Coupled Electric-Thermal-Fluid Analysis of High Voltage Bushing

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Abstract

Modern power transmission systems are in general designed to operate at high voltages in order to reduce resistive losses generated by high currents. This, however, tends to increase the risk for dielectric breakdown or flashovers if the equipment is not properly designed to withstand the stress. Out of the many components comprising the transmission system some of the most stressed are the so-called bushings, i.e. feed-through devices preventing flashover between a grounded conducting wall and a high voltage conductor penetrating the wall. Such bushings can for instance be used to connect transformer windings to high voltage feeding cables outside the oil-filled transformer tank. Other applications involve smaller power devices placed inside oil-filled containers or high voltage conductors connecting the different valve and reactor halls in an HVDC converter station. This work illustrates the necessity of using strongly coupled multiphysics simulations in order to properly describe and understand the complex behavior of a high voltage bushing. The model corresponds to a rather unconventional design, where for the sake of flexibility the electric field grading part of the DC bushing consists of a modified version of a standard ABB cable termination. The outside of the grounded container, through which the conductor penetrates, is surrounded by air while on the inside the container is filled with mineral oil acting both as an electrical insulator and a cooling liquid. The problem basically consists of minimizing the size and cost of the bushing while keeping the internal electric stress levels and the temperature rise within acceptable limits. Since we are studying a DC bushing the leakage current, and hence the electric field distribution, is to a large extent determined by the very small electric conductivities of the different insulating materials inside the bushing. These conductivities are in turn dependent on the local temperature (there is also materials present having an E-field dependent conductivity). The heat balance equation, with the resistive heating as source term, thus becomes strongly coupled to the equation governing the electric field, or current, distribution. In addition, most of the heat transported away from the solid inner parts of the bushing is removed with the help of natural convection in the oil. It is therefore crucial to solve for the oil flow pattern as well, a task which is further complicated by the fact that the viscosity is highly temperature dependent. Using the model described above we illustrate the different steps involved in the analysis, see Figure 1, Figure 2, Figure 3, and Figure 4. The sensitivity to variations in design and material parameters are studied as well as the accuracy of some simplifications that can be applied.

Figures used in the abstract

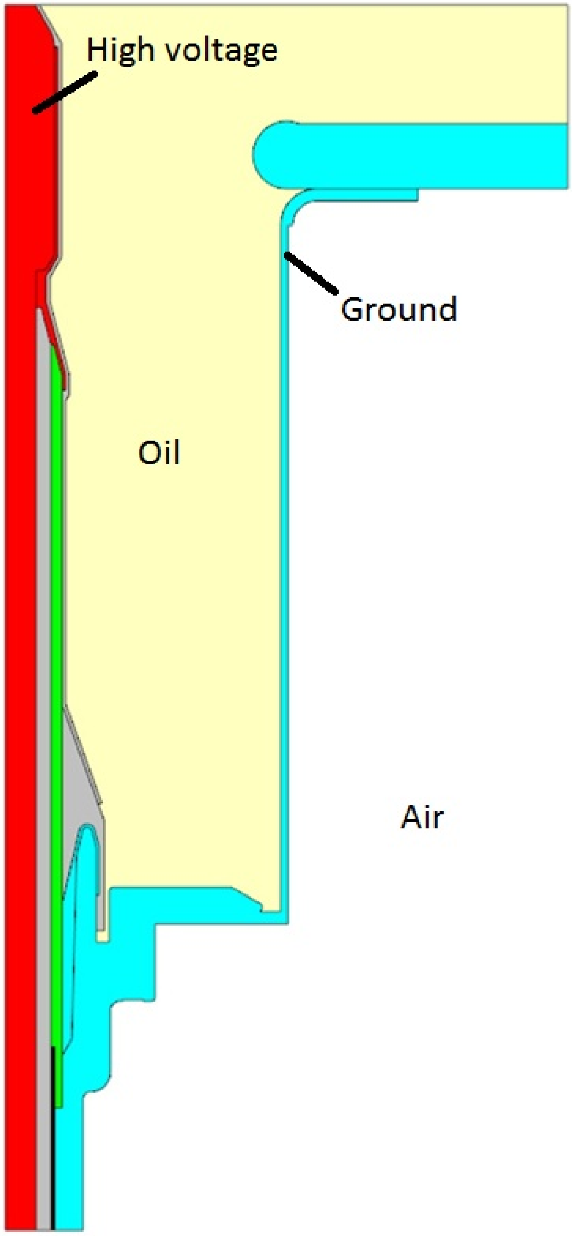

Figure 1: Axisymmetric geometry of the bushing.

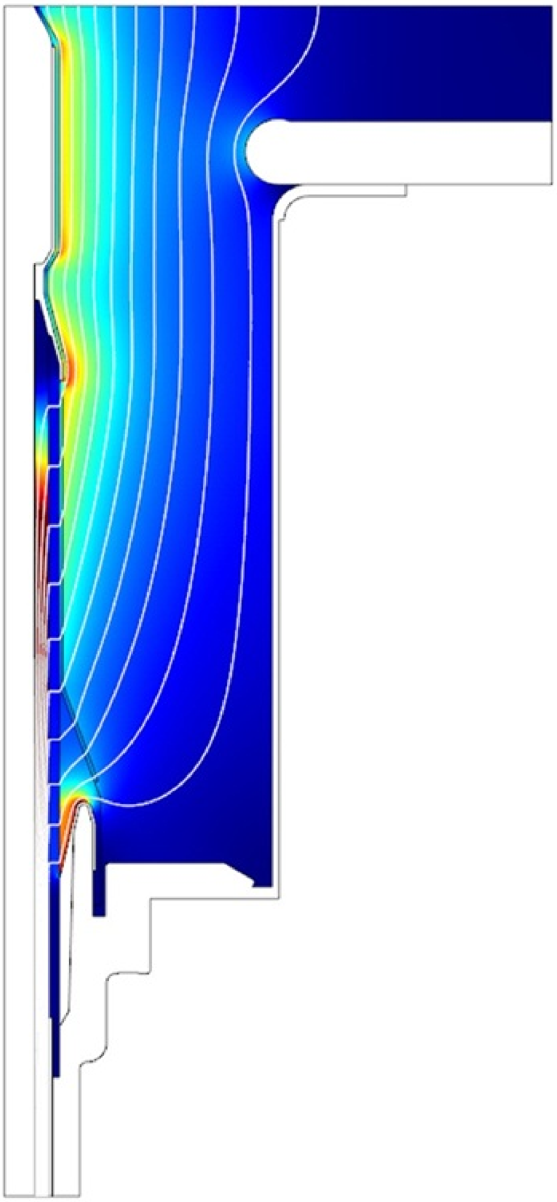

Figure 2: Equipotential curves and the electric field distribution.

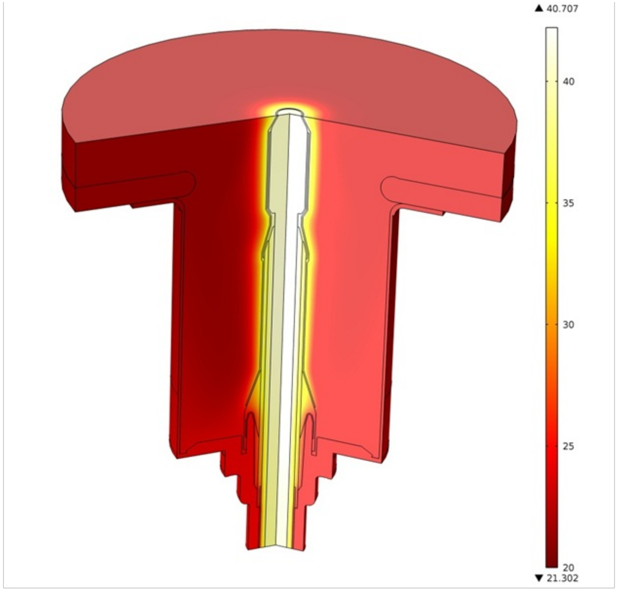

Figure 3: 3D view of the temperature distribution.

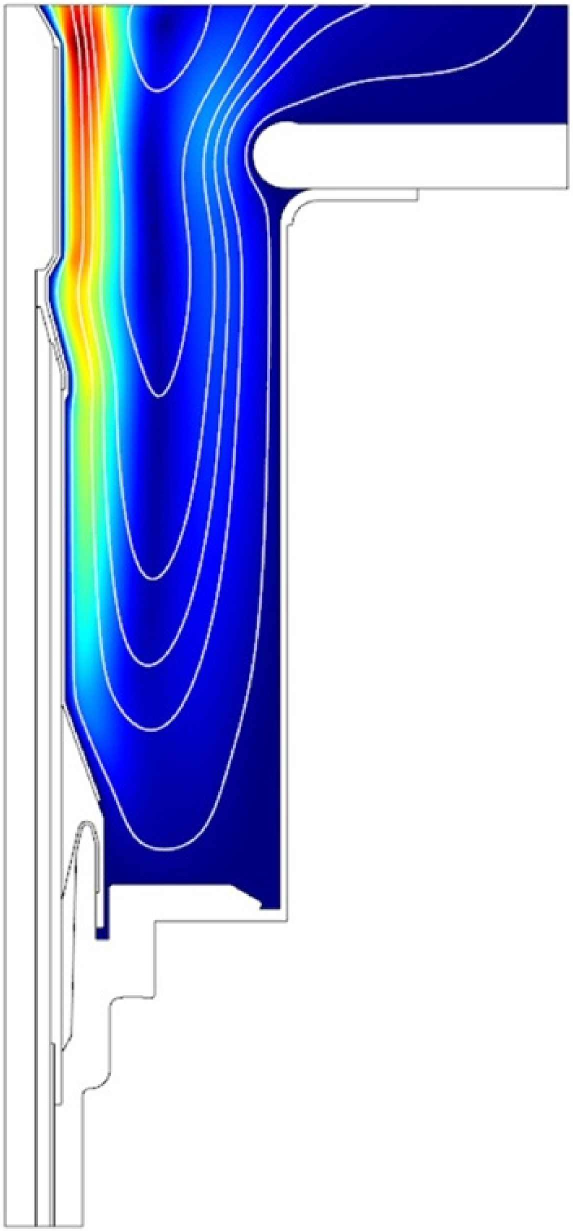

Figure 4: Flow curves and velocity distribution in the oil volume.