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# Study on Electric Field of Transmission Line Based on Simulated Charge Method

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## Abstract

**the simulation program of power frequency electric field based on analog charge method is studied to analyze the distribution law of power frequency electric field and its influencing factors. On the basis of meeting the requirements of engineering calculation, this paper simplifies the relevant calculation. Taking EHV transmission line as the research object, the distribution of power frequency electric field of transmission line based on simulated charge method is analyzed in detail. Some factors affecting the distribution and size of electric field are also considered, including conductor to ground height, phase to phase distance, sub conductor radius, number of split conductors and conductor layout. The results meet the actual needs and conform to the objective law.**

## Keywords

**Simulated charge method, electromagnetic field, numerical calculation, transmission line.**

## 1. Introduction

The laying height and spacing of transmission lines shall not only meet the needs of power transmission, but also consider the safety of surrounding buildings and personnel under various adverse conditions (such as wind, snow, temperature and different dry humidity), so as to ensure the stable operation of power system [1].

In the calculation of electric field of transmission line, there are three calculation methods: finite element method, simulated charge method and finite difference method. Both finite difference method and finite element method discretize the continuous field problem into a finite number of analysis nodes, so the premise of solution is the of bounded field. The simulated charge law is to replace the continuously distributed charge on the electrode surface with the internal discrete charge in the electrode, and the solution field of this method can be bounded or unbounded [2-4].

The program written by the finite difference method is relatively simple, the memory occupation is less, and the mesh generation may be relatively dense. The mesh generation form with unequal steps can be used to solve the boundary value problem under irregular boundary conditions. The cell division of finite element method is no longer the single of finite difference method, so it can solve the field boundary problem with complex shape more conveniently. Finite difference method, finite element method and simulated charge method are relatively simple in solving two-dimensional field or axisymmetric rotating field, but for finite difference method or finite element method, when calculating three-dimensional field, it is necessary to discretize the space of solving field into multiple nodes.

The simulated charge method can analyze the field model with relatively simple boundary [4-5]. It only needs to set a relatively small number of charges, and the calculation process is easy to realize. If the boundary shape of the analysis model is very irregular, more equivalent charges need to be placed for analysis and solution, and the requirement of computer capacity will increase accordingly. However, when using the simulated charge method to solve the field

problem, we can know that the number of equations in linear algebra is the same as the total number of charges, so the simulated charge method is relatively good for the calculation of three-dimensional field, and the amount of calculation is small. In order to make the calculation program universal, all the programs in this paper are written by MATLAB software.

## 2. Model of transmission line

In practical application, the sinusoidal time-varying electromagnetic field generated by AC transmission line can be analyzed and treated as a quasi-static field, because the pulsation period of the considered power frequency electric field is far less than the propagation speed of electromagnetic wave [2,6].

In the actual analysis, the line end effect and sag are ignored, that is, the conductor is considered to be an infinite straight conductor parallel to the ground. The height of the conductor to the ground is taken as the distance between the lowest point of sag and the ground. The high-voltage overhead transmission line can be approximately regarded as multiple cylindrical conductors parallel to the ground. The transmission lines of different phases have different voltage to the ground. The line voltage loss is not considered in the analysis. When there are no buildings near the line, Analyze and calculate various electromagnetic environment parameters in a two-dimensional plane perpendicular to the line extension direction. The calculation model of the line is an infinite straight conductor, so the electric field generated by it is an axisymmetric field or a parallel plane field. The calculation plane is solved by taking the cross section perpendicular to the lowest point of the sag of the transmission line. In this way, the three-dimensional electric field can be simplified into two-dimensional field for calculation [3,7-9].

Figure 1 shows the idealized structure of the transmission line. The actual line has the change law of catenary, and the generated electric field is also evenly distributed. Nevertheless, it can be seen from the figure that within a line span, at the sag position in the middle of the line, the field strength generated by the transmission line is the largest and the electromagnetic environment is the most serious. Therefore, the research on the electric field distribution of transmission line in this paper only discusses the spatial distribution law of electric field generated in the middle of a span.

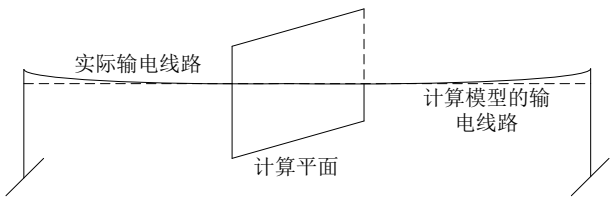


Fig. 1 Equivalent model of overhead transmission line

In the actual calculation, it can be assumed that the conductor is infinitely long and parallel to the ground, and the ground is regarded as a good conductor. The equivalent charge Q on the unit conductor in the multi conductor line is calculated by using the following formula through the voltage U and Maxwell potential coefficient ,that is:

$$[Q]=[\lambda]\cdot[U] \tag{1}$$

The maximum field strength of the ground is considered in the calculation, so the minimum height of the conductor to the ground at the maximum sag is generally taken to analyze and solve. In addition, in the case of split conductor, equivalent single conductor can be used instead [10-13].

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## 2.1. Calculation of equivalent radius of split conductor

In order to obtain the charge of the conductor, based on the basic principle of keeping the capacitance to the ground equal, the split conductor is replaced by a virtual equivalent single cylindrical conductor, as shown in Figure 2. The equivalent radius is given by equation (2）

$$R_i = R\sqrt[n]{\frac{r \cdot n}{R}} \tag{2}$$

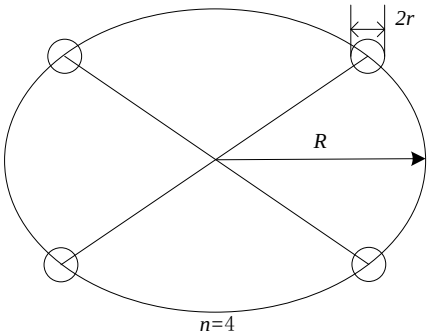


Fig.2 Sketch of four split lead

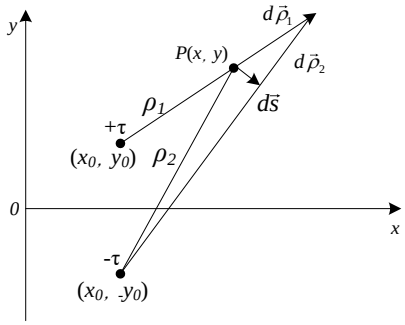


Fig.3 Line charge and its image

## 2.2. Calculation model of potential coefficient matrix

The transmission line is set as an infinite linear charge, and the mirror charge is set at the symmetrical position below the ground, which satisfies the basic equation in the effective region, i.e. Set the coordinates of (x0, Y0) and (x0, - Y0).According to the analysis of Gauss theorem, the electric field intensity generated at any point P (x, y) in space is

$$\begin{cases} E_1 = \dfrac{\tau}{2\pi\varepsilon\rho_1} \\ E_2 = \dfrac{\tau}{2\pi\varepsilon\rho_2} \end{cases} \tag{3}$$

## 2.3. Calculation of electric field strength under transmission line

According to the equivalent charge per unit length of each conductor, the electric field intensity at any point in the field can be obtained according to the superposition principle. If the components ex and ey of the electric field intensity at point (x, y) can be expressed as:

$$\begin{cases} E_x = \dfrac{1}{2\pi\varepsilon}\sum_{i=1}^{m} Q_i\left(\dfrac{x-x_i}{L_i^2} - \dfrac{x-x_i}{L_i^{'2}}\right) \\ E_y = \dfrac{1}{2\pi\varepsilon}\sum_{i=1}^{m} Q_i\left(\dfrac{y-y_i}{L_i^2} - \dfrac{y-y_i}{L_i^{'2}}\right) \end{cases} \quad (4)$$

Where: Xi and Yi are the abscissa and ordinate of conductor I respectively, I = 1, 2,..., m (M is the number of conductors) The distance from the wire I and its mirror image to the analysis calculation point. Since the voltage is a time variable, for the convenience of analysis, the voltage of each phase is represented by the complex number, and the corresponding space charge is also represented by the complex number. The subscript "R" represents the real part and "I" represents the imaginary part:

$$\begin{cases} \dot{E}_x = \sum_{i=1}^{m} E_{ix,R}^{'} + j\sum_{i=1}^{m} E_{ix,I}^{'} = E_{x,R}^{'} + jE_{x,I}^{'} \\ \dot{E}_y = \sum_{i=1}^{m} E_{iy,R}^{'} + j\sum_{i=1}^{m} E_{iy,I}^{'} = E_{y,R}^{'} + jE_{y,I}^{'} \end{cases} \quad (5)$$

Where:, are the real part and imaginary part of the horizontal component of electric field intensity generated by the real part charge and imaginary part charge of each conductor respectively;, They are the real part and imaginary part of the vertical component of the electric field intensity generated by the real part charge and imaginary part charge of each wire. The composite field strength at this point is:

# 3. Transmission line simulation research

This section will use MATLAB software to program and calculate the electric field under power frequency transmission line based on analog charge method. The research will calculate the synthetic electric field intensity of three-phase AC line, and mainly take the single circuit transmission line as the calculation model. This paper focuses on the analysis of the electric field curve distribution law of horizontal arrangement, regular / inverted triangle arrangement and double circuit transmission lines on the same tower under different arrangement modes and different voltage phase sequence, and the influence analysis and Research on the electric field 1.5m below the line from the ground. In each calculation example, the voltage level of the transmission line is 500kV, the conductor adopts lgj-300 / 50 four bundle conductor, the radius R is 0.341m, and the radius of sub conductor r = 13.31mm. The horizontal arrangement simulation model of 500kV transmission line is shown in Figure 5

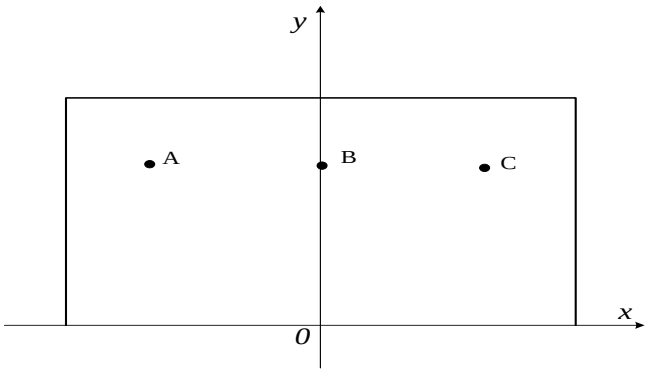


Fig.3-5 Simulation Model horizontally of 500kV transmission lines

## 3.1. Influence of line height to ground on electric field

According to the above split conductor parameters, assuming that the height of the lowest point of sag to the ground is 16m and the phase to phase distance is 12M, only the height of transmission line to the ground is changed to 13m, 14m, 15m, 16m, 17m and 18m respectively. Thus, the horizontal component diagram 6 (a) and the vertical component diagram 6 (b) of the electric field intensity at a height of 16m to the ground can be obtained; Fig. 7 shows the distribution curve of the corresponding synthetic electric field intensity. Fig. 8 (a) and Fig. 8 (b) are the three-dimensional electric field diagrams of the horizontal and vertical components of the electric field intensity at different heights of the observation point from the ground when the height to the ground is 16m respectively, while Fig. 9 is the three-dimensional distribution diagram of the synthetic electric field intensity. At the same time, FIG. 3-10 shows the electric field distribution law at different heights to the ground, so that the electric field intensity under transmission lines at different heights can be analyzed and studied

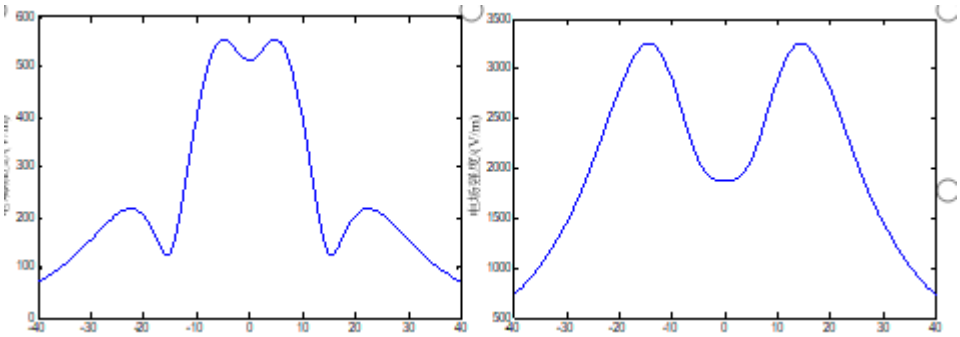

Fig. 6 Horizontal and vertical components of the electric field strength

As can be seen from Fig. 6 (a) and (b), the horizontal and vertical components of the electric field intensity at 1.5m above the ground are symmetrically distributed about the central conductor. The vertical component of the electric field presents a saddle distribution, and the field intensity is much larger than the horizontal component. Therefore, it can be concluded that the synthetic electric field intensity under the line mainly depends on the component in the vertical direction. In addition, it can be seen from Fig. 6 (a) that the maximum electric field value of the horizontal component is 0.56kv/m, and the overall curve is a symmetrical curve that first rises to the maximum and then decreases gradually. As can be seen from Fig. 6 (b), the maximum value of the vertical component of the electric field is located not far from the middle, showing a saddle shaped distribution law as a whole, and the electric field intensity value first rises to the maximum and then decreases gradually

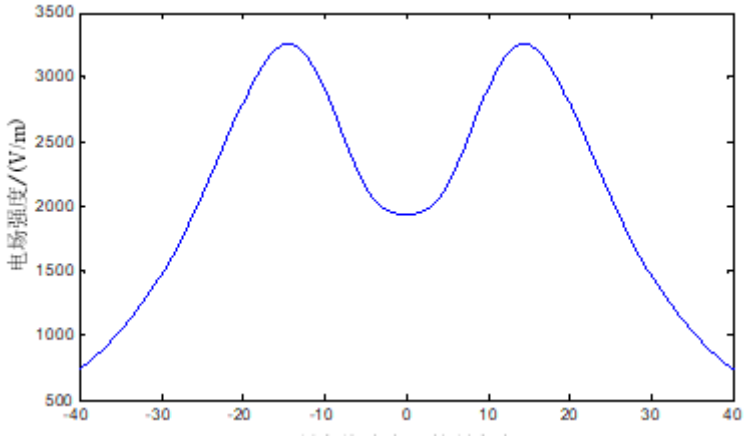


Fig. 7 Distribution curve of synthetic electric field intensity

It can be seen from figure 3-7 that the electric field intensity curve of horizontally arranged transmission lines rises first, then decreases, then rises and finally decreases. The curve presents a saddle curve as a whole, and the maximum field intensity at 15m from the center of the transmission line is 3.32kv/m

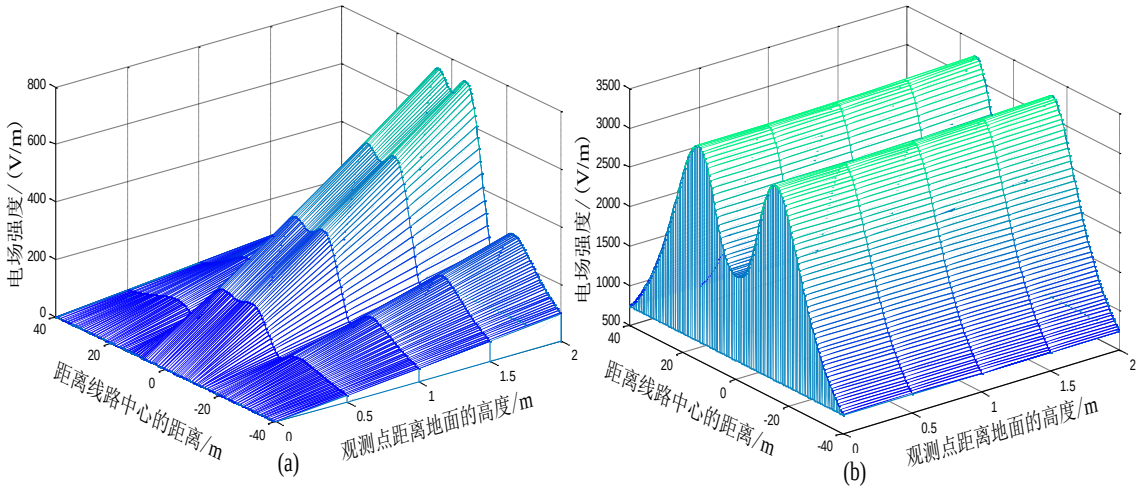


Fig. 8 3D horizontal and vertical components of the electric field strength

It can be seen from Fig. 8 (a) and (b) that the electric field intensity increases with the increase of the height from the observation point to the ground, and at a certain height, the horizontal and vertical components of the electric field are symmetrical about the center of the transmission line, both of which increase first and then decreas.

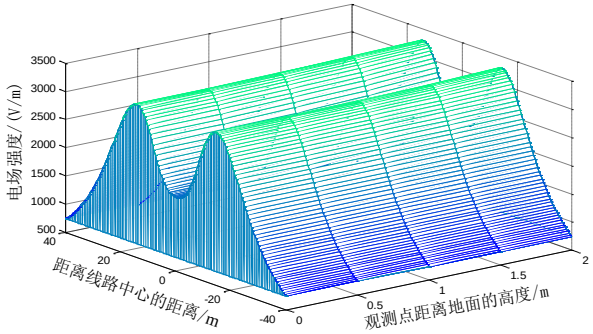


Fig. 9 3D distribution curve of synthetic electric field intensity

## 3.2. Influence of interphase distance on electric field

In order to keep the maximum electric field distance between phases of 11m and 12m under different electric field conditions, the calculation of the maximum electric field distance between phases of 11m and 12m under different electric field conditions is shown in the table. At the same time, the calculation results of the maximum electric field distance between phases of 11m and 12m are obtained under different electric field conditions. It can be seen from Fig. 11 that when other conditions remain unchanged, the range covered by the maximum electric field intensity and higher electric field intensity decreases accordingly with the decrease of phase to phase distance. In the actual engineering design, the phase to phase distance can not be infinitely reduced, because the constraints of phase to phase insulation factors should be considered. At the same time, with the decrease of phase to phase distance, the position of the maximum field strength gradually approaches the center of the line, and the width of the line corridor will be reduced accordingly. It can be seen from table 2 that the maximum field strength under the EHV transmission line decreases accordingly with the decrease of phase to phase distance. When the electric field strength under the transmission line is large, it is unreasonable to improve the electric field strength under the line by reducing the phase to phase distance, because the maximum electric field strength under the line decreases by only about 0.1kv/m every 1m of phase to phase distance. It can be seen that increasing the height of the conductor to the ground is better than reducing the phase to phase distance to reduce the power frequency electric field intensity

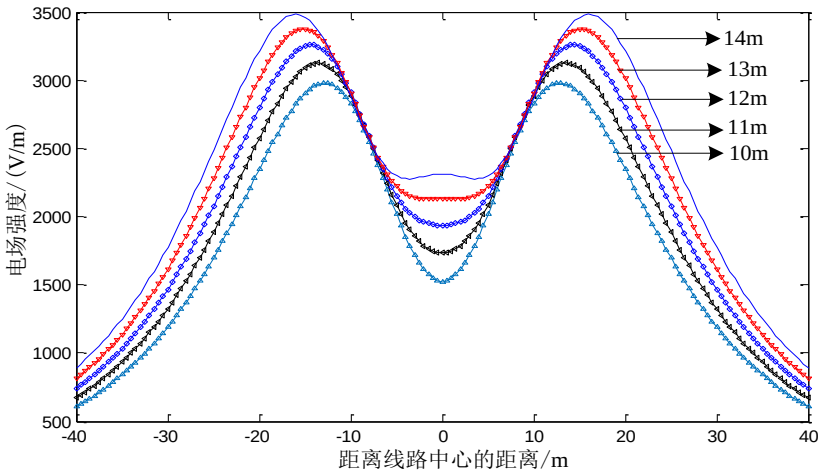


Fig. 11 Electric field distribution curve under different the distance of phase conductors

## 3.3. Influence of conductor radius on electric field

In order to analyze the influence law of the change of sub conductor radius on the ground field strength under the transmission line, the simulation analysis is carried out for four cases with sub conductors lgj400 / 35, lgj500 / 45, lgj630 / 45 and lgj720 / 50 respectively. The line operating voltage is still taken as 500kV, the distance between phase conductor and ground is taken as 16m, and different types of conductors are selected to make the equivalent radius of split conductor different, so as to study its influence law on the electric field For 500kV conductor, the model is 4 × Lgj-300 / 50, the radius of sub conductor of the line r = 12.1mm, the conductor adopts four split, and its 2R value is 450mm. The equivalent radius can be obtained according to formula (2). When other line parameters remain unchanged, change the radius of the sub conductor of the line to 0.0071m, 0.0096m, 0.0121m, 0.0146m and 0.0171m respectively. Analyze the influence of the sub conductor radius on the electric field intensity according to the change of the equivalent conductor radius of the calculation model. The results are shown in FIG. 12. At the same time, the maximum electric field Emax of the simulation results under different conditions is shown in Table 3. As can be seen from Figure 12, the

influence of the change of the radius of the sub conductor on the field strength of the offline space is relatively small. This is because the influence of conductor on space electric field intensity mainly depends on the radius of transmission line split conductor.

It can be seen from table 3 that the radius of the sub conductor of the transmission line has little impact on Emax. The change of the radius of the sub conductor will cause the change of the maximum value of the ground electric field, but this change is relatively small and can be ignored in practical engineering. The reason is that the influence of the split conductor on the spatial electric field strength near the line mainly depends on the equivalent diameter of the split conductor of the transmission line. According to the calculation formula of the equivalent diameter (2), the factors that have a great influence on the equivalent diameter of the conductor are the guide split spacing and the number of split conductors. In contrast, the influence of the diameter of the split sub conductor on the spatial field strength of the line is very small and can be ignored.

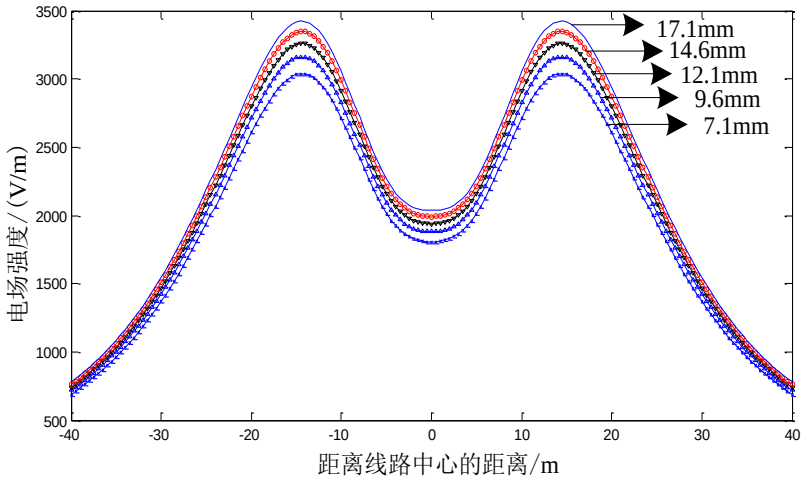


Fig. 12 Electric field intensity distribution for different subconductor radius

## 3.4. Influence of the number of split conductors on the electric field

In order to study the influence of the number of split conductors on the electric field, the following does not change the conductor model, ground height and other parameters, but only change the number of split conductors to 4, 6 and 8 respectively. The influence of the number of split sub conductors on the electric field intensity is obtained by programming and simulation, as shown in Figure 13. From the simulation results in Figure 13, it can be concluded that when the number of split wires is 4, 6 and 8 respectively, the maximum field strength of the line is 3.30kv/m, 3.43kv/m and 3.58kv/m respectively. The fewer the number of split wires, the smaller the electric field strength under the transmission line. It can also be seen from the simulation results that the number of split conductors basically does not affect the size distribution of electric field intensity, and has little impact on the line corridor. However, reducing the number of splits will increase the field strength on the surface of the conductor and increase the radio interference and audible noise of the transmission line.

In the actual conductor operation, there are often a variety of factors acting comprehensively, and the distribution law of electric field intensity becomes more complex. However, in general, the main factors affecting the distribution of electric field can be determined through reasonable analysis and research.

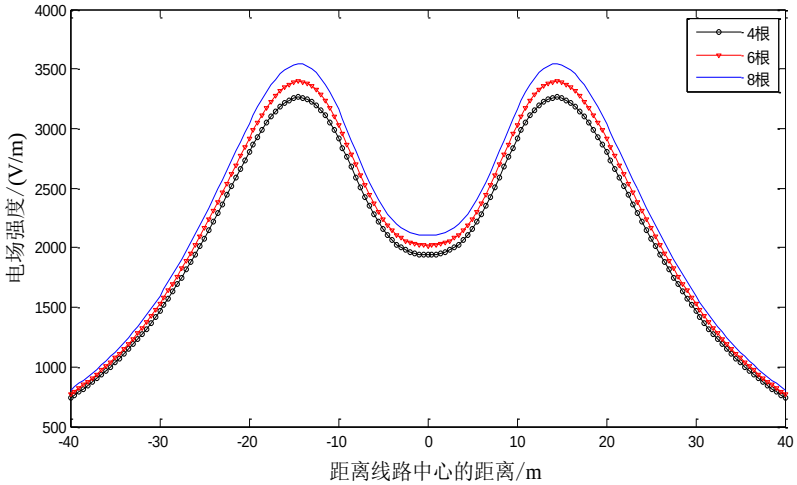


Fig. 13 Electric field intensity distribution of different numbers for split wire

## 4. Conclusion

Limited by space, the influence of other parameters on the electric field distribution will not be analyzed one by one in this paper. According to the calculation and research, the main factors affecting the electric field strength under the high-voltage transmission line are as follows:

(1) The higher the height of the conductor to the ground, the smaller the field strength under the line, and the height from the ground is small. Raising the height of the conductor will greatly reduce the field strength under the line, but blindly increasing the height of the conductor to the ground to reduce the field strength will increase the installation cost and difficulty.

(2) The range covered by the maximum electric field intensity and higher electric field intensity decreases with the decrease of phase to phase distance, but the phase to phase distance cannot be reduced indefinitely, because the restriction of phase to phase insulation factors should be considered. At the same time, with the decrease of phase to phase distance, the position of the maximum field strength gradually approaches the center of the line, and the width of the line corridor will be reduced accordingly.

(3) The radius of the sub conductor of the transmission line has little influence on the electric field. The change of the radius of the sub conductor will cause the change of the maximum value of the ground electric field, but this change is relatively small and can be ignored in practical engineering.

(4) The ground field strength decreases with the decrease of the number of split conductors; However, increasing the number of split conductors has little effect on the ground field strength.

(5) The field intensity curves under the three arrangement modes are symmetrically distributed. When the conductors are arranged in inverted triangle, the maximum value of electric field strength will appear below the central conductor. When the conductors are arranged in horizontal and regular triangle, the maximum value of electric field strength will be distributed around the lower part of the phase conductors on both sides. The coverage of high field strength area in horizontal arrangement mode and regular triangle mode is the largest, while the coverage of high field strength area in inverted triangle arrangement mode is relatively the smallest, and the maximum value of field strength is the smallest. However, when comparing the electric field intensity below the central conductor, the inverted triangle arrangement is the largest, the horizontal arrangement is the second, and the regular triangle arrangement is the smallest

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## References

[1] Markov-M S. Biophysical estimation of the environmental importance of electromagnetic field[J]. Rev-Environ-Health, 1994, (10) : 75-83.

[2] U.S. Department of Energy, National Institute of Environmental Health Sciences (NIEHS) and National Institutes of Health, Assessment of health effects from exposure to power-line frequency Electric and magnetic fields, EMF Working Group (EMF RAPID Program) Report, 1999.

[3] Florkowska B, Jackowicz-Korczynski A, Timler M. Analysis of electric field distribution around the high-voltage over-head transmission lines with an ADSS fiber-optic cable[J]. IEEE Trans on Power Delivery, 2004, 19(3) : 1183-1189.