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## Calculation of Power Frequency Electric Field Around Ultra-High Voltage AC Transmission Lines

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# Calculation of Power Frequency Electric Field Around Ultra-High Voltage AC Transmission Lines

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**Abstract.** Under the increasingly stringent situation of environmental protection management, it is necessary to research the distribution law of power frequency electric field around Ultra-High Voltage (UHV) AC transmission lines to provide technical basis for the design of transmission lines and the environmental impact assessment. Firstly the basic principle of equivalent charge method and its mathematical model are introduced in this paper. Then it is researched how to use equivalent charge method to analyze the electric field near the transmission lines. Based on the three-phase double-circuit overhead transmission line model, the influences of several factors on the power frequency electric field have been analyzed. These factors include the conductor-to-ground height, the phase sequence arrangement, the number of split conductors and the split spacing. Finally the frequency electric field of parallel UHV AC transmission lines is discussed. The results can provide reference for engineering design of UHV AC transmission lines.

## 1. Introduction

In power system, transmission lines bear the important task of the power transmission. With the sustained and rapid development of social economy, the demand for electricity is constantly rising, the scale of transmission lines is getting larger and larger, and the shortage of resources in transmission corridors is becoming increasingly prominent. People are paying more and more attention to the impact of transmission lines on the environment [1]–[2].

The power frequency electric field under the transmission line is an important issue that must be considered in the design and operation of the line. It is the foundation and basis for the selection of tower type, conductors, and distance to the ground [3]–[4]. In this paper, by using the equivalent charge method, the influence of conductor-to-ground height, phase sequence arrangement, number of split conductors, split spacing and other factors on the power frequency electric field is calculated and analyzed. With the large-scale construction of UHV transmission lines, more and more parallel lines are selected to improve corridor utilization. In this paper, the electric field distribution of UHV transmission lines under the parallel transmission mode is calculated and analyzed, which provides a reference for engineering design.

## 2. Principle and calculation steps of equivalent charge method



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### 2.1. Principle of equivalent charge method

The mathematical model of electrostatic field can be summed up as the solution of Poisson equation or Laplace equation with potential function  $\varphi$  as the quantity to be determined.

The basic potential equation is:

$$\nabla^2 \varphi = -\frac{\rho}{\varepsilon_0} \text{ or } \nabla^2 \varphi = 0 \quad (1)$$

The first boundary condition is:

$$\varphi|_{L_1} = f_1(P) \quad (2)$$

The interface conditions of different media are:

$$\varepsilon_1 \frac{\partial \varphi_1}{\partial n} - \varepsilon_2 \frac{\partial \varphi_2}{\partial n} = 0, \varphi_1 = \varphi_2 \quad (3)$$

However, in actual engineering calculation, the distributions of the continuously-distributed free charges on the electrode (conductor) surface and the continuously-distributed bound charges on the dielectric interface are often unknown, and cannot be solved directly by the given boundary conditions. If  $n$  discrete charges called simulated charges are set outside the calculation field to replace these continuously-distributed charges, the values of the simulated charges can be obtained according to the precondition that the boundary conditions unchanged before and after the equivalent replacement. Therefore, the potential and field strength of any point in the field can be obtained by superposition of the field quantity ( $\varphi$ ,  $E$ ) generated by simulated charge, which can be used as the approximate solution of the original field. This is the basic principle of the equivalent charge method [5]–[6].

### 2.2. Calculation steps of equivalent charge method

Taking the electric field problem of a single homogeneous medium as an example, the analysis and calculation steps of the equivalent charge method are as follows:

(1) Set  $n$  simulated charges  $Q_j (j=1, 2, \dots, n)$  outside the calculation field.

(2) Set matching points  $M_i (i=1, 2, \dots, n)$  on the electrode whose boundary conditions are given, and the number of matching points is equal to the number of simulated charges. Obviously, the potential value at each matching point  $\varphi_i (i=1, 2, \dots, n)$  is known.

(3) According to the superposition principle, the potential expressions of each matching point  $M_i$  can be listed individually:

$$\begin{cases} \varphi_1 = P_{11}Q_1 + P_{12}Q_2 + \dots + P_{1n}Q_n \\ \varphi_2 = P_{21}Q_1 + P_{22}Q_2 + \dots + P_{2n}Q_n \\ \dots\dots\dots \\ \varphi_n = P_{n1}Q_1 + P_{n2}Q_2 + \dots + P_{nn}Q_n \end{cases} \quad (4)$$

The interface conditions are:

$$\varepsilon_1 E_{1n} - \varepsilon_2 E_{2n} = 0, \varphi_1 - \varphi_2 = 0 \quad (5)$$

Thus, a set of linear equations is formed:

$$[P][Q] = [\varphi] \quad (6)$$

(4) Solve the equations and obtain the value  $[Q]$  of the simulated charge.

(5) Take several additional check points on the surface of the electrode to check the calculation accuracy. If the accuracy does not meet the requirements, re-correct it until the accuracy requirement is met.

(6) Finally, the electric field strength at any point can be obtained by using the calculated value  $[Q]$  of the simulated charge.

### 3. Mathematical model

#### 3.1. Calculation method of potential coefficient matrix

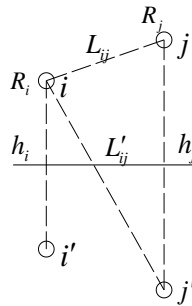
[*P*] can be obtained by the image theory. The ground is a plane whose potential is equal to zero. The induced charge of the ground can be replaced by the image charge of the corresponding ground conductor. The actual conductors parallel to each other are denoted by *i, j, ...*, and their mirror images are represented by *i', j', ...*, as shown in figure 1. The potential coefficient can be written as [7]–[8]:

$$P_{ii} = \frac{1}{2\pi\epsilon_0} \ln \frac{2h_i}{R_i} \quad (7)$$

$$P_{ij} = \frac{1}{2\pi\epsilon_0} \ln \frac{L'_{ij}}{L_{ij}} \quad (8)$$

$$P_{ij} = P_{ji} \quad (9)$$

Where:  $\epsilon_0$  is the air dielectric constant;  $R_i$  is the transmission conductor radius.



**Figure 1.** Schematic diagram of potential coefficient matrix.

From [*U*] and [*P*], [*Q*] can be solved by using equation (4).

#### 3.2. Calculation of electric field strength

The calculation of electric field strength at any point in space is as follows. When the equivalent charge per unit length of each conductor is found, the electric field strength at any point in space can be calculated according to the superposition principle. The electric field strength components  $E_x$  and  $E_y$  at (*x, y*) point can be expressed as:

$$E_x = \frac{1}{2\pi\epsilon} \sum_{i=1}^m Q_i \left( \frac{x-x_i}{L_i^2} - \frac{x-x_i}{L_i'^2} \right) \quad (10)$$

$$E_y = \frac{1}{2\pi\epsilon} \sum_{i=1}^m Q_i \left( \frac{y-y_i}{L_i^2} - \frac{y+y_i}{L_i'^2} \right) \quad (11)$$

Where:  $x_i$  and  $y_i$  are the abscissa and ordinate of the conductor *i*,  $i=1, 2, \dots, m$ ; *m* is the number of conductors;  $L_i$  and  $L_i'$  are the distances of the conductor *i* and its mirror image to the calculation point.

#### 3.3. Calculation of space field strength of three phase AC line

For a three-phase AC line, since the voltage is a time variable, the voltage of each phase conductor in calculation is expressed in complex number:

$$\dot{U}_i = U'_{i,R} + jU'_{i,I} \quad (12)$$

The corresponding charge is also a complex number:

$$\dot{Q}_i = Q'_{i,R} + jQ'_{i,I} \quad (13)$$

The matrix relationships can be represented as the real and imaginary parts of the complex number, respectively:

$$[Q_R] = [P]^{-1}[U_R]$$

$$[Q_I] = [P]^{-1}[U_I]$$
(14)

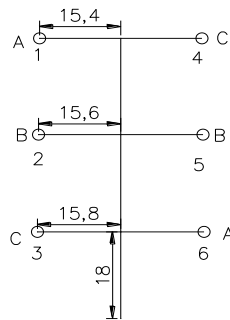
Thus, the horizontal and vertical components of the electric field strength at any point in the space are calculated based on the calculated electric charge, respectively:

$$\dot{E}_x = E'_{x,R} + jE'_{x,I}, \dot{E}_y = E'_{y,R} + jE'_{y,I}$$
(15)

## 4. Calculation

### 4.1. Calculation of double-circuit AC 1000kV lines on the same tower

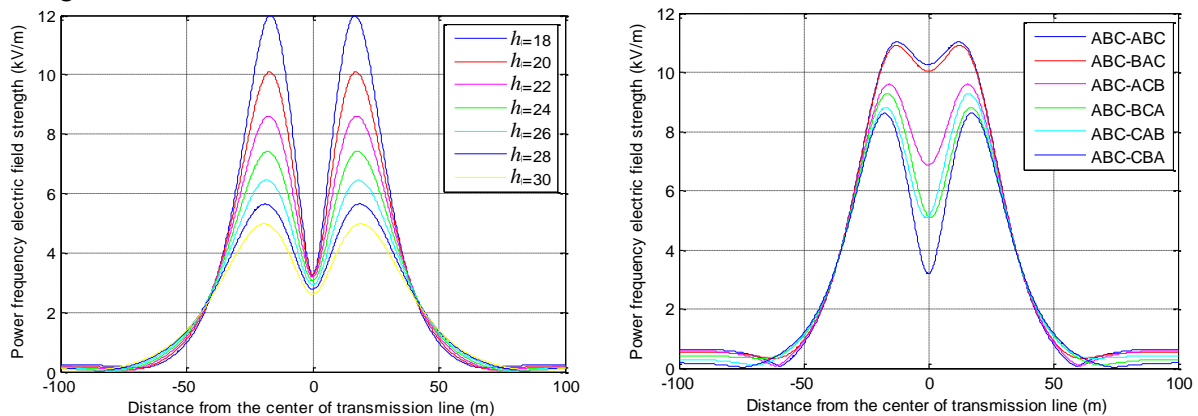
The arrangement schematic diagram of the double-circuit AC 1000kV lines on the same tower is shown as figure 2.



**Figure 2.** Schematic diagram of double-circuit 1000kV lines arrangement.

**4.1.1 The influence of the conductor-to-ground height.** The split type of the line is 8×LGJ-630/45, the outer diameter of the sub-line is 33.6mm, the split spacing is 400mm, and the phase sequence arrangement is ABC-CBA. When the height of the conductor to ground is raised from 18m to 30m, the horizontal distribution of power frequency electric field on the ground is shown in figure 3. It shows that the power-frequency electric field decreases with the increase of the height of the conductor to the ground, but the degree of reduction gradually becomes slow.

**4.1.2 The influence of phase sequence arrangement.** The split type of the line is 8×LGJ-630/45, the outer diameter of the sub-line is 33.6mm, the split spacing is 400mm, and the height of the conductor to ground is 22m. The horizontal distribution of power frequency electric field on the ground with different phase sequence arrangement is shown in figure 4. It shows that when the overhead transmission line is arranged in the same phase sequence, the electric field strength value under the line is maximum, while in the reverse phase sequence arrangement, the electric field strength value under the line is minimum, and the electric field strength values of the other phase sequence arrangement modes are in between.

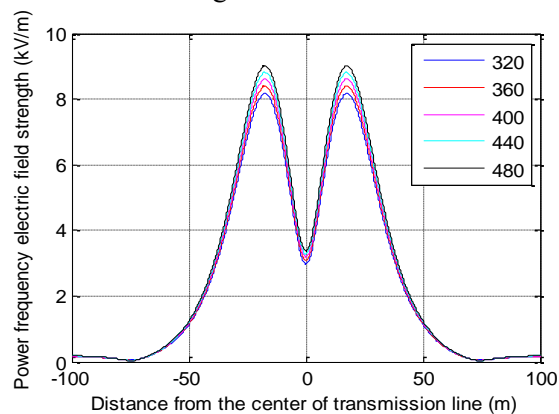


**Figure 3.** The horizontal distribution of power frequency electric field on the ground.

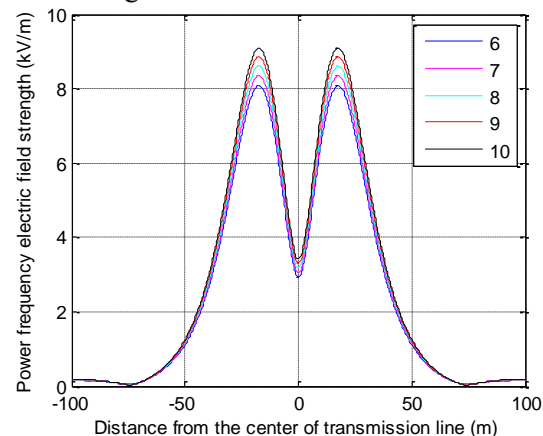
**Figure 4.** The horizontal distribution of power frequency electric field on the ground.

**4.1.3 The influence of split spacing.** The height of the conductor to ground is 22m, and the phase sequence arrangement is ABC-CBA. The horizontal distribution of power frequency electric field on the ground with different split spacing is shown in figure 5. We can find that with the increase of the splitting spacing, the electric field strength value under the line increases, but it changes little.

**4.1.4 The influence of the number of split conductors.** The conductor split spacing is 400mm, the height of the conductor to ground is 22m, and the phase sequence arrangement is ABC-CBA. The horizontal distribution of power frequency electric field on the ground with different number of split conductors is shown in figure 6. It shows that with the increase of the number of split conductors, the electric field strength value under the line increases, but it changes little.



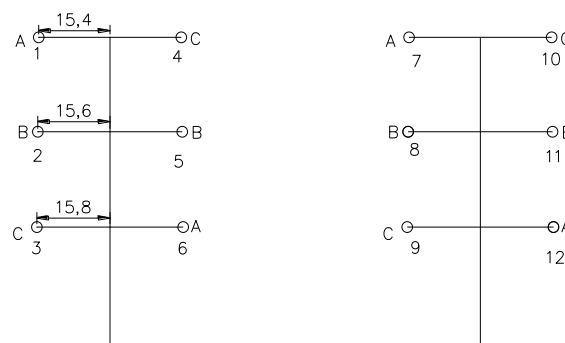
**Figure 5.** The horizontal distribution of power frequency electric field on the ground.



**Figure 6.** The horizontal distribution of power frequency electric field on the ground.

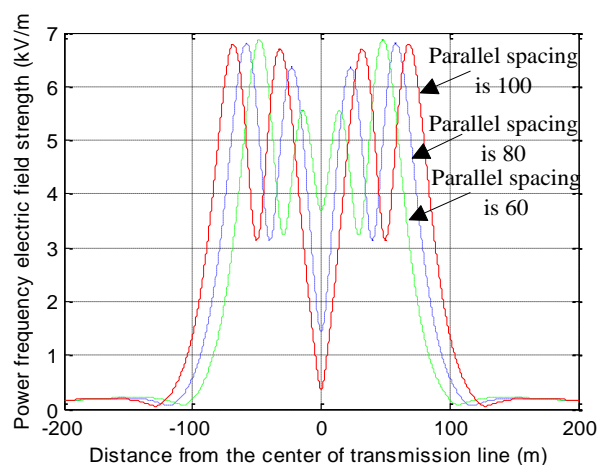
#### 4.2. Calculation of double-circuit AC 1000kV parallel lines on the same tower

The schematic diagram of parallel arrangement of double circuit AC 1000kV lines on the same tower is shown in figure 7.

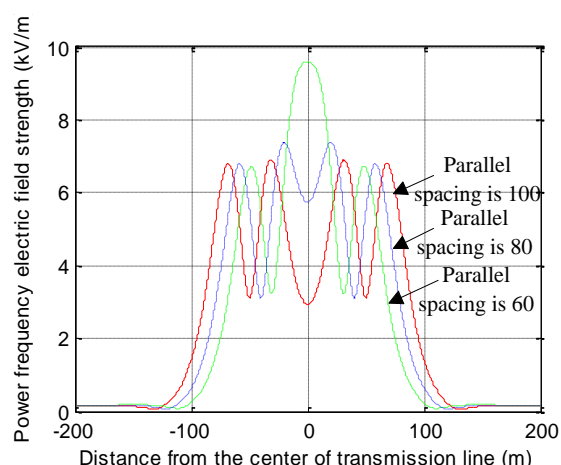


**Figure 7.** Schematic diagram of the parallel lines arrangement.

As shown in figure 8, when the phase sequence arrangement of double-circuit parallel lines is ABCCBA-ABCCBA, the electric field strength on the ground between the two lines is weakened, and the degree of weakening decreases with the increase of the parallel spacing. And as shown in figure 9, when the phase sequence arrangement of double-circuit parallel lines is ABCCBA-CBAABC, the electric field strength on the ground between the two lines is enhanced, and the degree of the enhancement becomes smaller as the parallel spacing increases. And one line has very little effect on the electric field on the ground outside the other line.



**Figure 8.** The horizontal distribution of power frequency electric field on the ground.



**Figure 9.** The horizontal distribution of power frequency electric field on the ground.

## 5. Conclusion

The electric field strength of UHV AC transmission lines can be reduced by adjusting the conductor-to-ground height, the distance between the lines, and the split spacing of the sub-lines and etc. And the most effective way to reduce the electric field strength under the line is to increase the height of the conductor to the ground properly and arrange them in reversed phase order. Reducing the split spacing and the number of split conductors can reduce the field strength under the line, but the effect is not obvious. When the double-circuit AC 1000kV lines are running in parallel on the same tower, and the parts between the two lines are arranged in reverse phase sequence, the electric field strength on the ground is weakened, and as the parallel spacing increases, the weakening degree becomes smaller and smaller. In addition, when the parts between the two lines are in the same phase order, the electric field strength on the ground between the two lines is enhanced, and the degree of the enhancement becomes smaller as the parallel spacing increases. And one line has very little effect on the electric field on the ground outside the other line.

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