The Effect of Dielectric Mist on Electrical Breakdown in Insulating Gases

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Motivation

The breakdown strength of gases can be increased with the introduction of dielectric mist (non-conductive droplets). This is of interest, e.g. in electrically stressed cooling systems like heat pipes, which use a refrigerant as a working fluid, or if one aims to replace the environmentally critical but dielectrically optimal insulating gas SF₆ with other insulating gases.

Many factors potentially play a role in the electrical breakdown behavior of a two-phase mixture of this type. This project aimed to give a general overview of several effects of mist on the electrical breakdown of insulating gases.

Methodology

This work was of theoretical nature and studied:
• The interaction between mist and electric field, using theoretical estimates and orders of magnitude.
• The effects of mist on streamers and the breakdown (streamers are thin – hundreds of μm diameter – plasma channels which precede electrical breakdown), with two different models and numerical simulations.

Both a macroscopic approach (e.g. using effective medium theories) and a microscopic approach were followed, as mist basically influences electron attachment (to droplets) and acts on photoionization (an important mechanism for the propagation of positive streamers). An insight into some experimental results is also provided.

Effect of electrode wetting

A simple model based on streamer theory and the streamer inception criterion
\[ \int_0^L \alpha_{eff}(E) \, dx \geq C_{crit} \]
allowed to numerically study the effect of a dielectric layer on a needle electrode tip. The streamer inception voltage was found to increase significantly with liquid thickness, especially for low liquid dielectric constants.

Experimental measurements

Breakdown voltages and leakage currents were measured in a needle-plane geometry with a nozzle generating mist made of the dielectric fluid Novec™ 649 from 3M™. Heating was applied on the needle to study the effect of electrode wetting. The two distinct curve trends are interpreted by the level of dryness of the electrode.

Effect of droplets on streamer dynamics

A fluid model has been used for the simulation of a streamer and droplets have been placed on its way in an axisymmetric geometry:

It was found that for given distances between droplets, certain droplet radius values make the propagation of the streamer stop in front of the “droplet cloud”. The effect of the dielectric constant is rather low and a relevant parameter in this particular arrangement is believed to be the relative size of the streamer with respect to the gap between two droplets.

Conclusion

Many effects are dependent on the mist density (e.g. volume fraction, number density) and some of them turned out to be not significant for typical values encountered in practical applications.

The novelty of this work lies in the study of streamers in the presence of droplets in a microscopic way. However, further research needs to be done to determine accurate model parameters that can be used for applications.

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