

## Effect of Voltage Polarity on Icicles Grown on Line Insulators

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### ABSTRACT

The morphology and microstructure of icicles formed around the skirts of insulators energized under both direct and alternating voltages were analyzed in the present study. Wet ice accretion promoting the formation of icicles was grown at  $-12^{\circ}\text{C}$  from  $80\ \mu\text{m}$  supercooled droplets at a wind velocity of  $4.2\ \text{m}\cdot\text{s}^{-1}$ . In general, the icicles grown under all three energized conditions are shorter than those formed without voltage. Bubble and crystal features show that icicles are very sensitive to heat exchange at the water/ice interface, and they grow as hollow ice cores filled with liquid water at the tips. In the absence of applied voltage as well as in dc-, the core is circular, 5 mm in diameter, while in ac and dc+, where ionic wind velocity is stronger, they are deformed and shrink to a size of 4 mm and 3 mm, respectively. The decrease in core diameter and increase in the ionic wind velocity at the tip of the icicle in dc+ and ac produce cooling effects. These, however, are counteracted by heating due to the conduction current on the icicle surface.

### INTRODUCTION

In cold regions, ice accretions on power lines are the origin of a number of problems including a substantial reduction in the electrical insulation strength of insulators (Kawai, 1970; Phan and Matsuo, 1983). Under atmospheric conditions favouring the formation of icicles, where the surfaces of ice deposits are covered by a water film, the spaces between the insulator units often become bridged by icicles. This considerably reduces the withstand voltages and causes insulator flashover under normal voltages and, consequently, line outages. The growth of icicles around the skirts of energized insulators is a complicated process and sensitive not only to atmospheric conditions but also to corona discharge intensity, affecting the heat exchange rate with the environment.

The general characteristics and crystal texture of icicles have been studied by several authors (Lenggenhager, 1978; Knight, 1980; Maeno and Takahashi, 1984). In a laboratory study, Maeno and Takahashi (1984) proposed an empirical relationship between icicle growth and environmental conditions. A model of icicle growth predicting the shape and weight of icicles was recently proposed by Makkonen (1988). It was shown that icicles elongated into hollow, thin-walled tubes of ice with liquid water trapped inside the tip.

Under energized conditions, electrical phenomena, namely corona discharges, conduction current at the surface of the icicles, water drop elongation and ionic wind add to the environmental parameters. Corona discharge and conduction current have a heating effect, whereas elongation of water drops and ionic wind have a cooling effect. The interaction of these phenomena considerably influences the characteristics of the icicles.

Moreover, the above electrical parameters vary as a function of voltage polarity (Teisseyre and Farzaneh, 1990) and could influence the morphology of icicles. Regarding voltage polarity, it was shown that the minimum flashover voltage of line insulators covered by wet ice grown with icicles was considerably influ-

enced by the polarity of applied voltage (Farzaneh, 1991).

Although the effect of voltage polarity on ice deposition on cylindrical collectors simulating high voltage conductors has been investigated by some authors (Phan and al., 1983), there has been no study of that particular effect on the ice and icicles grown on line insulators. Therefore a research program related to this subject was undertaken. The first results involved microscopic observation of bulk ice deposits on the top surface of insulators (Farzaneh and Laforte, 1991). Those results indicated that there was no evidence of a significant change in porosity and crystal texture due to the voltage polarity.

The main purpose of the present work is to study the porosity and crystal texture of icicles formed around the insulators energized by positive, negative and alternating applied voltages.

### PROCEDURES AND FACILITIES

The experimental setup was identical to the one previously described by Farzaneh and Laforte (1991). It consists of a short string of 4 fog-type porcelain insulator units suspended vertically in a cold environmental chamber at  $-12^{\circ}\text{C}$  and sprayed with supercooled droplets. The droplets, with a mean volume diameter of  $80\ \mu\text{m}$ , were produced by 5 pneumatic nozzles and a horizontal wind with a velocity of  $4.2\ \text{m}\cdot\text{s}^{-1}$ . The electrical conductivity of the tap water used to feed the sprays was about  $80\ \mu\text{S}\cdot\text{cm}^{-1}$  at  $20^{\circ}\text{C}$ .

The growth conditions chosen for the icing tests were similar to those used in the previously mentioned work. The liquid water content of the air, measured by the single cylinder method, was about  $6.8\ \text{g}\cdot\text{m}^{-3}$  in order to keep the icing period within a reasonable limit. During each test, the amount of ice accumulated on the surface of the insulators was also controlled by measuring the ice thickness collected on a monitoring cylinder, 3.8 cm in diameter and rotating at 1 rpm. The accumulation time under these growth conditions was fixed at 75 min, this being the time required to form a uniform, 2-cm-thick ice deposit.

During the icing tests under energized conditions, a constant voltage of 60 kV giving 15 kV per unit was applied to the insulator string. This corresponds to the nominal value of the operational voltage of one insulator unit in service. Leakage current was also recorded during each test under energized conditions. After each icing test, the iced insulator string was photographed before removing icicle samples, which were then stored in a

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