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Method of Quality Improving of Electric Energy by Changing the Topology of Wires Connection on Overhead Power Transmission Lines

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Abstract

The article describes the problem of the unbalance of a three-phase voltage system in order to propose the practical recommendations for improving the quality of electric energy. The numerical methods of electric fields calculating, namely the integral equation method, are used for this purpose. Based on this method, the expressions for the calculation of potential coefficients are defined. The authors proposed the method of levelling the parameters of a power line by changing the height of the wire suspension, taking into account its real structure. A power line of 500 kV with horizontal wires was analysed as an example of the particular case. We obtained the dependencies of the modulus of charge argument differences and the potential of extreme phases depending on the ratio of the equivalent radius of the extreme phase to the equivalent radius of the middle phase, and by changing the height of the middle phase of the suspension.

Keywords: electromagnetic field, electric field, integral equation method, potential factors.

INTRODUCTION

The main effect of voltage unbalance on the operation of electric equipment is related to the increase in electricity losses in the electricity mains. At that, the receivers of electric energy do not work at the nominal voltages, which causes the same effect as when you reject at voltage fluctuation with decreasing of the service life of transformers and appearing of inhibitory magnetic fields in electric motors. Therefore, the reduction or elimination of voltage unbalance is an important task of national economy requiring the immediate solution.

As is known [1], the unbalance of the three-phase voltage system is caused by the unbalanced load of electricity consumers or the unbalance of the electrical network elements. This article examines the impact of the parameters of the overhead power transmission line (OHPL) on the voltage unbalance, namely the capacity.

As is shown in [2], these procedures can be used to align the charges in phases:

- Increase the height of the wires suspension of middle phase;
- Increase the equivalent radius of extreme phase wires.

To determine the exact numerical values in the proposed procedures, it is necessary to take into account the real structure of power lines. Not only the height of the wires suspension affects the charge distribution along the wires in the span, but also the sag defined depending on the span. Solid metal constructions – power pylons also affect the redistribution of charges, especially close to wire connections to traverse. We show how to take into account the effect of metal poles.

METHODS

Structurally, a power pylon consists of corners and metal bands, which can be replaced by cylindrical conductors with a circular cross-section with a radius that provides the same capacity of round and non-round wires per unit of length (this radius is called equivalent). The equivalent radius can be determined, for example, by the formulas given in [3]. Thus, the equivalent radius for a small band of small thickness and a width of *a* is:

$$r_e = \frac{a}{4} \tag{1}$$

and for the equilateral corner with the side of

$$r_e = \frac{a}{2.5} \tag{2}$$

The metal support of the high-voltage power line can be replaced by a set of N cylindrical wires of L_k length and the equivalent radiuses of r_e, calculated by the formulas (1) – (2), where $k \in N$ (Figure 1). The charge induced on the conductors due to electrical induction per unit of length of the *k*-th conductor we denote as τ_k. It is not constant throughout the length of the conductor and depends on the specific point. The total amount of wire and protective earth wire, suspended on a support, is denoted by N_{wir}. A linear charge on the wire is also not constant over the entire length; we denote it by τ_{wi}, and the radius of wire – by r_{0wi}.

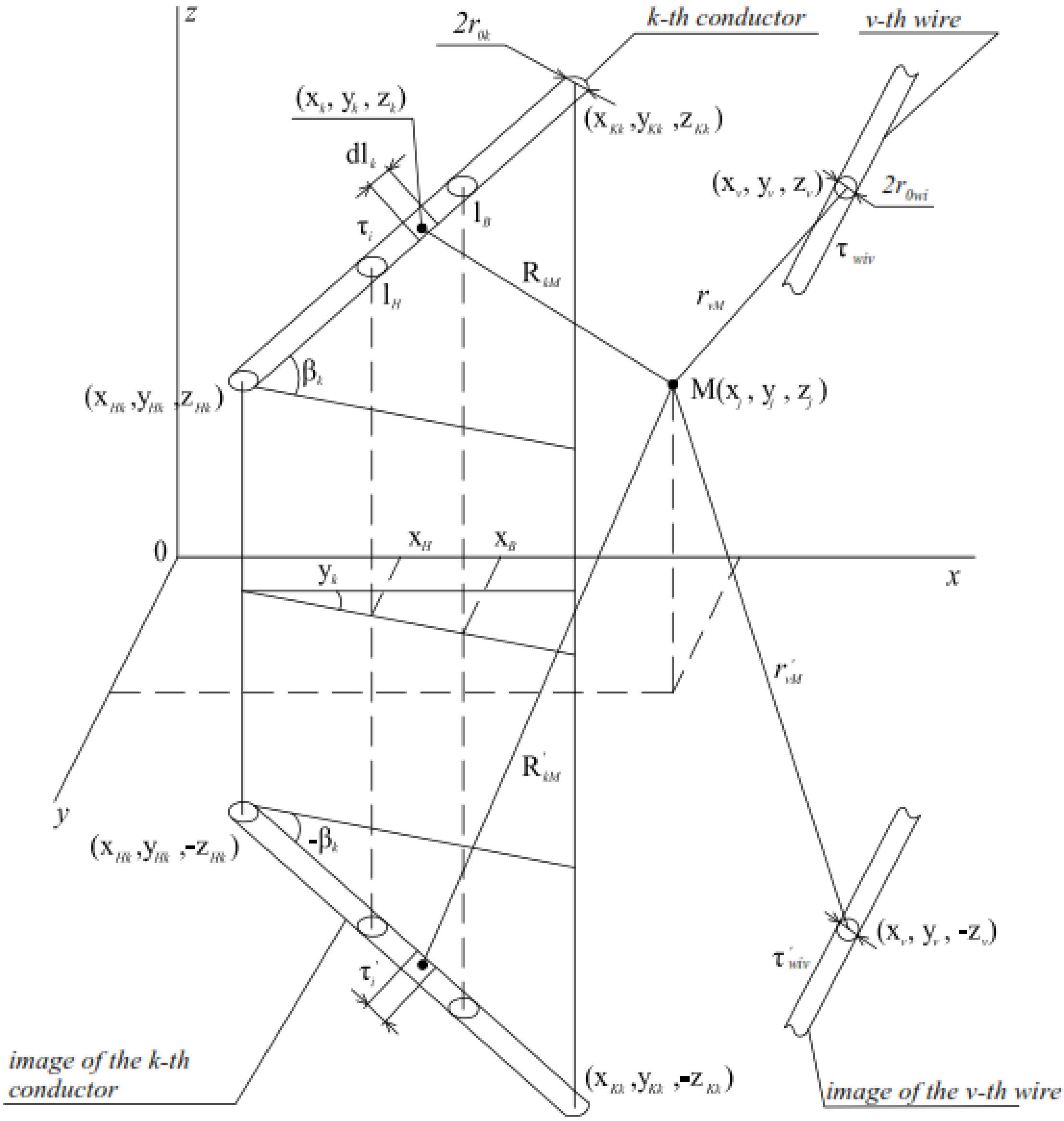


Figure 1. Identification of potential coefficients from the element of real support

When selecting a coordinate system *xyz* in such a way that $z = 0$ corresponds to the ground level, the potential arbitrary point of observation $M(x_j, z_j, y_j)$ is determined from the superposition principle and is equal to the algebraic sum of the potentials of all *N* conductors and mirror images, as well as all N_{wi} of wires and their images

$$\varphi_M = \frac{1}{4\pi\varepsilon\varepsilon_0}\left[\sum_{k=1}^{N}\int_{L_k}\left(\frac{\tau_k(l_k)dl_k}{R_{kM}} + \int_{L_k}\frac{\tau'_k(l_k)dl_k}{R'_{kM}}\right) + \sum_{v=1}^{N_{wi}}\int_{l_{sp}}\left(\frac{\tau_{wiv}(l_v)dl_v}{r_{vM}} + \int_{L_k}\frac{\tau'_{wiv}(l_v)dl_v}{r'_{vM}}\right)\right], \qquad (3)$$

where $\tau_k(l_k)$ is a linear charge of *k*-th conductor in its elementary section dl_k; R_{kM} is the distance from the elementary section *dl* of the *k*-th conductor to the point *M*; R'_{kM} is the distance from the elementary section *dl* of the mirror image of the *k*-th conductor to the point *M*; r_{vM} is the distance from the *v*-th elementary section *dl* of wire to the point *M*; r'_{vM} is the distance from the elementary section *dl* of the mirror image of the *v*-th wire to the point *M*; l_{sp} is the length of the span.

The functional equation (3) comprises the integral transform of the unknown function $\tau_k(l_k)$ and $\tau_{sp}(l_{sp})$, and is an integral equation, i.e. the Fredholm equation of the first kind. Given that $\tau'_k = -\tau_k$ and $\tau'_{wi} = -\tau_{wi}$ we can rewrite it as

$$\varphi_M = \frac{1}{4\pi\varepsilon\varepsilon_0}\left[\sum_{k=1}^{N}\left(\int_{L_k}\frac{\tau_k(l_k)dl_k}{R_{kM}} - \int_{L_k}\frac{\tau_k(l_k)dl_k}{R'_{kM}}\right) + \sum_{v=1}^{N_{wi}}\int_{l_{sp}}\left(\frac{\tau_{wiv}(l_v)dl_v}{r_{vM}} - \int_{L_k}\frac{\tau_{wiv}(l_v)dl_v}{r'_{vM}}\right)\right]. \tag{4}$$

By alternately placing the point of observation first to the surface of the cylindrical conductors, and considering the capacity of all conductors is equal to zero, and then, consequently on the surface of each wire, we obtain a system of integral equations based on (4).

$$\begin{cases} 0 = \frac{1}{4\pi\varepsilon\varepsilon_0}\left[\sum_{k=1}^{N}\left(\int_{L_k}\frac{\tau_k(l_k)dl_k}{R_{k1}} - \int_{L_k}\frac{\tau_k(l_k)dl_k}{R'_{k1}}\right) + \sum_{v=1}^{N_{wi}}\int_{l_{sp}}\left(\frac{\tau_{wiv}(l_v)dl_v}{r_{v1}} - \int_{L_k}\frac{\tau_{wiv}(l_v)dl_v}{r'_{v1}}\right)\right] \\ \dots \\ \varphi_{Nnn} = \frac{1}{4\pi\varepsilon\varepsilon_0}\left[\sum_{k=1}^{N}\left(\int_{L_k}\frac{\tau_k(l_k)dl_k}{R_{kN.wi}} - \int_{L_k}\frac{\tau_k(l_k)dl_k}{R'_{kN.wi}}\right) + \sum_{v=1}^{N_{wi}}\int_{l_{sp}}\left(\frac{\tau_{wiv}(l_v)dl_v}{r_{vNnN}} - \int_{L_k}\frac{\tau_{wiv}(l_v)dl_v}{r'_{vNnN}}\right)\right]. \end{cases} \tag{5}$$

To solve the integral equations and their systems we use the method of quadrature formulas (finite sums), in which we replace the integral equation with an approximating system of algebraic (finite) equations relative to the discrete values of the unknown function and its decision [4].

To compose the system of linear algebraic equations (SLAE), we split each conductor into *g* equal portions of h_k length, and each wire and cable into g_{wi} equal portions of l_{el} length. We assume that the linear charge density on each section of the conductor, wire and cable τ_i remains constant. At the same time, all the total charges of every electrode are equal at a smooth change of the linear density and the same stepwise. In order not to increase the number of equations in the SLAE, considering the expression (3), we write the resulting potential from the *g* section of the *k*-th of conductor and its image, and also from the section g_{wi} of the *v*-th wire (cable) and its image

$$\tau_i(\alpha_{ijW} - \alpha_{ijI}) = \tau_i\alpha_{ij} \text{ or } \alpha_{ij} = \alpha_{ijw} - \alpha_{ijI}, \tag{6}$$

where α_{ijw} is the coefficient caused by the charge of the wire section or cable; α_{ijI} is the coefficient caused by the charge of a mirror image of the same section of the conductor, wire or cable.

Thus, the system of integral equations (5), considering (6), may be replaced by SLAE which in the matrix form has the form of:

$$\begin{cases} [\alpha_{ij}][\tau_i] = [0]; \\ [\alpha_{ij}][\tau_i] = [\varphi'_i]. \end{cases} \tag{7}$$

The algorithm for the calculation of the potential coefficients by the proposed method is shown in [5].

RESULTS OF THE STUDY

We will consider the measures efficiency identification on aligning of electrical charges in phases on the example of HVPL of 500 kV, formed by pillars showed in Figure 2. The equivalent height of the cable suspension was taken at 15 m [6]; the equivalent radius of the phases is 0.16 m for AS-400 wire and the number of conductors in a split phase is 3. The distance between the phases is 12 m. Calculations and graphical dependences were carried out in a specially designed application. [7]

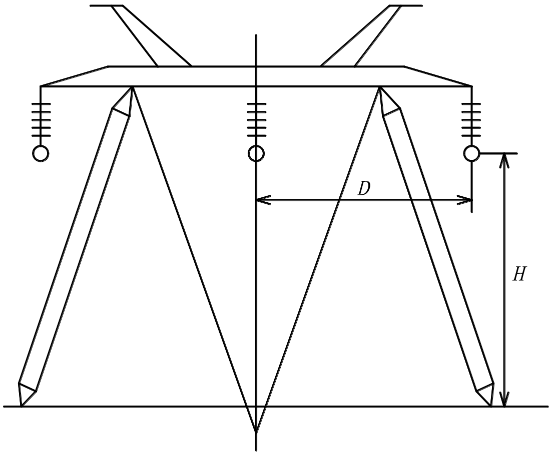


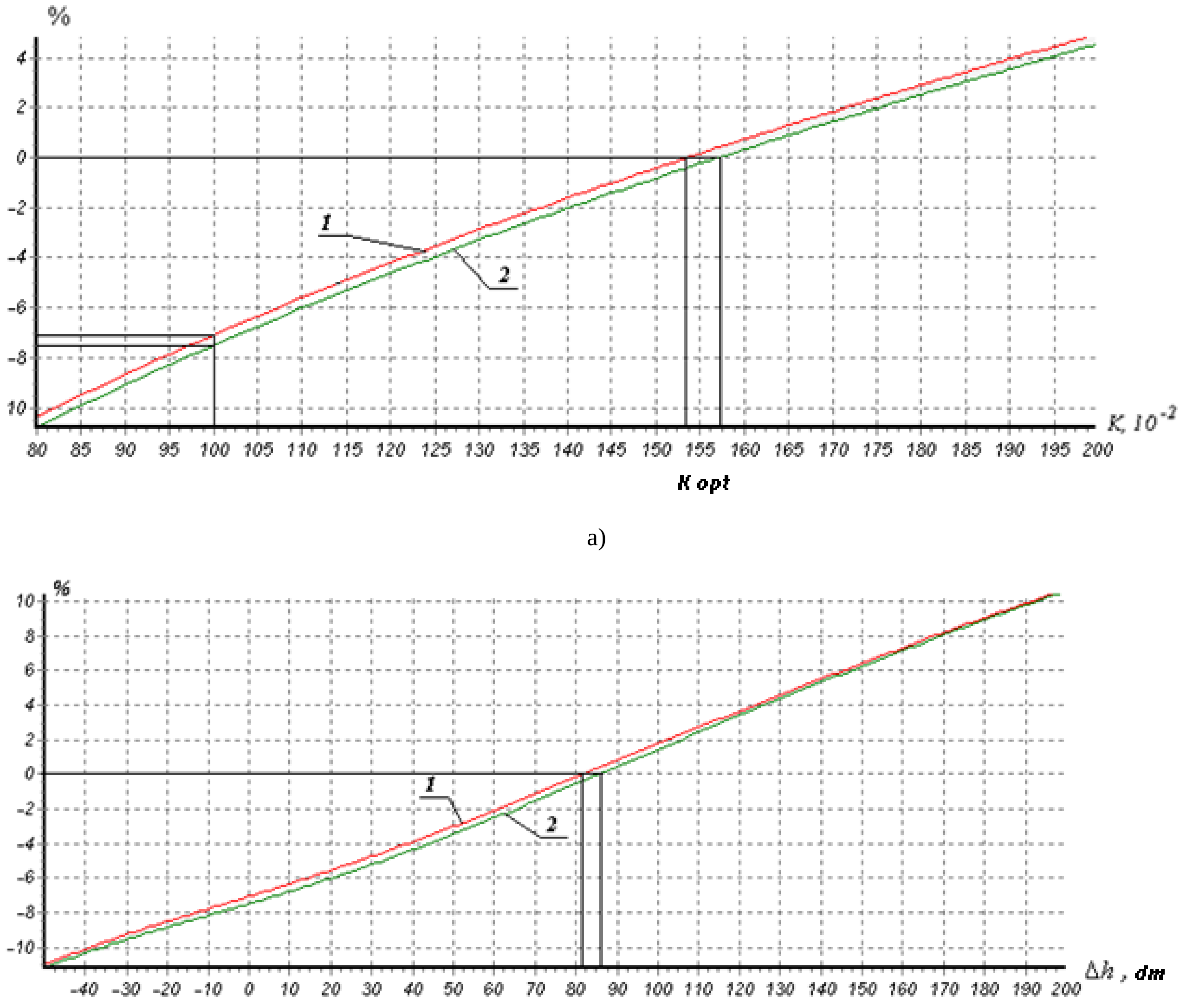
Figure 2. Structure of pillars for a power-line of alternating current with the voltage of 500 kV

We introduce the coefficient ***K***, showing the ratio of the equivalent radius of the extreme phase to the equivalent radius of the middle phase. The dependencies of electrical parameters, given as a percentage of middle phase parameters from the ***K*** coefficient, are shown in Figure 3.

The figure shows that the modulus charge does not differ from each other in all phases, in case if the equivalent radius of the extreme phases is 1.53 times higher than the equivalent radius of the middle phase or if the height of the middle phase is increased by 8.2 m. The working capacities of all phases are the same in case if the ratio of the equivalent radius of the extreme to the equivalent radius of the middle phase is 1.57, or by increasing the height of the middle phase height by 8.6 m.

DISCUSSION OF RESULTS :

By virtue of the geometrical symmetry, the charge and the potential on the middle phase coincide with each other, i.e. the phase difference between them is equal to zero. The dependences of the modulus difference of charge arguments and potential of extreme phases $|\varphi_\tau - \varphi_U|$ on K and changing the height of the suspension in medium phase are shown in Figures 4 and 5.



a)

b)

1 – deviation of the charge on the extreme phases as a percentage of the charge on the middle phase $\frac{|\tau_{mid} - \tau_{ex}|}{|\tau_{mid}|}100\%$;

2 – deviation of the operating capacity at the extreme phases as a percentage of operating capacity at the middle phase $\frac{|C_{mid} - C_{ex}|}{|C_{mid}|}100\%$

Figure 3. Dependence of the electrical parameters on:

a) ratio of the equivalent radius at the extreme phase to the equivalent radius of the middle phase;

b) changes in suspension height of the middle phase Δh

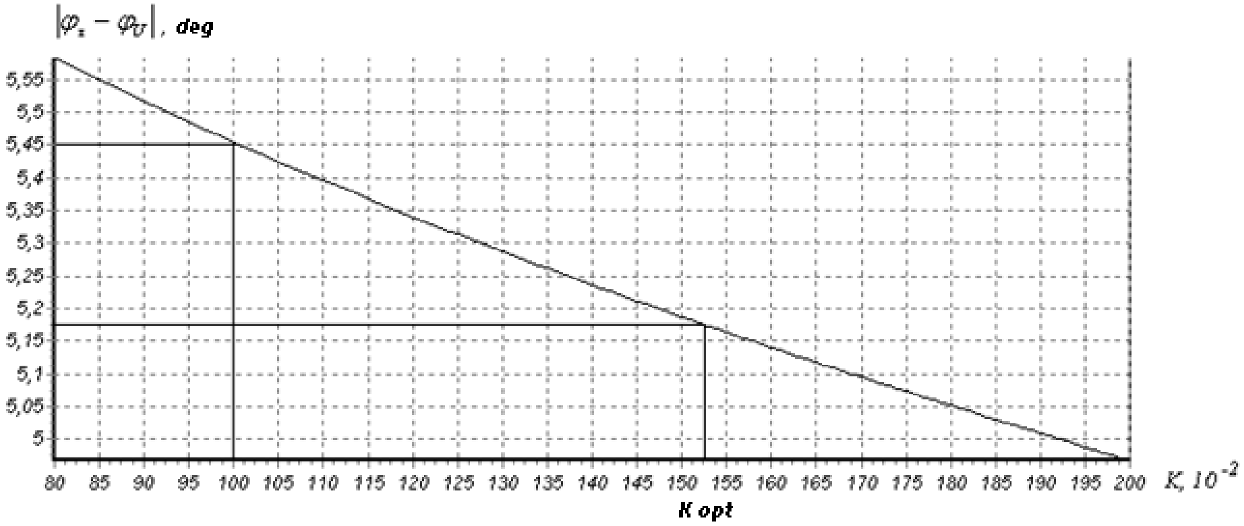


Figure 4. Dependence of the difference modulus of charge and potential arguments at the extreme phases $|\varphi_\tau - \varphi_U|$ on the ratio of the equivalent radius to the extreme phase to the equivalent radius of the middle phase

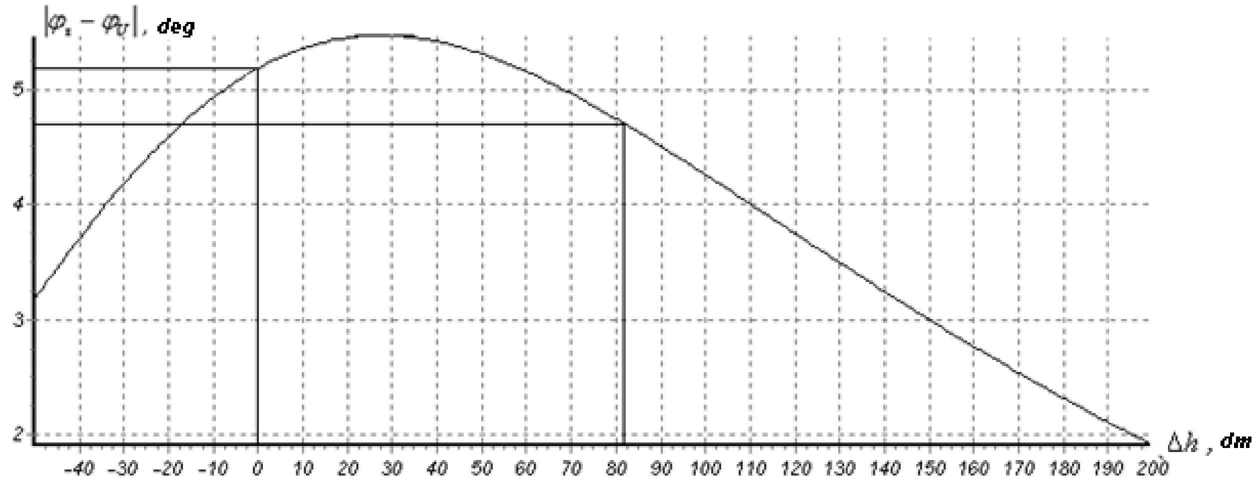


Figure 5. Dependence of the difference modulus of charge and potential arguments at the extreme phases $|\varphi_\tau - \varphi_U|$ on the suspension height changing of the middle phase Δh

It follows from the above figures that at the optimum ratio and the equivalent radius at the extreme and middle phase the modulus of the charge argument difference and the potential of the extreme phases decreases compared with the initial value equal to 5.45 to 5.17 degrees, or by 5%.

The calculations were performed for power lines of 500 kV with the intermediate pillars on stay guys of PB1 type with the parameters: the equivalent height of the wire suspension of 15 meters, the equivalent radius of phases of 0.16 m (for AS-400 wire and the number of conductors in a split phase 3), the distance between the phases 12 m.

CONCLUSION

1. The sequence of phase position does not affect the location of the dependence of electrical parameters of the ratio of the equivalent radius at the extreme phase to the equivalent radius of the middle phase.
2. To align the capacitances of each phase, first of all, rely on the alignment of the charge modulus instead of the argument.
3. The working capacity of all phases is the same, provided that the ratio of the equivalent radius of the extreme phase to the equivalent radius of the middle phase is equal to 1.57, or by increasing the height of the middle phase by 8.6 m.

4. The proposed method of capacities alignment can be extended to other classes of voltages and types of pillars, particularly to the power lines of high voltage for agricultural purposes.

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