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V-I Characteristic of Snow and its Electrical Behavior under High Alternating Voltage

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Abstract:
In many cold climate regions of the world, ice and snow accretions on overhead transmission lines is sometimes the cause of mechanical damage to various equipment and flashover on insulators. This paper presents the results of a laboratory study on the electrical behavior of snow-covered equipment. From the results obtained, it has been found that the voltage across snow and the current through it are nearly in the same phase, which means that the snow acts as a pure resistor. This resistor is non-linear and varies by voltage applied across it. Based on the results, a mathematical model allowing simulating the electrical behavior of snow is introduced.

1-Introduction

Ice and snow accumulation on high voltage transmission lines may cause mechanical damage to towers and conductors, and increase the corona power losses of overhead lines. In addition, due to damage caused by galloping or steel jump, a number of short-circuits and outages of power systems, have been reported [1-2]. Another major problem under these conditions is insulator flashover, which has been studied to some extent by researchers in several countries [3-5]. A number of worthwhile experimental investigations have helped further knowledge on the effects of snow parameters on the critical flashover voltage of insulators [4-6] and have led to the proposal of several mitigation methods. A review of most of the investigations in this field was reported in recent publications by IEEE and CIGRE Task Forces [7-8]. 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.

As concerns the electrical behavior of snow, laboratory tests are currently being carried out on snow-covered insulators, within the framework of CIGELE/INGIVRE at UQAC. The main objective of the present study is to determine the V-I characteristics of snow and to introduce a mathematical model allowing to simulate its electrical behavior.

2- Parameters affecting the electrical characteristics of snow

Snow is a two-component system made up of air and ice [9], and the ice in a snow crystal is not different from that found in 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, the ice and water particles considered to be inclusions embedded in air, which is the background material, as shown in Figure 1.

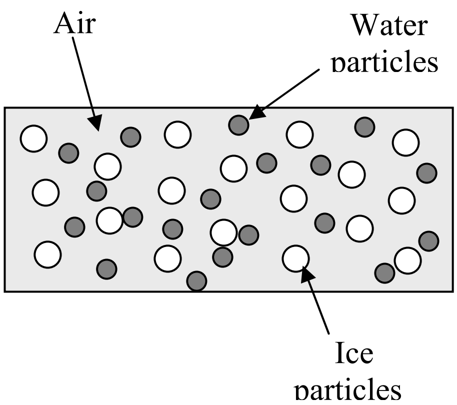


Figure 1: Wet snow as a three-phase mixture.

The electrical properties of snow should be altered according to the content of ice within it, that is, according to its density. The parameters characterizing the nature of snow are its resistive volume, dielectric constant, salt content, water content, volume density, particle diameter, crystal structure, impurities, and electric field frequency [8]. The electrical properties of snow also depend on geometric factors and contact with the electrodes. However, it has been acknowledged that among these, the resistive volume is the major parameter that affects the electrical characteristics of snow. The resistive volume of snow is largely influenced by its volume density and salt content [6, 9].

All the snow parameters listed in the literature [7-8] are important, but some have a special merit for the characterization of its electrical properties, such as those that are likely to vary significantly with snow purity and composition, as well as with external parameters, such as temperature, contamination, and electric field. These include resistive volume and density, followed by liquid water content and melted-snow conductivity. In this regard, an insulator is completely covered by snow and ac high voltage is applied. Then, the current that passes through this complex system is measured. More than fifty tests under various densities and contamination levels were carried out and the obtained results are described.

3- Experimental set-up

Figure 2 shows the schematic diagram of the experimental set-up, which consists of a 350-kV ac high voltage system, a vertical circulation climate room with sliding roof, making possible not only very realistic simulation of different types of atmospheric ice, but also the collection of natural cold precipitation, snow in particular. It is also comprised of a capacitance divider for applied voltage measurements, a shunt resistor to measure the current passing through the test object, and a data acquisition system [9]. Natural snow was collected from the surrounding area of the laboratory and put manually on the horizontal insulator, and its density and impurity were measured. The temperature of the climate room in each test was adjusted to -12°C.

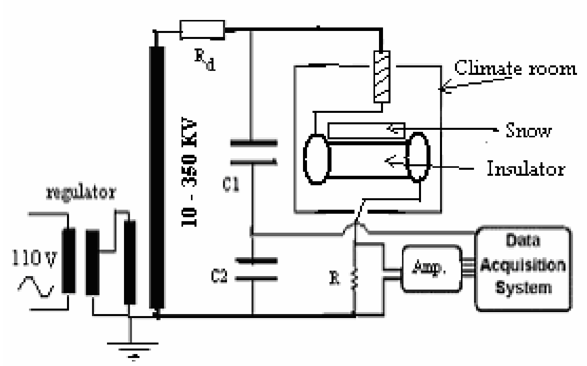


Figure (2) schematic diagram of experimental set-up

4- Observation of voltage and current

Figure 3 shows the experimental set-up and equivalent electrical circuit. To cover the insulator with snow, the natural salt-contaminated snow is compressed using a specially prepared frame, which is removed before voltage application.

The set-up is placed in the climate room at a temperature of -12°C for 2 hours. The applied voltage is then increased at a rate of 5 kV/sec. The evolution of the voltage across the sample and the current passing through it are monitored using Labview software.

Figure 4 shows an example of the variation of voltage and current as a function of time.

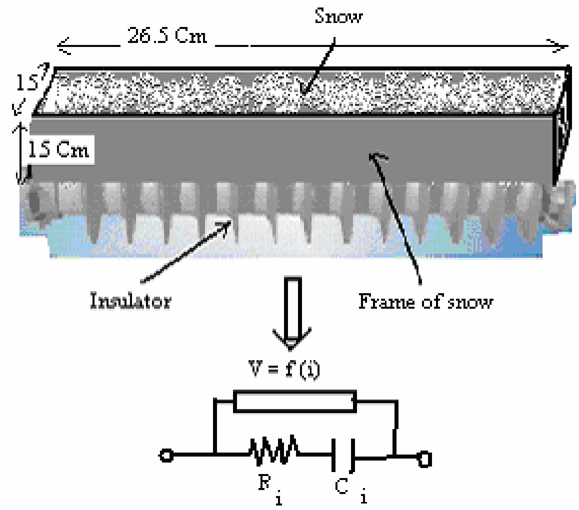
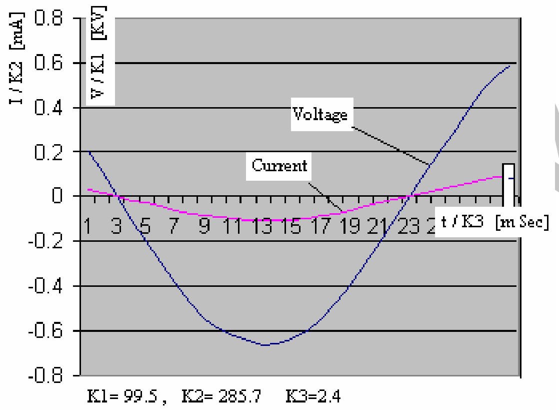
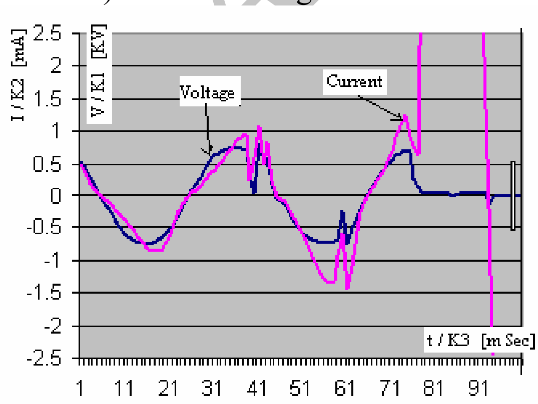


Figure (3) Experimental set-up and equivalent electrical circuit



a) Before voltage breakdown



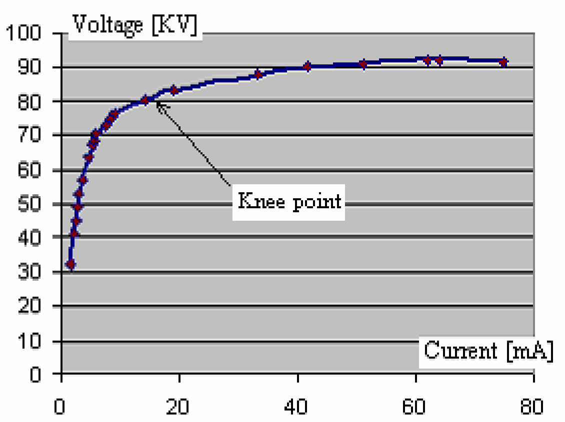
b) At the instant of voltage breakdown

Figure (4) Evolution of voltage and current as a function of time

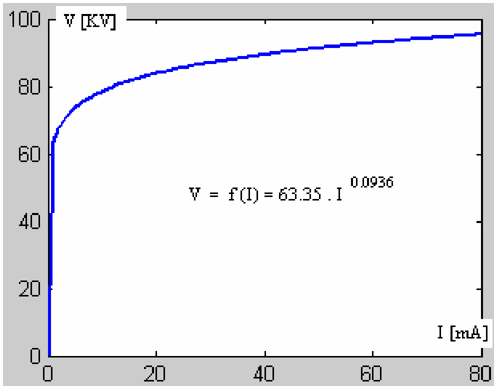
As shown in Figure 4, the voltage and current are almost in the same phase and their phase difference, in all cases measured, is less than 2 degrees. This means that the insulator covered with snow acts as a pure resistance. Indeed, the capacitive impedance of the insulator in parallel with snow resistance at 60 Hz power frequency is very large and, therefore, may be neglected. The resistance of snow is not linear and it decreases as the voltage across it increases, much like SiC or ZnO arrestors [11]. Figure 5 shows an example of voltage variation as a function of current through the snow, taken from the registered results of more than fifty tests. In all cases, the form of evolution is the same, but the rate of non-linearity of the V-I curve changes depending on snow density and contamination level. The relative resistance of the snow with a density equal to 0.367 g/cm^3 and water melting conductivity equal to 85 $\mu S / cm$ is shown in Table 1.

Table 1: Relative resistance of snow

No. of points	I [mA]	V [KV]	R [M Ω]	ρ [M Ω.Cm]
1	1.714	32.437	18.924	160.67
2	2.2856	41.093	17.984	152.69
3	2.571	45.173	17.57	149.18
4	2.857	49.053	17.169	145.77
5	3.143	53.133	16.905	143.53
6	3.714	57.013	15.350	130.33
7	4.857	63.779	13.131	104.73
8	5.428	67.162	12.373	105.05
9	5.714	68.555	11.998	101.87
10	5.999	70.446	11.743	99.70
11	7.714	73.033	9.468	80.39
12	8.571	74.923	8.741	74.21
13	9.142	76.316	8.348	70.88
(V_1 , I_1)	14.284	80.495	5.635	47.84
(V_2 , I_2)	19.142	83.48	4.361	37.03
16	33.426	87.958	2.631	22.34
17	41.712	90.047	2.159	18.33
18	51.14	91.142	1.782	15.129
19	61.997	92.236	1.487	12.62
20	63.997	92.236	1.441	12.23
21	74.853	91.838	1.227	10.42
22	404.837	2	0.00494	0.0045



a) Experimental



b) Mathematical

Figure (5) Evolution of voltage across the snow as a function of current through it

5- Mathematical model

A mathematical model can be elaborated to establish a relationship between the voltage, V, across 1-cm layer of snow and the current, I, through it. Indeed, V may be expressed as a function of I through the following equation.

$$V = K \cdot I^{\alpha} \qquad (1)$$

where, V is the voltage in kV, I is the current in mA, and K and α are the constant coefficients depending on snow characteristic and frame dimensions. These coefficients can be determined over the knee point of the V-I curve of snow (see Figure 5). They are as follows;

$$\alpha = \frac{\ln(V_2) - \ln(V_1)}{\ln(I_2) - \ln(I_1)} \quad \Rightarrow \quad \alpha = 0.0935 \quad (2)$$

$$K = \frac{V_1}{I_1^{\alpha}} \quad \Rightarrow \quad K = 63.35 \qquad (3)$$

Substituting K and α from equations 2 and 3 into 1 gives

$$V = 63.35 \cdot I^{0.0935} \qquad (4)$$

The evolution of voltage across snow versus its current, using equation 4, is shown in Figure 5-b. It can be observed that this curve is in very good concordance with the experimental results. Since the coefficients K and α depend on snow characteristics, equation 4 is only valid for snow density and melting conductivity 0.367 g/cm^3 and 85 $\mu S / cm$, respectively. Further research is necessary to establish a more precise mathematical equation of V-I characteristics of snow, considering the greatest number possible of atmospheric parameters.

6- Concluding remarks

A number of experimental investigations by various authors have helped further knowledge on 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 aimed to further fundamental and comprehensive research on the electrical behavior of snow.

From the V-I characteristics of snow, as determined in this study, it was found that the voltage across snow and the current through it are almost in the same phase, within 2 degrees. 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 as the voltage across it increases. Based on the results, a mathematical model allowing simulating the electrical behavior of snow is introduced.

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