Hybrid Resistive-Capacitive and Ion Drift Model for Solid Gas Dielectrics

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Abstract

INTRODUCTION: Many electrical insulation systems use a combination of gas and solid media. Typical examples considered here include the combination of solid epoxy insulation and SF6 in a gas insulated subsystem (GIS). To understand how such a system performs under DC voltages, accurate modelling of the conduction of charge and the electric field distribution is needed.

To model the solid insulation a resistive-capacitive description can be used, but for the gas region this approach is less appropriate. This has to do with the non-linear current-voltage characteristic of gases. In this medium, conduction happens through ion movement. For electric fields below the onset of electron-impact ionization, the ions are produced mainly through background ionization from processes such as cosmic rays. In typical applications, the ion production rate limits the current. To model a system with both solids and gas, the ion-drift equations for the gas must be combined with the resistive-capacitive model describing the solid.

USE OF COMSOL MULTIPHYSICS®: In COMSOL Multiphysics® software, the resistive-capacitive model is implemented using the Electric Currents physics interface and the ion-drift equations using the Transport of Diluted Species physics interface. The two sub-models are combined by adding boundary current sources to the Electric Currents interface based on the charge flux across the boundaries obtained from the ion-drift equations. This approach works but is rather cumbersome computationally and can show stability problems.

In this article a more lightweight model is introduced, where we consider the ion flow as quasi-stationary, approximating the time derivative term to zero. This speeds up the computations significantly and also produces more stable simulations. The approximation introduces an error compared to the time-dependent ion-drift equations, which can be shown to be small for the cases of interest for DC electrical apparatus, where the electric field varies slowly compared with the transit time of the ions in the gas and the contribution from the initial sweep-out is small.

RESULTS: The model is implemented for two simple test geometries designed to capture the physics of insulator charging in GIS, which have been investigated experimentally at ETH Zürich. The geometries consist of an epoxy rod surrounded by a high voltage cup, where two different cup sizes are used. The electric field at time zero is shown for one of the test geometries in

figure 1. The model reproduces the experimental results well, and the simulation times are much shorter compared to using the full ion-drift model.

CONCLUSIONS: We demonstrate that, by neglecting the time dependent parts of the ion flow, it is possible to shorten the solution time and improve the numerical stability of COMSOL models where hybrid solid-gas insulation systems are studied. This quasi-stationary approximation is shown to give a small error term compared to the full equations and the results from the model match two test geometries well. The model is expected to be useful for simulation and design of GIS in particular, and be more generally applicable for studying a wide range of dielectric insulation systems combining gas and solid material under DC stress.

Reference

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Figures used in the abstract

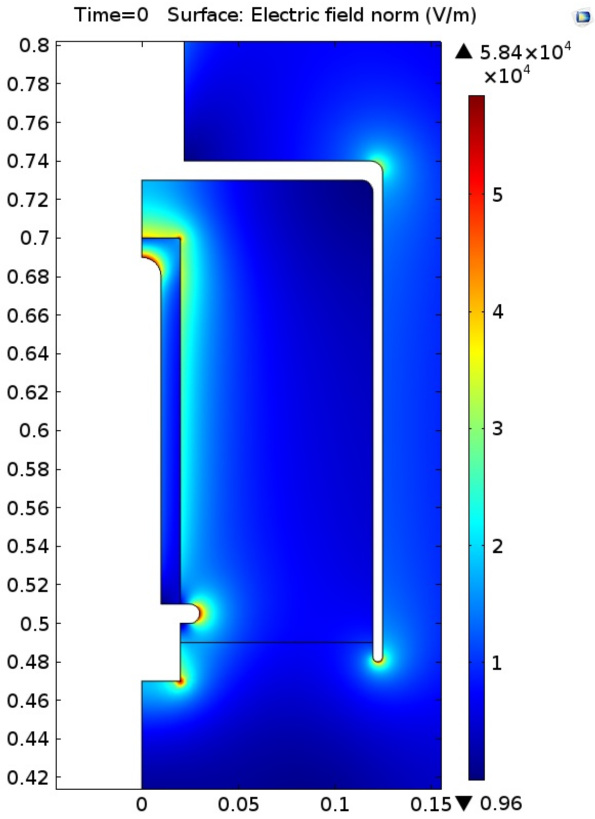

Figure 1: Electric field at time zero for the test geometry with large high voltage electrode.

Figure 2

Figure 3

Figure 4