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EMBEDDED ELECTRODES SYSTEM APPLICATION ON ELECTRIC FIELD REGULATION AT CABLE TERMINATIONS

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ABSTRACT

There is a large number of cable terminations developed in last few years. Cable failures still happen, causing great economic losses, mainly because of a cable termination breakdown. For that reason any improvement in the cable termination construction is of great interest. Cable joints and terminations represent the weakest part of a HV cable power line. At the places of cable connections and endings exterior cover is removed, and the radial character of electric field is disturbed. Because of high voltage, the inhomogeneous electric field exists on those parts of the cable, having the highest intensity at the ends of the covers, or screen. There are many approaches for solving the problem of minimizing electrical field intensity at the places of power cable splicing. Application of a metal screen and embedded electrodes system for electric field control is presented in this paper.

Index Terms - Cable accessories, Maxwell's equations, grounded embedded electrodes, toroidal equivalent electrodes, charge density, equivalent electrode method, electrical field distribution

1. INTRODUCTION

Semi-conducting (SC) materials with non-linear behavior are implemented in HV insulating system to make as uniform as possible the electric field near the end of the cable shield [1, 10-12]. To optimize this kind of structure, it is necessary to estimate the normal electric field at the SC boundaries with a fine accuracy.

Most common solutions are those based on the application of geometrical potential shaping or application of a metal screen for electric field control. This leads to a homogeneous technology which permits to design very compact cable termination.

An evolutionary approach to the variability analysis of nonlinear systems, like cable accessories, was presented few years ago [2]. Quasi-static approximation of the Maxwell's equations for electric field distribution in cable terminations was applied.

Conformal mapping (Schwartz-Cristoffel's transform) and analogies between plan-parallel and axi-symmetrical electric systems are possible to use for analytical determination of electric potential and electric field distributions at the non modeled cable terminations [5].

Some calculation for plan and axi-symmetrical systems can be carried out using equivalent electrodes method (EEM), and it can be obtained very high accuracy of the calculated values [4-8]. This method is applicable for systems with different materials having different electric permittivity and magnetic permeability [3, 9].

2. THEORETICAL APPROACH

One method for reducing strong axial fields at the end of cables is based on application of the grounded embedded electrode. Position and width of added electrodes make influence on strength of electrical field at ends of cables.

The added electrodes are being placed at distances L_{pn} from the end of the coaxial cable outer conductor and at distances b_{UEn} from system's axes (Fig. 1). The length of this electrode is L_{UEn}.

Due to the symmetry of the problem, by adopting a cylindrical system with the z-axis coincident with the axis of the conductor, an equivalent two-dimensional problem can be studied. It is possible to determine potential and electric field in arbitrary chosen point of cable end region.

Charge density per unit surface is constant in the distant regions from cable breaks, which are on the interior conductor (having radius a), and on the exterior conductor (having radius b), respectively.

Appropriate electrical field is:

$$E_{\mathrm{hom}} = \frac{a E_0}{r \log \frac{b}{a}}, \qquad (1)$$

where $E_0 = \frac{U}{a}$, and U is voltage the coaxial cable is supplied with.

The charge distributions mentioned above do not coincide with the real ones, because the boundary conditions are not satisfied, so consequently the conductors are not of constant potential.

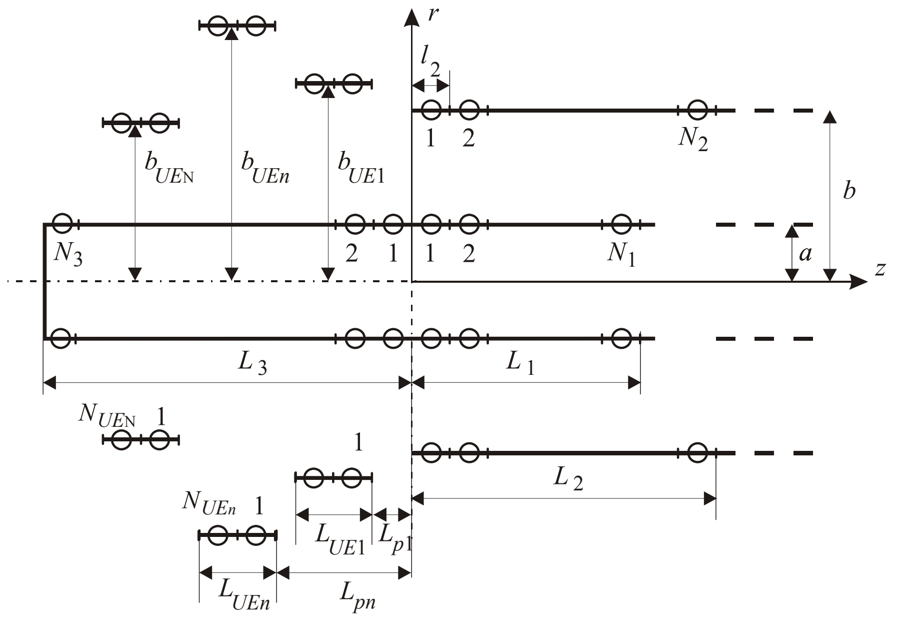

Figure 1 Cable termination with N embedded electrodes

Due to this, additional expressions are superposed to the previous ones. Equivalent electrodes are used as additional elements. Embedded and grounded electrodes are replaced by toroidal equivalent electrodes.

Interior conductor's equivalent electrodes radii are:

$$a_{e1} = \frac{L_1}{4N_1}, \; a_{e2} = \frac{L_2}{4N_2}, \; a_{e3} = \frac{L_3}{4N_3}, \tag{2}$$

and their centers are:

$$z_{1n} = (2n - 1)\frac{L_1}{2N_1}, \; n = 1,2,\ldots,N_1, \tag{3}$$

$$z_{2n} = (2n - 1)\frac{L_2}{2N_2}, \; n = 1,2,\ldots,N_2, \tag{4}$$

$$z_{3n} = (2n - 1)\frac{L_3}{2N_3}, \; n = 1,2,\ldots,N_3. \tag{5}$$

Relative charge is:

$$Q_n = \frac{q_n}{2\pi^2 \varepsilon a U}, \tag{6}$$

where q_n denotes the total charge of the n-th equivalent electrode and ε is permittivity of the medium.

Arbitrary chosen embedded electrode (the n-th) is replaced by toroidal equivalent electrodes, placed at position:

$$z = z_{UEn} = -L_{pn} - (2n - 1)\frac{l_{UEn}}{2}; \; r = b_{UEn}; \tag{7}$$

where is:

$$l_{UEn} = \frac{L_{UEn}}{N_{UEn}}; \; a_{eUEn} = \frac{l_{UEn}}{4}. \tag{8}$$

Number of those electrodes is N_{UEN}.

The distance from the end of the broken coaxial cable exterior conductor to the n-th embedded electrode, L_{pn}, influences to the electrical field and potential distribution in cable termination. Axial component of electric field is several times higher then the radial component. Consequently, in process of cable termination constructing, the position of embedded electrodes are chosen in such way to decrease axial field strength.

3. NUMERICAL RESULTS

The system of $N = 3$ additional electrodes is analyzed in this paper.

The added electrodes are placed at distances $L_{p1} = a$, $L_{p2} = 2.5a$ and $L_{p3} = 4a$ from the end of the outer conductor, and at distances $b_{UE1} = 3a$, $b_{UE2} = 4a$ and $b_{UE3} = 5a$ from system's axes. The length of electrodes are $L_{UE1} = L_{UE2} = L_{UE3} = 2a$.

Equipotential lines shape is ploted and presented in Fig. 2. Electric field intensity is reduced, but not enough.

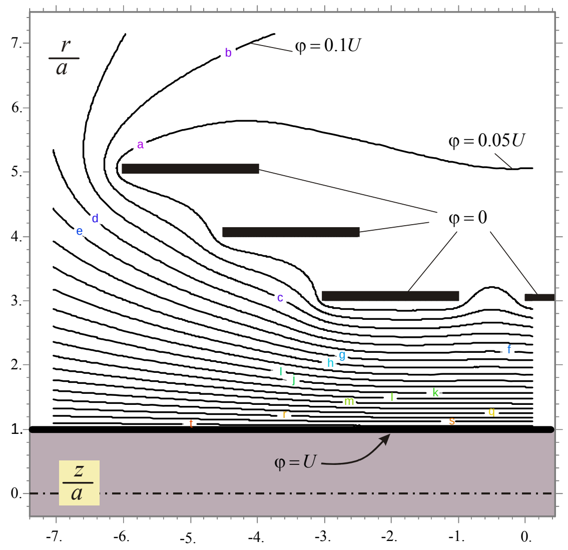

Figure 2 Equipotential surfaces at the cable termination with $N = 3$ continously placed embedded electrodes

The best results are given for next arrangement of embedded electrodes (Fig. 3). Equipotential surfaces at the cable termination in this case (with three not continously placed embedded electrodes) is shown in Fig. 3.

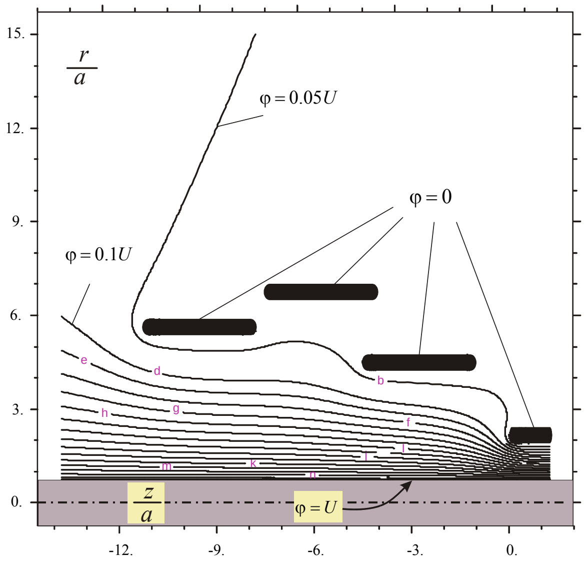

Figure 3 Equipotential surfaces at the cable termination with $N = 3$ not continously placed embedded electrodes

Electric field distribution on the first, the second and the third embedded electrode for 110 kV cable line is shown in Fig. 4.

The influence of the material properties of insulation and the stress control shapes are determined, too (Fig. 5).

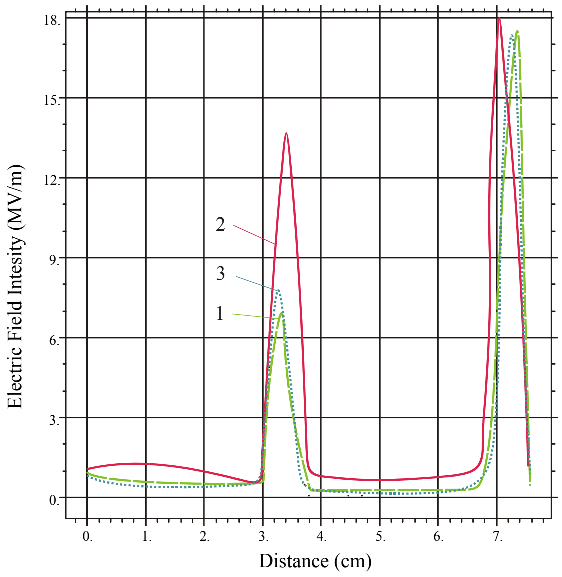

Figure 4 Electric field distribution at embedded electrodes of cable termination

Region between interior, 1, and the exterior conductor is filled with dielectric (ε_k). Deflector (4) is placed in refracting dielectric (3) with very high values of permittivity (ε_{ref}).

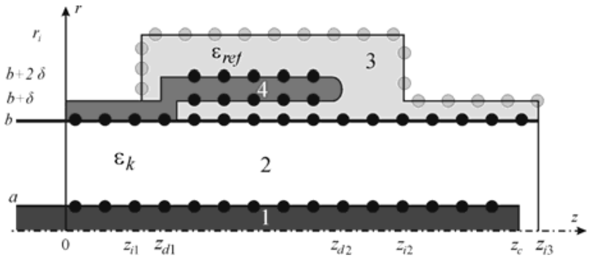

Figure 5 Refractive modeled cable termination

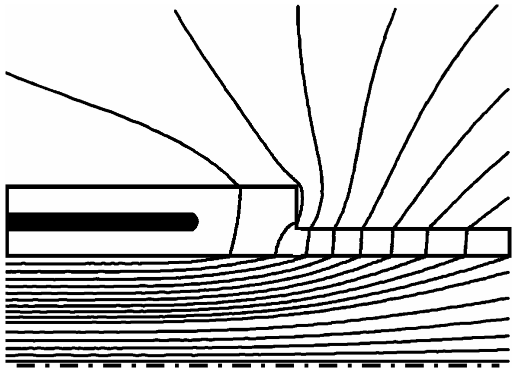

Figure 6 Equipotential curves

Equipotential curves are shown in Fig.6. Calculations are done for 35 kV cable, where: $b = 3a$, $\delta = a/10$, $r_i = 4.3a$, $z_{i1} = 0$, $z_{d1} = 4a$, $z_{d2} = 8a$, $z_{i2} = 12a$, $z_c = 32a$, $z_{i3} = 37a$.

Values for maximal electric field intensity obtained by using the finite element method (FEM) and equivalent electrode method are compared. Results are shown in Table 1.

Number of EE placed on electrode surfaces are N_1, N_2 and N_4, while number of “EE” placed on the boundary between electrode and dielectrics are N_{d1}, N_{d3} and N_{d4}.

Table 1 Maximal electric field intensity [MV/m].

N_1	N_2	N_4	N_{d1}	N_{d3}	N_{d4}	$E_{\max}[MV/m]$
5	5	5	5	5	5	2.01956757
10	10	10	10	10	10	2.10375645
20	20	20	20	20	20	2.69561009
50	50	20	20	30	30	3.09095675
100	100	50	30	50	50	3.11760922
100	100	50	50	70	70	3.19892444
200	200	100	50	70	70	3.27220331
200	200	200	100	150	150	3.27992710
1000	1000	1000	200	500	500	3. 27992711
FEM						3.27880152

4. CONCLUSION

Electric field of highest strength exists at the cable end and from exterior side of the second embedded grounded electrode. On which of those two points exist higher field depends on the embedded electrodes positions and sizes. The best results, (the lowest values of the electric field) can be obtained when those two values are equal.

Equalizing of the electric field strength at the cable break with the fields’ values at the exterior end of the second embedded grounded electrode is obtained by appropriate choosing of its position.

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