Electrical Behavior of Snow Accumulated on a Post Insulator under AC High Voltage

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***Abstract*—Snow and ice accumulation on high voltage equipment like insulators, transmission lines and towers, may cause mechanical and electrical damage to power distribution networks. One of the major problems related to snow and ice accumulation is insulator flashover, which has been studied in several countries. In spite of a fairly good number of valuable investigations, these reviews reveal the necessity of further fundamental and comprehensive research on the physics of arc and its behavior on ice surfaces and inside snow. The main objective of this paper is to present an evaluation and determination of the electrical characteristics of snow and to introduce a mathematical model to simulate its behavior under alternating voltage at a power frequency of 60 Hz. From the V-I characteristics of snow, as shown in this paper, an insulator covered with snow acts as a pure resistance. However, the resistance of snow is not linear.**

I. KEYWORDS

Snow, v-i characteristic, non-linear resistance

II. NOMENCLATURE

V: Apply voltage.
I: Leakage current through the snow.
K_1, K_2, K_3: Model constants.

III. INTRODUCTION

Snow and ice accumulation on high voltage equipment like insulators and transmission lines and towers may cause mechanical and electrical damage to power distribution networks. For example, due to damage caused by galloping or steel jump, a number of short-circuits and outages of power systems have been reported [1]. Another major problem resulting from snow and ice accumulation is insulator flashover, which has been studied to some extent by researchers in several countries [2,3]. A number of worthwhile experimental investigations have helped further knowledge on the effects of snow parameters on the critical flashover voltage of insulators [4] and have led to the proposal of several mitigation methods. A comprehensive review of these investigations was reported in recent publications by IEEE and CIGRE Task Forces [5-6]. In spite of a good number of valuable investigations, these reviews revealed the necessity of further fundamental and comprehensive research on the physics of arc and its behavior on ice surfaces and inside snow.

Study of electrical behavior of snow and related laboratory experimentation on snow-covered insulators is currently being carried out within the framework of CIGELE/INGIVRE at UQAC. One of the main objectives of this paper is to present the evaluation and the determination of the electrical characteristics of snow and to introduce a simple mathematical model simulating its behavior under alternating voltage at the 60 Hz power frequency.

Snow is a two-component system made up of air and ice [7]. Furthermore ice in a snow crystal is not different from ordinary ice. In the case of wet snow, it becomes a three-component system composed of air, ice, and water. It is treated as a three-phase mixture, where ice and water particles are considered to be inclusions embedded in air, with the latter being the background material, as shown in Figure 1.

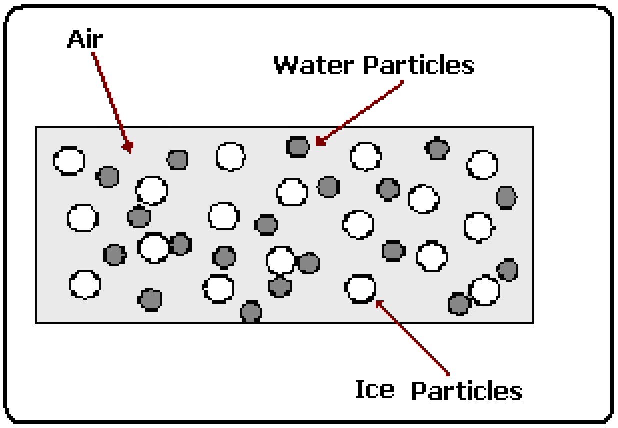


Fig.1: Wet snow as a three-phase mixture

The presence of water causes the electric conductivity of snow 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 the amount of impurities, and the higher the electrical conductivity. Thus, as the quantity of conductive liquid water increases, so does conductivity [8].

The conductivity of snow, as shown in figures 2 and 3, increases as 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 behavior because dc conductivity for ice generally increases with increasing temperature [9, 10]. This apparently curious behavior already observed by Takei et al. for low frequency [4] seems to indicate important changes in 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 4 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 have undergone alternative heating and cooling processes.

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, reorganization of water molecules changes the microstructure of the snow sample, affecting considerably the properties of the latter.

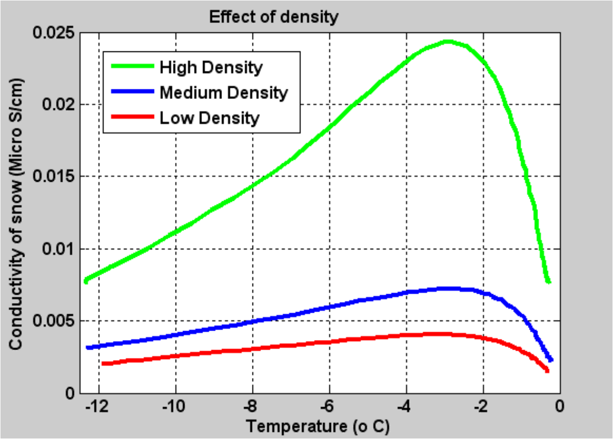


Fig. 2: Effect of the density on the dc conductivity of snow in the heating process

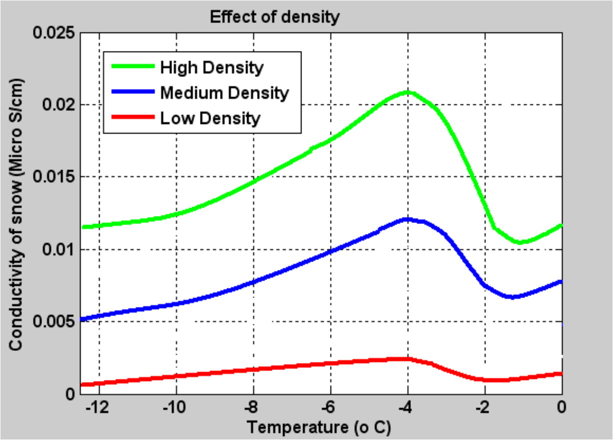


Fig. 3: Effect of the density on the dc conductivity of snow in the cooling process

The electrical properties of snow should be altered according to the content of water and ice within it, which is its density. The parameters characterizing snow are its resistive volume, dielectric constant, salt content, water content, volume density, particle diameter, crystal structure, impurities, and electric field frequency [5]. Electrical properties are dependent on the measurement method, e.g. contact with electrodes, etc. However, it has been acknowledged that among these parameters, resistive volume is the major parameter affecting the electrical characteristics of snow. The resistive volume of snow is largely influenced by its volume density and salt content [4, 7].

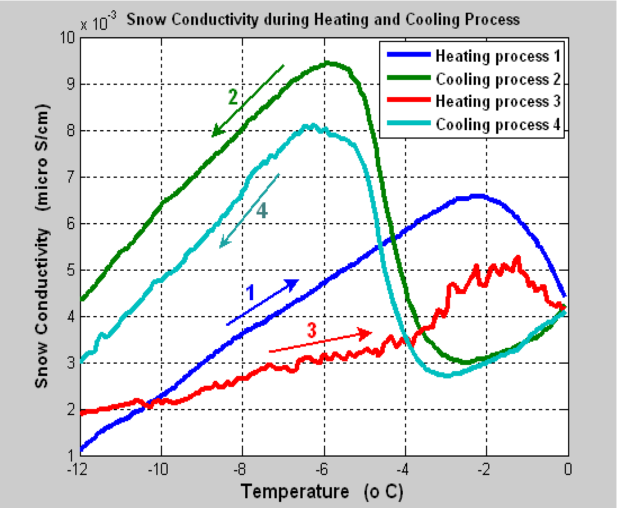


Fig.4: Temperature dependence of the dc conductivity for snow in the heating and cooling process sequences

IV. EXPERIMENTAL SETUP

Figure 5 shows the schematic diagram of the experimental setup, which consists of a 350-kV AC high voltage system and a vertical circulation climate room with sliding roof, which makes possible not only very realistic simulation of different types of atmospheric ice, but also the collection of natural cold precipitation, snow in particular. The setup also comprises a capacitance divider for applied voltage measurements, a shunt resistor to measure the current passing through the test object, and a data acquisition system. Natural snow was collected from the surrounding area of the laboratory and put manually on the horizontal insulator, where its density and impurity were measured.

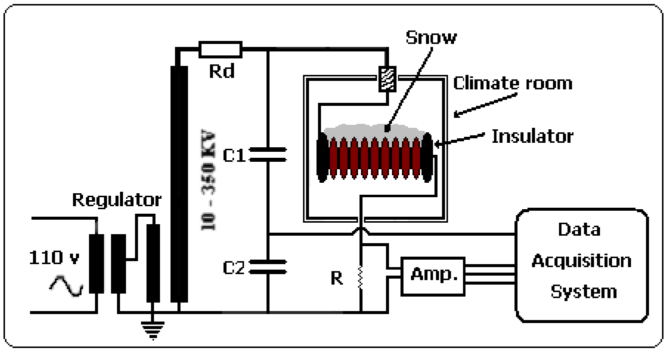


Fig.5: Schematic diagram of experimental setup

Figure 6 shows the test object and its equivalent electrical circuit. To cover the insulator with snow, the natural salt-contaminated snow is compressed using a custom-made frame, removed before voltage is applied. Before testing, the setup is placed in the climate room at -12°C for 2 hours. Applied voltage is then increased at a rate of 4.8kV/sec. The evolution of the current flow and voltage across the test sample is monitored using Labview software. Figure 7 shows voltage and current as a function of time with time interval in milliseconds and seconds respectively.

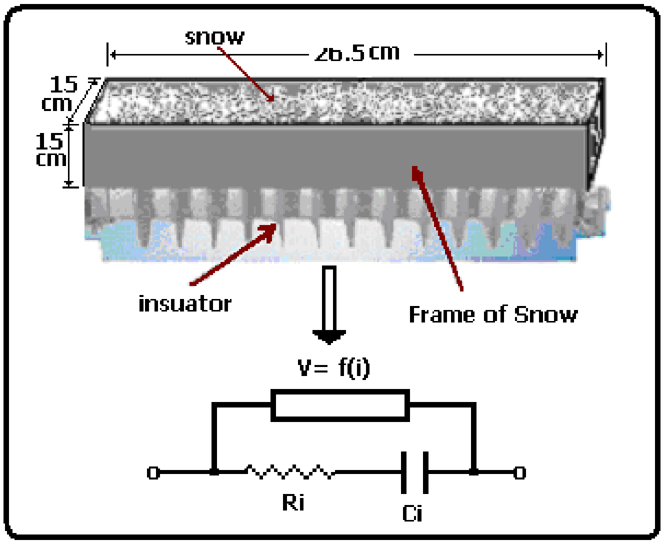
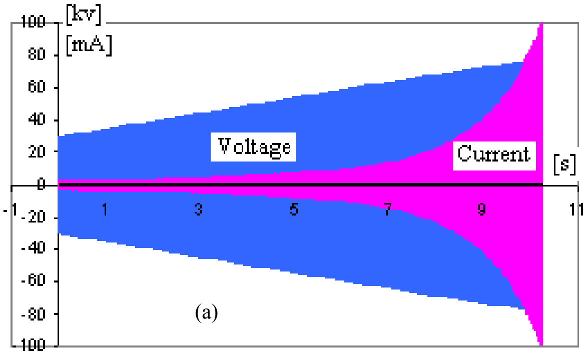


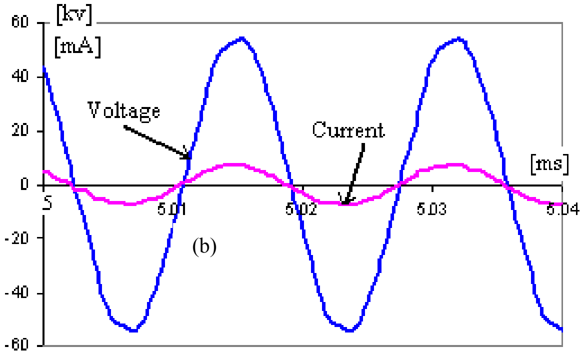
Fig.6: Test object and its equivalent electrical circuit.

V. RESULTS AND DISCUSSION

As shown in Figure 7-b, voltage and current are almost in the same phase, their phase difference being less than 2 degrees in all cases measured. This means that the insulator capped with snow acts as a pure resistance. Indeed, the capacitive impedance of the insulator in parallel with snow resistance at 60 Hz power frequency is very large and, therefore, may be neglected when compared to the snow resistance.



a) Time interval in seconds



b) Time interval in milliseconds

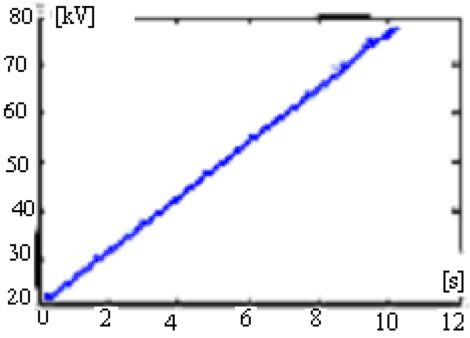
Fig.7: Evolution of voltage and current as a function of time.

Snow presents a milieu having only the resistive effect with non-linear V-I characteristics [11]. As shown on figure 8-a, if voltage across the snow increases linearly, the current flowing through it will increase exponentially (figure 8-b). Therefore, as the voltage across snow increases, the current flowing through it grows sharply (figure 8-c) and its resistance decreases rapidly as shown on figure 9. During each test, controlling and adjusting the density and conductivity of snow are not simple, and the V-I characteristic will be greatly affected by these parameters.

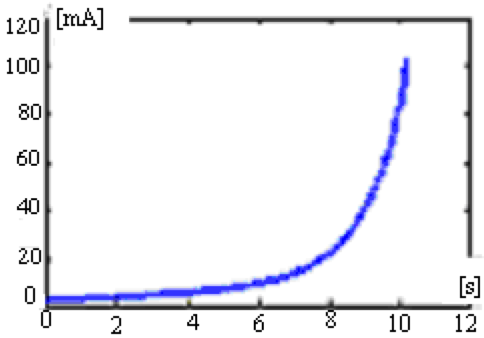
A mathematical model can be elaborated to establish the relationship between the voltage across a one centimeter layer of snow and the current flowing through it. Indeed, from the Figure 8-c, current may be expressed as a function of voltage by the following equation:

$$I = K_1 \exp(K_2 V + K_3) \tag{1}$$

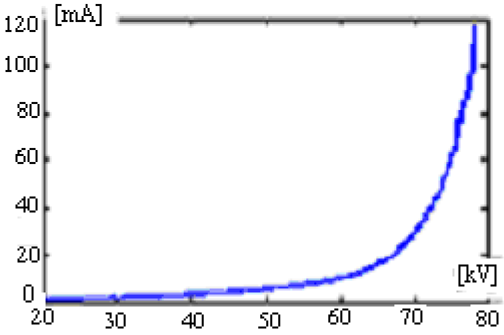
where V is the voltage in kV, I is the current in mA, and K_1, K_2 and $K_{3,}$ the constant coefficients depending on the snow characteristics (density and the conductivity of melting point of snow) and the frame dimensions for covering the insulator with snow.



a) time-voltage



b) time-current



c) current- voltage

Fig. 8: V-I characteristic of snow.

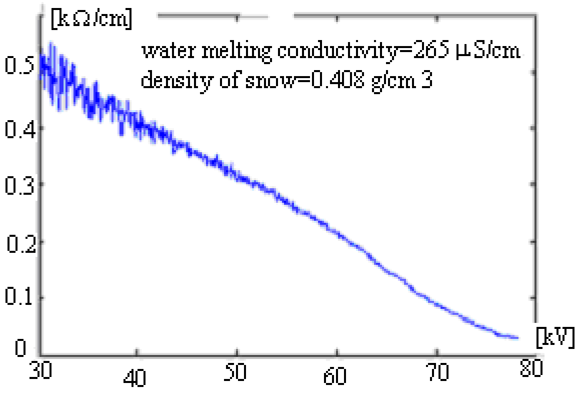


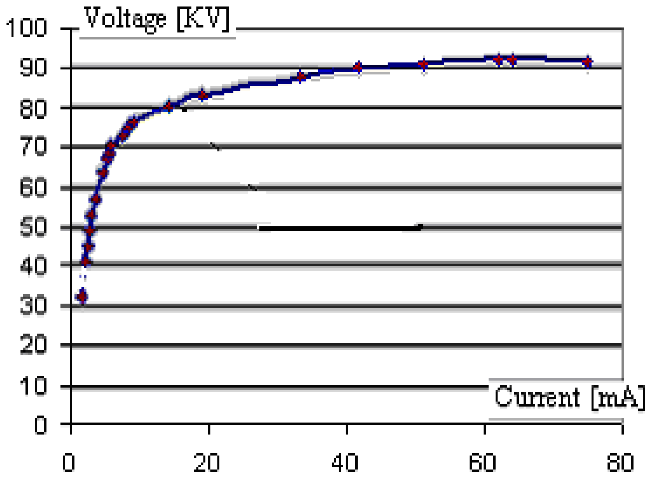
Fig. 9: Evolution of the resistance of snow as the function of applied voltage.

Equation (2) shows the relation between the current flow and applied voltage across snow with density and melting conductivity of 0.367 g/cm^3 and 85 $\mu S / cm$ respectively.

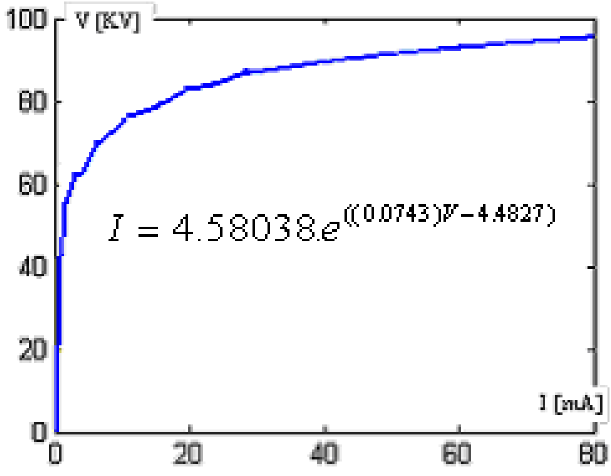
$$I = 4.58038 e^{((0.0743)V - 4.4827)} \qquad (2)$$

Figure 10 compares the v-i characteristics of the snow measured experimentally with those obtained using equation (2). It can be seen that there is in very good concordance between them.

As equation 2 shows, we can determine the v-i characteristics of snow as a function of the density and conductivity of its melting point. Using this equation allows us to obtain the v-i characteristics of snow by considering its density and its conductivity of melting point.



a) Experimental



b) Analytic

Fig. 10: Evolution of voltage across snow as a function of current through it.

VI. CONCLUSION

Experimental investigations have helped further our knowledge of the effects of snow parameters on the critical flashover voltage of snow-covered insulators, and have led to the proposal of several mitigation methods. However, the present study aims to further fundamental and comprehensive research on the electrical behavior of snow. From the V-I characteristics of snow, it is found that the voltage across snow and the current through it are almost in the same phase. This means that an insulator covered with snow acts as a pure resistance. Indeed, the capacitive impedance of an insulator in parallel with snow resistance at 60 Hz power frequency is very large, and therefore may be neglected. The resistance of snow is not linear, as it decreases faster than the voltage across it increases. Based on the experimental results, a mathematical model simulating the electrical behavior of snow is proposed.

The authors are engaged in a study to further investigate to develop a precise mathematical model for determining the electrical characteristic of snow as the function of the density and the melting point of snow which can be used in predicting of the flashover voltage of a snow capped insulator and they expect to publish their results in the near future.

VII. ACKNOWLEDGEMENTS

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