Modeling of a new type of reinforcing insulation of 110 kV cable joints

D. Seleznev[1,*], *G.* Greshnyakov[2], *Valery* Kosmach[1], *Igor* Loshchakov[1], *Dmitrii* Vasil'kov[1], *Nikolai* Kirillov[1], *Sergej* Savin[1], *Andrey* Timofeev[1], and *Yuriy* Pankratov[1]

[1] Peter the Great St.Petersburg Polytechnic University, Polytechnicheskaya, 29, St. Petersburg, 195251, Russia
[2]Research Institute "Sevkabel", St. Petersburg, Russia

Abstract. This article is devoted to the creation of a new reinforcing insulation of high-voltage cable joints at 110 kV. According to statistics for 2016, about 65% of accidents on the cable line occur at the junction of the two cable segments. The problem of leveling the electric field in the cutting is one of the important in the cable industry. To date, it has become possible to create new composite materials with special properties. With this help, a new type of 110 kV amplifying insulation will work on a new combined method of leveling the electric field. Using the finite element method, the model of amplifying insulation (tube-regulator) was modeled. It consists of several components that are responsible for a different principle of leveling the field.

1 Introduction

With the development of new technologies, it is possible to improve existing designs, to find new solutions to known problems in various areas of human activity.

Throughout the cable history, one of the main problems in the cable line was the connection of two cable segments. It is here that the basic insulation of the cable breaks down, which leads to a violation of the distribution of the electric field and the appearance of a tangential component of the electric field strength (Fig. 1).

[*] Corresponding author: Di.Sel92@ya.ru

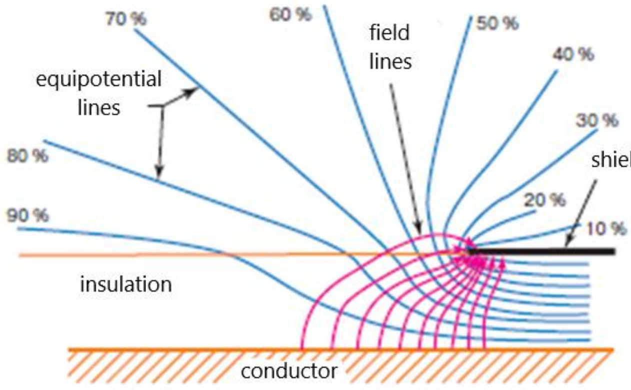

Fig. 1. Sharply uneven field in the cutting zone when cutting the screen.

Such a distribution negatively affects the resource of the cable line. According to statistics for 2016, approximately 65% of accidents on the cable line occur at the connection point of the cables. These data indicate that it is necessary to pay close attention to the cable fittings.

2 Field leveling methods

There are several ways to control the electric field in the cutting:

1. Geometric method (Fig. 2). It is based on the superimposition of a special form of a semiconducting material on the cut-off screen by means of which the equipotential lines of the field are aligned and, consequently, the unevenness of the tension is reduced;

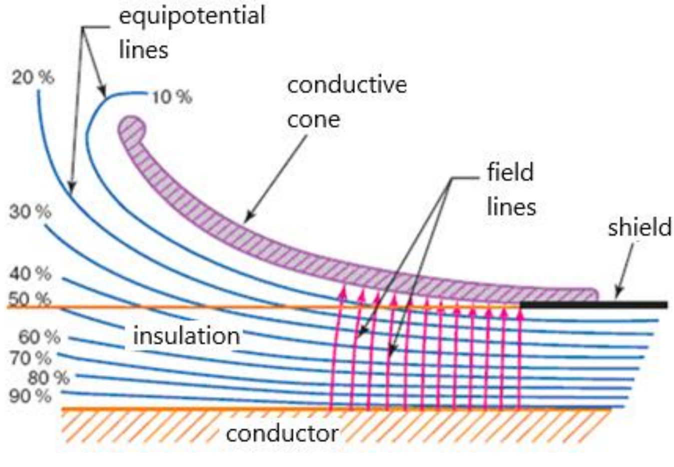

Fig. 2. Geometric method of alignment the electric field.

2. Refraction method (Fig. 3). Here, regulation occurs by imposing a material with a large dielectric constant on the main cable insulation, because of this the lines of force change direction (the larger the value of ε of the reinforcing insulation, the stronger the refraction) [8, 17];

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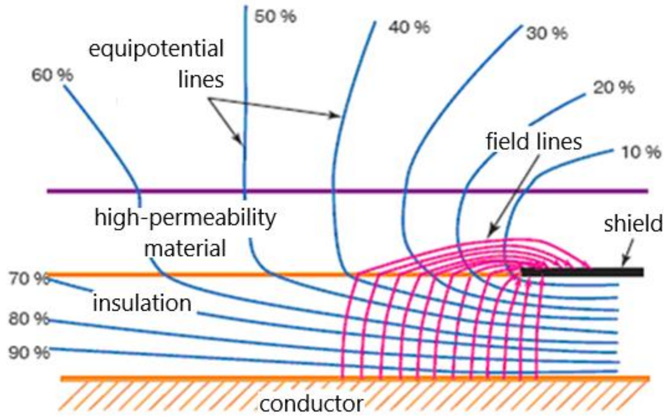

Fig. 3. Refraction method of alignment the electric field.

3. Resistive method (regulation of the active component of longitudinal conductivity) (Fig. 4). A material with a high electrical conductivity is superimposed on a section with a high value of the electric field strength. As a result, the lines of the field shift from the critical zone, which leads to a decrease in the value of E in the region [11, 12, 19].

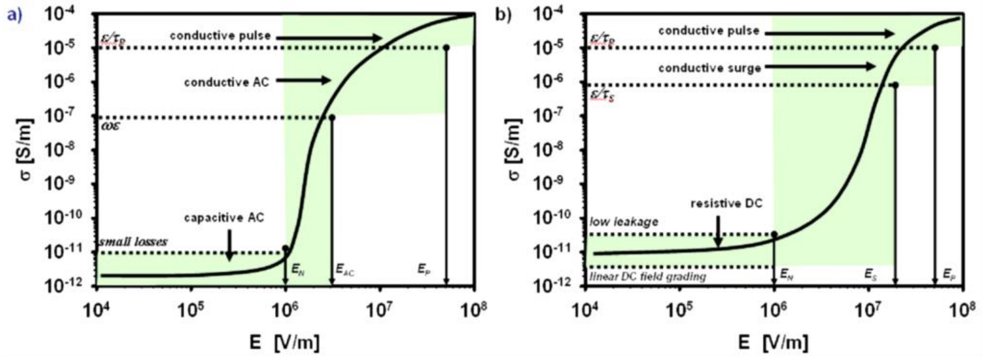

Fig. 4. A qualitative illustration of where the region is located in the E -σ plane for σ (E) curve of an ideal nonlinear resistive field smoothing material: (a) with alternating current, (b) at direct current.

3 Existing trends

Currently, in the couplings of 110 kV power cables, the stress-cone acts as the main element leveling the field [1, 16, 18]. This is a two-component cylinder based on ethylene-propylene rubber with special additives, which provide each element with the required properties (Fig. 5).

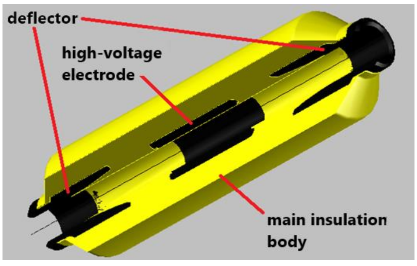

Fig. 5. Stress-cone coupling 110 kV

The stress cone combines the refractive (basic insulating body) and geometric (diplectors and high-voltage electrode) methods of field alignment [3, 4, 15]. This is achieved by introducing into the matrix additives with a high dielectric constant and additives with high conductivity [5].

Mechanical pulling with special winches carries out the installation of such a stress cone. This procedure is physically complicated, due to the large dimensions and high mass of the stress cone (21 kilograms for the coupling), it requires considerable effort and great experience from the working staff.

At the same time, the process of thermal shrinkage requires much less effort. This method does not require the presence of special equipment, except for the heating apparatus, it is not necessary to use physical force to shrink the structure for cable cutting. Therefore, the heat-shrink process looks more profitable for use in the installation of high-voltage couplings.

When using the heat shrink process, polyethylene is most suitable as a matrix. This material is very widely used in cable insulation; it is well cross-linked and has good electrical properties.

Analyzing the existing methods of leveling the field, it was concluded that the most compact and at the same time not inferior in electrical properties would be a design that combines the refractive and resistive methods of alignment the electric field [2].

4 Creating a model of a tube-regulator

To implement these ideas, an initial rough model of a new equalizing design was created-the regulator tube (Fig. 6). Preliminary calculations were made, for which all critical zones in the structure were found.

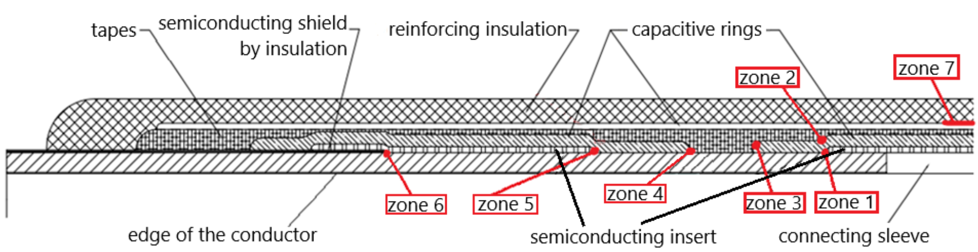

Fig. 6. The initial model of a tube-regulator with critical zones.

After determining the critical zones, the main geometric and physical parameters of the regulator tube were found, which greatly affect the distribution of the electric field:

- Length of the semiconducting insert (**SI**);
- The difference in lengths of SI and capacitive rings (**CapR**);
- Thickness of SI;
- Thickness of CapR;
- Thickness of tapes;
- Thickness of reinforcing insulation;
- The distance between the CapRs (near the sleeve and near the semiconducting screen for insulation);
- Dielectric permeability of SI;
- Dielectric permeability of CapR;
- Electrical conductivity of SI;

4.1 Theoretical component

The purpose of the calculations was to fix the optimal values of the investigated parameters, under which the tangential component of the electric field strength assumed a minimum value in the critical zones. In this case, it should not exceed 5 kV / mm (the threshold for the onset of the formation of sliding discharges in PE).

The calculations were carried out in a specialized software complex, whose work is based on the finite element method [9, 10, 13]. The value of the core potential was set equal to the amplitude value of the phase voltage, the screen potential was assumed to be zero. The semiconductive insert of our multifunctional element is electrically connected to the grounded shield of the cable, performing the function of restoring the "cropped" screen.

The proposed algorithm solved the problem of calculating the electric field of an alternating current. Taking into account the sinusoidal nature of the field in time, the equations below are written with respect to complex quantities (electric potential U, current density vector **j**, electric field strength E) [6, 7].

$$\nabla(\varepsilon \cdot \mathbf{E}) = 0 \quad (1)$$

$$\nabla \mathrm{j} = -i\omega \cdot \gamma \quad (2)$$

$$\mathbf{J} = \gamma \cdot \mathbf{E} \quad (3)$$

$$\nabla \cdot \left(\left[\varepsilon - \frac{i\gamma}{\omega} \right] \nabla U \right) = 0 \quad (4)$$

Using the formula **E** = -gradU, you can calculate the electric field strengths at any point in the model.

4.2 Methods

Using the software complex Elcut Professional [14, 20], the task of the magnetic field of alternating currents was solved, where the following conditions were set:

- At the boundary of the problem, the magnetic potential was equated to 0;
- The potential of the conductor was equal to 90500 V (phase amplitude value);
- The cable to which the tube was simulated was a conductor cross-section of 1200 mm^2, with insulation and a sheath of cross-linked polyethylene [21-28];
- All the necessary properties of known materials for the solution of the problem were taken from the corresponding directories;
- The shield potential for insulation was equated to zero;

4.3 Intermediate results

As a result of the calculations, the dependences of the electric field strength in critical zones on the parameters under study were obtained (Figures 7-16):

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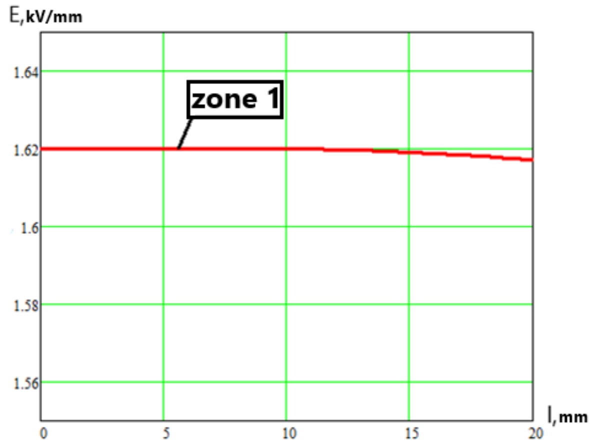

Fig. 7. The graph of the dependence of the intensity in zone 1 on the length SI over the sleeve

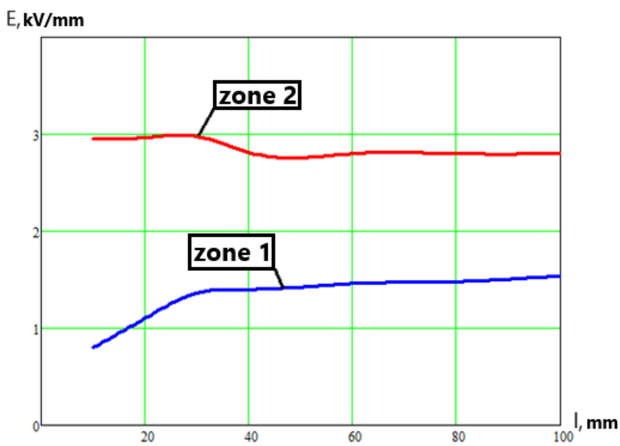

Fig. 8. Graphs of the dependence of the intensity in zone 1 and zone 2 on the distance between SI and CapR over the sleeve.

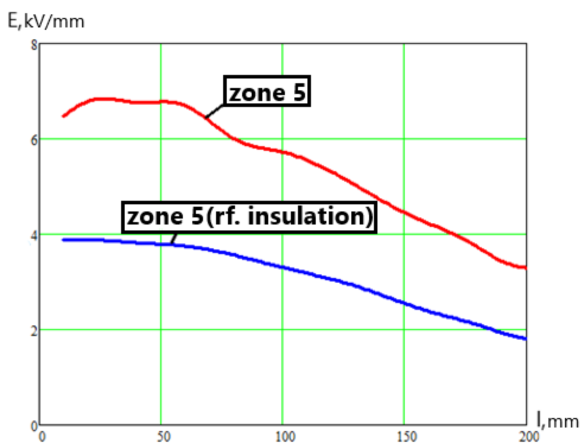

Fig. 9. Graphs of the dependence of the intensity in zone 5 on the side of the reinforcing insulation and on the side of the main cable insulation from the distance between the edge of the semiconducting shield along the insulation to the edge of the SI.

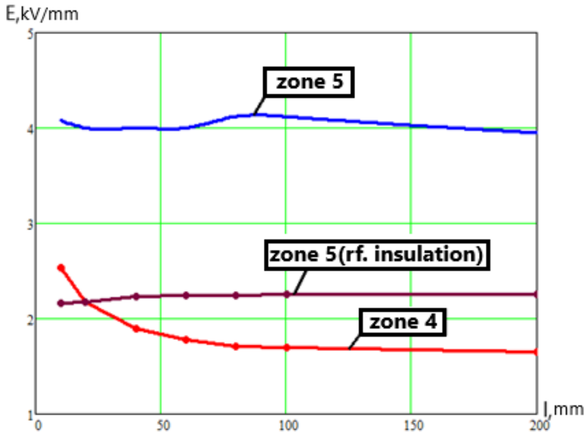

Fig. 10. Graphs of the dependence of the field strength in zones 5 and 4 on the distance between SI and the edge of CapR (near the shield cut by insulation)

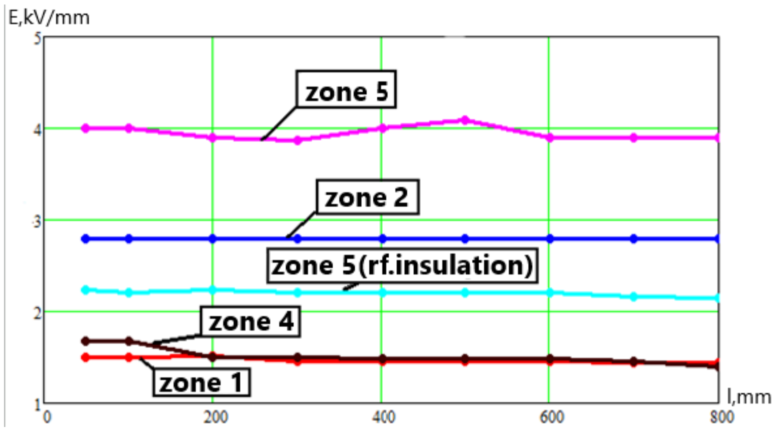

Fig. 11. Graphs of the dependence of the field strength in zones 1, 2, 4 and 5 on the distance between the edges of CapRs.

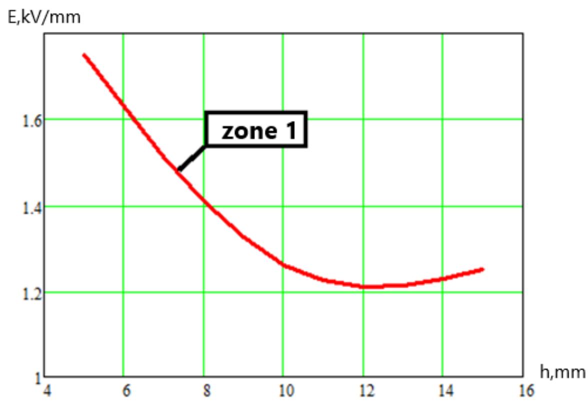

Fig. 12. The graph of the dependence of the electric field strength in zone 1 on the thickness SI above the sleeve

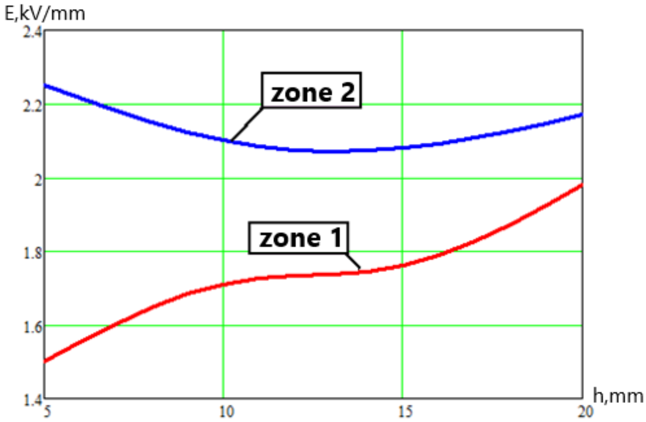

Fig. 13. Graphs of the dependence of the field strength in zones 1 and 2 on the thickness of CapR over the sleeve.

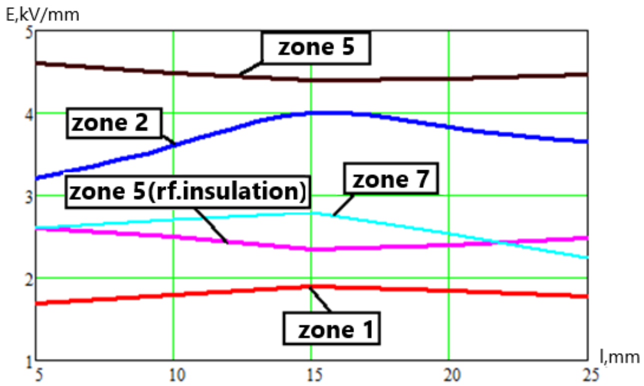

Fig. 14. Graphs of the dependence of the field strength in zones 1, 2, 5 and 7 on the thickness of tape

Due to the complex influence of the thickness of the reinforcing insulation and the thickness of the large capacitive ring, the influence of both components was considered simultaneously (Fig. 15, tables 1, 2)

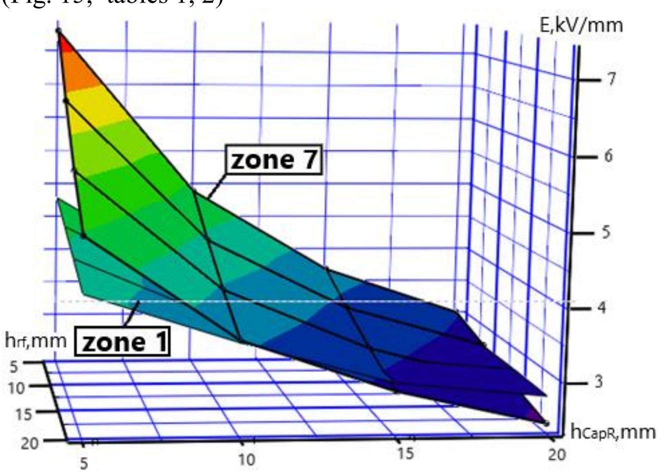

Fig. 15. A flat graph of the dependence of the electric field strength in zones 1 and zone 7 (reinforcing isolation zone)

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Table 1. Values of electric field strength in zone 7, kV/mm

		Thickness of reinforcing insulation, mm			
		5	10	15	20
Thickness of CapR, mm	5	7.3	4.9	3.9	3.02
	10	6.4	4.4	3.4	2.83
	15	5.6	3.96	3.13	2.6
	20	4.96	3.58	2.89	2.43

Table 2. Values of the electric field strength in zone 1, kV/mm

		Thickness of reinforcing insulation, mm			
		5	10	15	20
Thickness of CapR, mm	5	4.8	3.6	3.0	2.82
	10	4.6	3.6	3.08	2.82
	15	4.4	3.54	3.06	2.82
	20	4.2	3.55	3.05	2.8

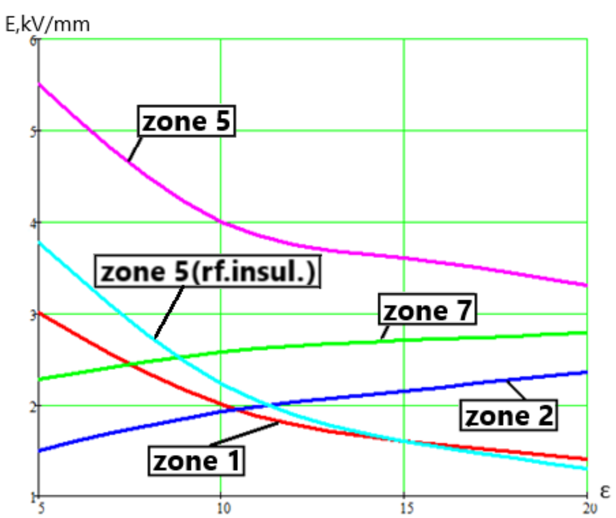

Fig. 16. Graphs of the dependence of the electric field strength in zones 1, 2, 5 and 7 on the dielectric constant of capacitive rings.

4.4 Results and Discussion

As a result of the study, the values of the parameters were obtained under which the distribution of the electric field was optimal.

Geometric parameters:
- Thickness of SI = 5 mm;
- Length of the SI above the sleeve= 250 mm;
- The length of the SI on the cut of shield by insulation = 170mm;
- Distance between SI and CapR on the sleeve = 55 mm;
- Thickness of CapR = 10 mm;
- Distance between CapRs= 80 mm;
- Thickness of large CapR ≤ 10 mm ≤ 10 mm;
- Thickness of reinforcing insulation = 20 mm;
- Length of CapR = ≥ 280 mm;

Physical parameters:
- ε(CapR) = 10;
- ε(reinforcing insulation) = 2;
- ϒ(SI) = $2\cdot10^{-2}$ S/m;
- ϒ(tape) = $2\cdot10^{-4}$ S/m

And, accordingly, the distribution of the electric field in the optimal design (Fig. 17) and the field strengths in the critical zones (Table 3)

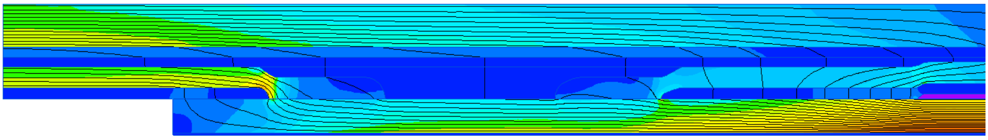

Fig. 17. Distribution of the electric field in the final design of the tube-regulator.

Table 3. Values of electric field strength in critical zones

Zones	Zone 1	Zone 2	Zone 3	Zone 4	Zone 5*	Zone 6	Zone 7
E_{Σ}, kV/mm	3.57	0.10	1.51	1.74	1.37/2.71	3.64	2.60
E_{τ}, kV/mm	3.27	0.04	1.50	1.72	0.07/2.62	**3.62**	2.60

5 Conclusions

This study confirms the possibility of creating a new type of coupler, the work of which will be based on the resistive-capacitive principle of equalizing the electric field, as a result, this design will be much easier to install, smaller in mass-dimension parameters, which will simplify the installation and reduce the probability of errors work with couplings.

- The design of a multifunctional element is proposed;
- Parameters that need to be optimized and critical zones on the values of the strengths in which they were oriented were determined;
- Computer simulation of our element;
- The final preliminary design of the multifunctional element is obtained;

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