Control of the Electrical Field in the Connectors for High-Voltage Cables

Ion T. Cârstea[1] and Daniela P. Cârstea[2]

Abstract – **The paper presents the analysis and control of electrical field in the mechanical connectors of the high-voltage (HV) cables. In the cable terminals a field enhancement occurs because the core has a sharp edge and the shield is interrupted. A mechanical connector links the cables and controls the electric field using special materials to ensure a homogeneous potential distribution.**

We present the analysis of the electric field in connectors and the control of the electrical field using Raychem technology. A semiconductor shield and a control tube can optimise the field distribution in cable connectors and terminals.

Keywords – **Numerical analysis; High-voltage cables; Finite element Method.**

I. Introduction

The problem of the analysis and control of the electrical fields in cable terminals is an open problem that involves a multidisciplinary research. The problem of an insulated electrical conductor fitting into a grounded screen is a common configuration in many electromagnetic devices so that the results from our case can be extended in other similar areas.

We consider a high-voltage cable (Fig. 1) where the significances of the components are [1]: 1 – conductor; 2 – phase insulation; 3 – a layer for field control; 4 – a semiconductor shield.

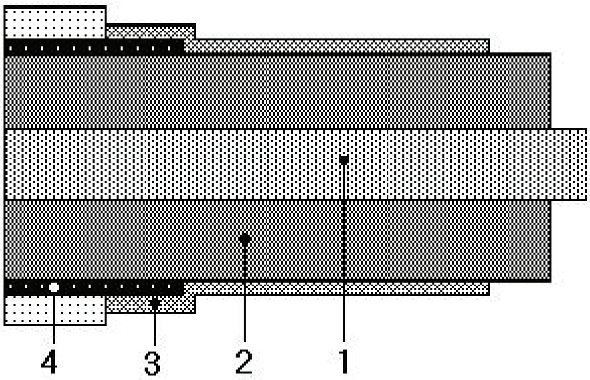

Fig. 1. Cable terminal

[1]Ion T. Cârstea is with the Faculty of Automatics, Computers and Electronics. Craiova, str. Doljului 14, bl. C8c, sc.1, apt.7, judet Dolj, Romania, E-mail: incrst@yahoo.com

[2]Daniela P. Cârstea is with the Industrial Group of Romanian Railways, Craiova, str. Brâncuşi nr. 15, Craiova, Romania, E-mail: danacrst@yahoo.com

The role of the control tube is to do a uniform distribution of the field lines and electrical field in terminal. The material of the tube has a volume resistivity and permittivity controlled rigorously. The tube has a non-linear resistivity with behaviour of a varistor. It has a direct contact with the semiconductor shield of each terminal of the two cables that are connected.

At the joints of two cables the mechanical connectors can be used [1]. In Fig. 2 an axial section of the connection is presented with the following components: 1 – conductor; 2 – phase insulation; 3 – control tube; 4 - muff insulation; 5 – semiconductor layer; 6 – the connector; 7 – a special material for filling (mastic); 8 – semiconductor layer (mantle).

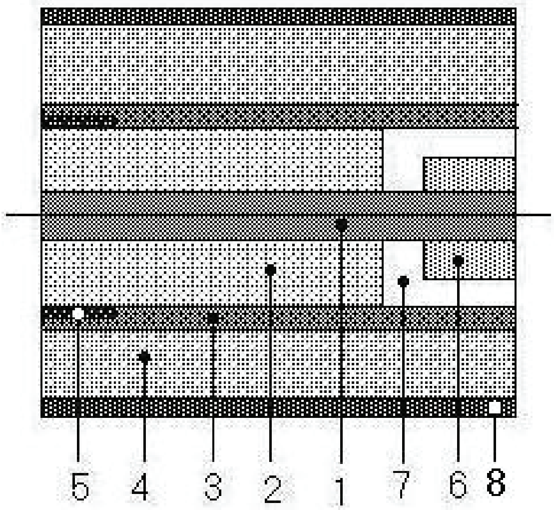

Fig. 2. An axial section in muff

Generally speaking there is no perfect dielectric insulation so that a leakage current exists. Ohmic losses cause the dielectric heating. A parallel-plane model can be used to compute the electric and thermal fields.

The tube for the field control covers the semiconductor shields of each cable terminal of the muff. The mastic has a high permittivity and realises a uniform distribution of the electrical field. In this way the electrical stresses are reduced at the cable terminals. The muff insulation is in direct contact with the external semiconductor and the thick is selected to prevent the partial discharges in the separation zone [1].

II. Mathematical Model

The electric field distribution can be obtained by approximation of the Maxwell equations. These approximations take different forms in accordance with material properties of the equipment. In modelling of these physical systems we must consider both perfect dielectrics and imperfect (or polluted) dielectrics. The control layer of the field has a finite resistivity and controls the electrical stress in the terminals.

The static field distribution can be modelled by the following equations [2]:

$$\nabla \times \overline{E} = 0; \quad \overline{E} = \rho \overline{J}$$

with: ρ - the material resistivity, E - the electric strength and J – the current density.

A 2D-field model was developed for a resistive distribution of the electric field. An electric vector potential P is introduced by the relation:

$$\overline{J} = \nabla \times \overline{P}$$

Laplace's equation describes the field distribution (for anisotropic materials):

$$\frac{\partial}{\partial x}(\rho_x \frac{\partial P}{\partial x}) + \frac{\partial}{\partial y}(\rho_y \frac{\partial P}{\partial y}) = 0 \qquad (1)$$

Mathematical model for the thermal field is the conduction equation:

$$\frac{\partial}{\partial x}(k_x \frac{\partial T}{\partial x}) + \frac{\partial}{\partial y}(k_y \frac{\partial T}{\partial y}) + q = \gamma c \frac{\partial T}{\partial t} \qquad (2)$$

with: T (x, y, t) - temperature in the point with co-ordinates (x, y) at the time t; kx , ky – thermal conductivities; γ-specific mass; c – specific heating; q – heating source.

It is obviously that there is a natural coupling between electrical and thermal fields. Thus, the resistivity in equation (1) is a function of T, and the heating source q in (2) depend on J. Numerical models for the two field problems can be obtained by the finite element method. An iterative procedure was used for the temperature distribution.

The imperfect insulation leads to local heating of the connectors so that a coupled model can be a good approach of the electrical field computation. In our work we consider the electrical properties are constant with the temperature.

III. CONTROL OF THE FIELD DISTRIBUTION

In the real engineering, the designer of an electromagnetic device starts from an imposed performance of the device and tries to reach the performance by a command that can be a distributed or boundary command. In the area of the electrical engineering we can have a parametric optimisation. Practically, there are three possible parameters [3]:

- A physical property as electrical property (for example the permittivity);
- The excitation of the system (voltage or electrical current);
- A geometrical parameter (configuration, dimensions in any direction etc.)

In our target example, there are many regions involving different materials as conductor, semiconductor and dielectrics (insulation). In a synthesis problem we seek the material property – the permittivity that needs to be used in a certain part of the device. In other words, the optimisation parameter that we seek is the permittivity of those parts so that the object function goes to the extreme value. Gradient techniques can be used to reach the optimum parameter.

Optimisation with respect to geometry of the device is much more complex than with respect to material or excitation.

IV. NUMERICAL RESULTS

We considered the example from the figure 2. Because of the symmetry the analysis domain is limited to a half of the field domain. In the Fig. 3 the meshed domain is plotted with the axis Oz as symmetry axis (the horizontal line).

The finite element method was used for numerical simulation. The program Quickfield [4] uses the triangular elements.

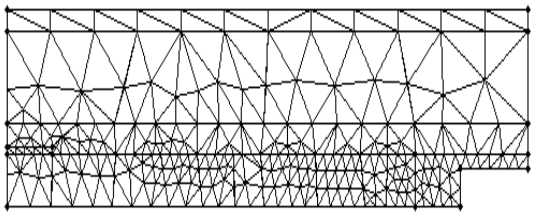

Fig. 3. Meshed domain for a muff

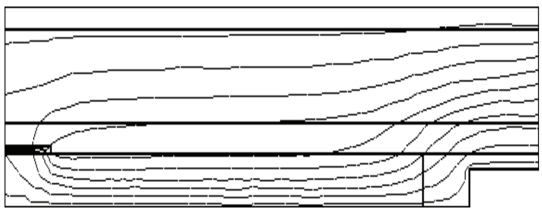

Fig. 4. Equilines of potentials

The geometrical properties of the device are:

- the radius of the conductor is 5 [mm];
- the external radius of the phase insulation is 12 [mm];
- the external radius of the control tube is 16 [mm];
- the external radius of the muff insulation is 28 [mm];
- the external radius of the second semiconductor layer is 31 [mm]
- the width of the internal semiconductor layer is 1 [mm];
- the external radius of the connector is 10 [mm];
- the length of the connector is 15 [mm];

The physical electrical properties are:

- The voltage of the cable is U=10 [kV];
- Relative permittivity of the first insulation layer is 3.5
- Relative permittivity of the muff insulation layer is 4
- Relative permittivity of mastic is 6
- Relative permittivity of control tube is 2

In the Fig. 4 the distribution of the field lines are plotted for the data mentioned above.

In our simulation tests we considered many values of the permittivity of the mastic. In Fig. 5 the variation of the electrical field at the external radius of the phase insulation is plotted. If the value of the permittivity of the control tube is

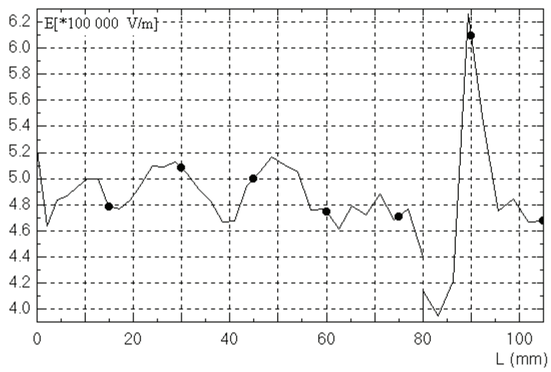

Fig. 5. Strength E versus space (ε_r=6)

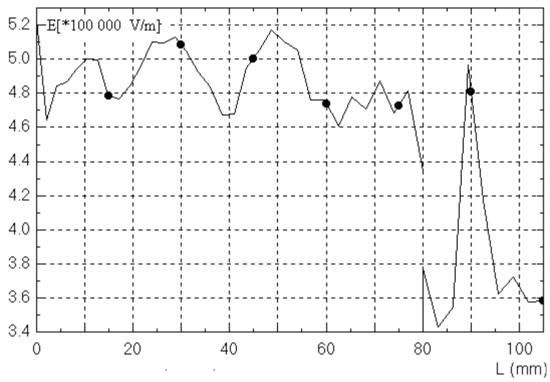

Fig. 6. Strength E versus space (ε_r=8)

increased at 8, the distribution of the electrical strength is modified. In the zone of the joint, the electrical field strength is reduced (see Fig. 6).

It is obvious that we can find an optimum value of the material property (in our case the permittivity) so that an objective function can reach a minimum value. In our particular application the objective function is a measure of the deviation of the electrical field from a desired value. The solution of the inverse problem is done iteratively.

V. Conclusion

In this paper we presented some aspects of analysis and control of the electric field in cable connectors. We limited the discussion at the material properties as optimisation parameter. The influence of the material properties on the field distribution in connectors is analysed. The numerical models were obtained by the finite element method in a 2D-space [4].

An optimisation with respect to geometry is an open problem that involves increased computational efforts. At each step of iteration the application software must rebuild the mesh of the finite element program. To simplify the optimisation process, the initial problem is divided into subproblems so that the gradient technique that involves differentiation with respect to geometry is divided into differentiation subproblems.

References

[1] *** Catalog 2001/2002. Tyco (Electronics).*Accesorii pentru cabluri de energie*

[2] Cârstea, D., Cârstea, I. *CAD in electrical engineering. The finite element method*. Editor SITECH. 2000. Craiova, Romania.

[3] Hoole, S.R.H., *Finite elements, electromagnetics and design*. 1995, Elsevier, Amsterdam.

[4] *** QuickField program, version 5.2. Year 2004. Page web: www.tera-analysis.com. Company: Tera analysis