Charge transport in high voltage DC insulation systems

Applications for OpenFOAM in high voltage power transmission

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Abstract

Modern society requires transmission of power over large distances, from the power plants where electricity is generated to the populated areas where energy is consumed. The transmission becomes more efficient by increasing voltage levels and thereby reducing electric losses. Traditional power transmission systems use alternating current (AC) because it simplifies transformation of voltages. However, losses due to reactive power oscillating between inductances and capacitances in the systems puts a limit on the effectiveness of high voltage AC transmission over very large distances. By conversion to direct current (DC), transmission power loss can be minimized. As an example, the power superhighways that are being constructed to take power from hydropower plants in western China and transfer it to the industrialized coastal areas is an important application for high voltage DC transmission.

The conversion from AC to DC is done in converter stations. Design of electric insulation systems for the transformers used in converter stations is challenging because they are subject to both AC and DC stress. In particular, analysis of the DC behavior is complex because space charge effects must be taken into account. Typical electric insulation systems for transformers are composite systems of oil and pressboard. Relevant physical properties like charge carrier mobility and their concentration might differ by several orders of magnitude for these materials.

A theoretical model for build-up of space charge in a composite oil/pressboard insulation system can be formulated by considering transformer oil as a weak electrolyte. The oil contains ionic pairs that continuously dissociate into positive and negative ions, which can then recombine. The steady-state equilibrium of ions in the oil can be obtained by measuring the conductivity. When an electric field is applied, free ions move under its influence according to the mobility of the material. Strong electric fields will enhance the dissociation of ionic pairs. The behavior of the system can be described by transport equations for the charge carriers as well as Poisson's equation for the electric field.

Numerical solution of the governing equations is not straight-forward. For high voltage applications the transport equations are strongly dominated by the migration term with a Peclet number of order 10000. Discontinuities in material parameters require special discretization schemes to describe the behavior of the transported charge carriers. Large differences in geometrical length scales put high requirements on meshing to keep the problem at a manageable size. These considerations make OpenFOAM a suitable tool for testing discretization schemes and solving industrial scale problems in parallel.

In the presentation we present the mathematical representation of the ion transport problem. We discuss how the numerical challenges are addressed in OpenFOAM and show some examples to illustrate the results.

Key words: High voltage, power engineering, electrical insulation, charge transport

References

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