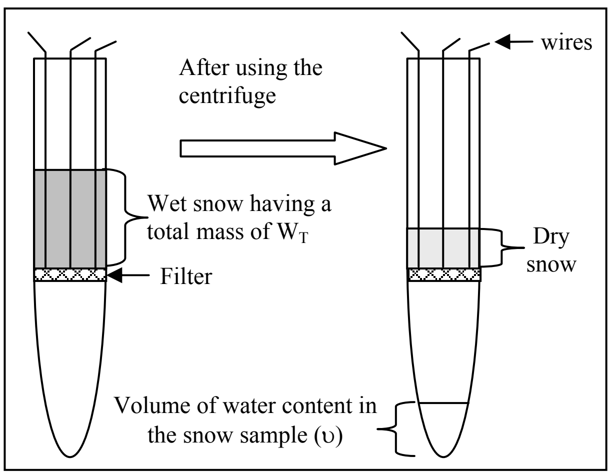

Figure 1: Test-tube before and after the utilisation of the centrifuge.

After each water-percentage test, the test-tubes are cleaned and dried, in order to avoid any deposit that could influence further measurements. After drying, the test-tubes are kept in a cold chamber at the same temperature as the snow sample in order to avoid further melting during centrifuge measurements. The temperature inside each snow sample is measured before and after the test using thermocouples, to determine an average value.

The weight of the water (M_W) extracted from the snow sample is then calculated:

$$M_W = \rho \upsilon \tag{1}$$

where ρ is the density of water (in g/cm^3) separated from the snow sample, and υ indicates the water volume contained in the snow. Water content in the snow sample is then expressed in percentage of the total mass of M_T, ie. the mass of ice crystals and water:

$$LWC = \frac{M_W}{M_T} 100 \tag{2}$$

Figure 2 depicts the results of some tests performed using snow sample having a density equal to 0.36 kg/m^3 with the measured conductivity of water melted from snow about to 83 μS/cm.

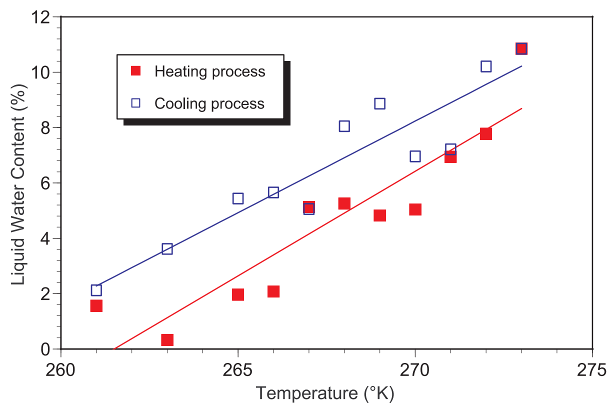

Figure 2: liquid water content according to the temperature.

Clearly, the liquid water content (LWC), determined either during heating or cooling of snow samples, increases with temperature. A mathematical approach to data suggests the existence of some kind of relationship between the LWC and the snow sample temperature (T_S). Indeed, the LWC can be described as a mathematical function of the temperature T_S represented by the solid-line curves, fitting the experimental data plotted in Fig. 2:

$$LWC = 0.76\,T_S - 200 \text{, for the heating process} \tag{3}$$

$$\text{and } LWC = 0.662\,T_S - 170.5 \text{ for cooling,} \tag{4}$$

where T_S is expressed in Kelvin (K).

DC conductivity of Snow: For this purpose, a snow sample was packed into a capacitive cell with guard rings so as to obtain a desired volume density.

Since the liquid water content is defined as the ratio of the amount of water contained in snow to the total weight of the snow sample, LWC suffers no alteration from packing. The capacitive cell used had a volume of about 190 cm^3. Figure 3 shows the experimental set-up used for measuring snow sample conductivity.

For the measurements, the capacitive cell was placed inside a small cold chamber, type 'Envirotronics EH40-

2-3' that had been pre-cooled to the desired temperature T_S. The air temperature accuracy, ± 1.1°C, was ensured by a microprocessor-based temperature-humidity programmer controller. Temperatures inside both the cold room and the snow sample were also recorded during the experiment.

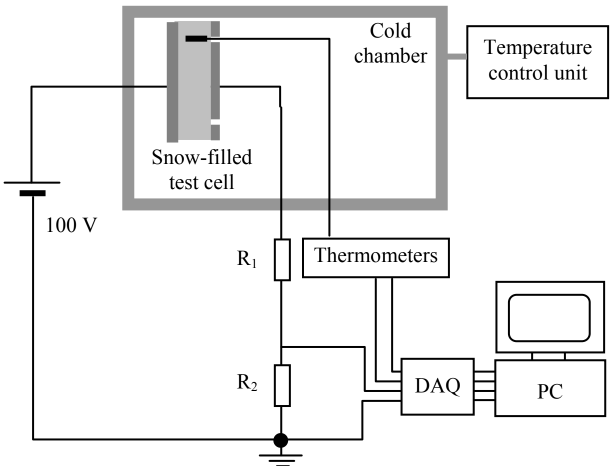

Figure 3: Experimental set-up used to determine the dc conductivity of the natural snow samples.

The temperature setting of the capacitive cell was changed every 15 minutes in both the heating and cooling processes, and the conductivity was measured just before the temperature changed to a new value.

The snow sample conductivity σ_S was calculated from the direct current strength flowing through a sample 2.4 cm in length and 78.5 cm^2 in section, and submitted to 100 Vdc (average field 41.25 V/cm). It should be noted that snow volume conductivity is independent of the applied electric field strength [10]. The current is sampled at a rate of 1,200/s, transferred to a data buffer and stored. The main components of the data acquisition system are a National Instrument DAQ plug-in board in a PC, and LabVIEW^{TM} application software. The data is stored as both ASCII text files and binary files. This ensures that the LabVIEW^{TM} data could also be analyzed further using other software applications like MATLAB^{TM}.

The resistance, R_S, of the snow sample in this circuit is calculated using the following basic relation:

$$R_S = \frac{V}{I} = \frac{l}{\sigma A} \qquad (5)$$

and so to speak the conductivity of the snow sample.

In addition to the conductivity, snow sample densities were measured.

Also, the chemical impurities of the snow sample, including NaCl, were quantified by measuring the conductivity of the water melted from this snow sample. Snow conductivity is well known to depend not only on snow temperature, but also on the density of the sample.

Some of the results, as a function of snow temperature for different densities of natural snow, collected in various places, for both the cooling and heating processes, are shown in Figures 4 and 5. The results show that the higher the density, the higher the conductivity of the snow sample.

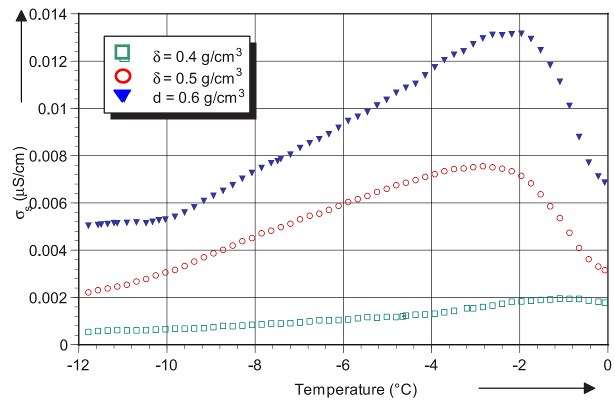

Figure 4: Effect of the density on the dc conductivity of snow in the heating process.

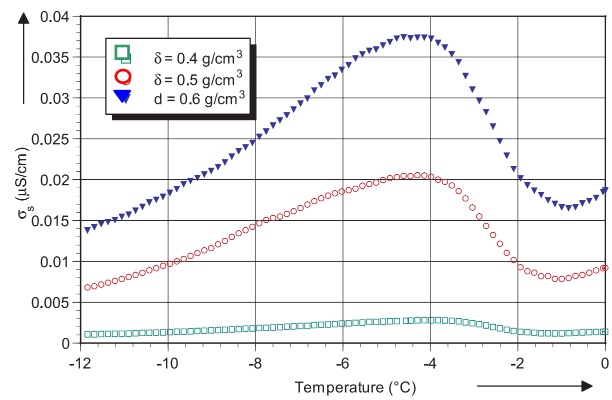

Figure 5: Effect of the density on the dc conductivity of snow in the cooling process.

By compressing snow, one breaks its structure, and increases the density and the surface of contacts between crystals. The resistance of the contacts to the passage of current influences the sample conductivity. Indeed, compression generates an increase in activation energy and, it follows, an increase in conductivity [10].

The conductivity values from -12°C to around the temperature corresponding to its peak value can be explained with data in Figure 3. Indeed, liquid water content increases as temperature of the snow sample increases. The presence of water in liquid phase, which increases with temperature, causes the electric conductivity to increase. Pure water is a poor conductor of electricity. It is the impurities in water, such as dissolved salts, that enable water to conduct electricity. The higher is the amount of impurities, the higher is the electrical conductivity. Thus, as the quantity of conductive liquid water increases, so does conductivity.

Figures 4 and 5 show that conductivity increases as the temperature increases, from -12°C to around the temperature corresponding to its peak value, and then decreases as the temperature increases from peak conductivity to the melting temperature. This is a curious behaviour because dc conductivity for ice generally increases with increasing temperature [10]. This apparently curious behaviour already observed by Takei et al. for low frequency [12] seems to indicate important changes of the texture of snow near the melting temperature.

Peak conductivities around -2°C and -4°C are respectively observed in the heating and cooling processes. This indicates that conduction mechanisms during heating and cooling processes may be different.

Figure 6 shows the temperature dependence of the dc conductivity for a snow sample having a density of 0.42 g/m^3 and the measured conductivity of water melted from snow equal to 41.2 µS/cm which undergone alternatively heating and cooling processes.

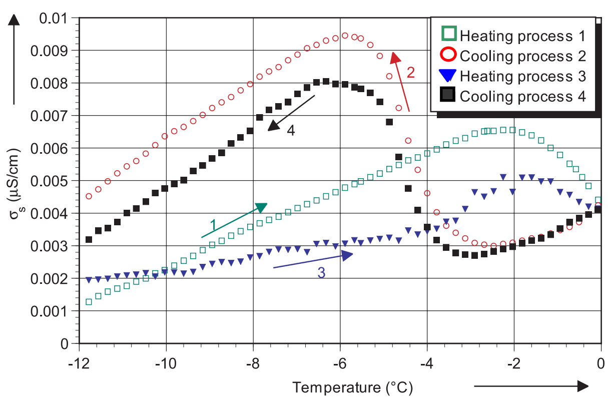

Figure 6: Temperature dependence of the dc conductivity for snow in the heating and cooling process sequences.

During the first heating process from -12°C to 0°C (sequence 1), part of the snow sample melts and transforms to ice when cooled down to -12°C (sequence 2). When heated again from -12°C to 0°C (sequence 3), a reduction in the dc conductivity is noticed. During the fourth sequence, the conductivity is also found to be lower than values obtained during the second sequence. Clearly, reorganisation of water molecules changes the microstructure of the snow sample, affecting considerably the properties of the latter.

Conclusion

The parameters that affect the electrical properties of natural snow have been considered. The liquid water content and dc conductivity were measured as a function of density and temperature for a large number of snow samples, and relationships were established between them. An apparently curious behaviour was observed in the temperature dependence of the dc conductivity of snow near the melting temperature. One of the most important consequences of such a curious behaviour for outdoor insulation coordination could indicate that temperatures corresponding to peak values of snow conductivity in both cooling and heating processes constitute a major factor determining the flashover performance of snow-covered insulators. The authors are engaged in a study to further investigate this curious behaviour, and they expect to publish their results in the near future.

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