Modeling and Simulation Analysis of Power Frequency Electric Field of UHV AC Transmission Line

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***Abstract*—In order to study the power frequency electric field of UHV AC transmission lines, this paper which models and calculates using boundary element method simulates various factors influencing the distribution of the power frequency electric field, such as the conductor arrangement, the over-ground height, the split spacing and the sub conductor radius. Different influence of various factors on the electric field distribution will be presented. In a single loop, using VVV triangular arrangement is the most secure way; in a dual loop, the electric field intensity using reverse phase sequence is weaker than that using positive phase sequence. Elevating the over-ground height and reducing the conductor split spacing will both weaken the electric field intensity, while the change of sub conductor radius can hardly cause any difference. These conclusions are important for electric power company to detect circuit.**

Keywords—boundary element method; electric field distribution; power frequency electric field; UHV

I. Introduction

The world's first UHV AC with tower of 1000 kV in dual loop-Anhui Power Transmission was officially put into operation on September 25, 2013. Thus the State Grid has built two 1000 kV AC and two 800 kV DC projects so far marking the great new achievements of China's UHV construction. Liu Zhenya said, "National Grid is building two 800 kV DC projects and at the same time developing the technology and equipment of 1100 kV DC whose transmission capacity can be 13.75 million kilowatts and economic transmission distance is 5000 km. Such projects make contributions to constructing trans-regional, transnational and transcontinental transmission channels. For example, if Africa and the Middle East can be connected, South America can build up a large power grid."

With the rising voltage level and increasing current of UHV transmission line, the effects of its power frequency electric field on the surrounding environment and ecology have attracted growing concerns. UHV power frequency alternating electric field can not only bring environmental issues like the radio interference and the audible noise but also has rather great harm on people's health and spirit [1]. Now the power frequency electric field distribution near the UHV AC transmission line has become one of the issues that scholars all over the world focus on and discuss.

This paper based on boundary element method which is used for modeling and calculation on the influence of various factors, the power frequency electric field distribution, such as the arrangement of conductors, the simulation of the height, split spacing and sub conductor radius.

II. The Calculation Method of The Power Frequency Electric Field

The boundary element method is an accurate and effective engineering numerical method which uses the boundary integral equation defined on the boundary as governing equation. It transforms boundary element interpolation into algebraic equation sets through discrete method [2-4]. This essay uses line model when simulating the power frequency electric field of UHV transmission lines, thus reducing the difficulty of modeling as well as improving the operational efficiency.

Supposing that all radius of transmission line conductor are r_0, the charge in the center line of wire is line charge, the charge is in the form of surface charge distribution on the surface of other devices and its density is θ, the electric potential of a point in this space can be expressed as

$$\varphi = \int_l \frac{\lambda dl}{4\pi\varepsilon P} + \int_S \frac{\theta dS}{4\pi\varepsilon P} \tag{1}$$

In the formula, P is the space between source point and field point, S is the surface integral region and l is the line integral path. When this formula is discrete, field and source units may be either line element or surface element. Thus, formula (1) can produce 4 kinds of discrete form. Supposing the field unit is the line unit and source unit is the surface unit, the formula can be written as

$$\sum_e \sum_j \sum_i \int_{l_e} N_j N_i \varphi_i dl = \frac{1}{4\pi\varepsilon_0} \sum_e \sum_{e'} \sum_j \sum_i \int_{l_e} N_j \int_{S_{e'}} \frac{N_i \theta_i}{P} dS' dl \tag{2}$$

In the formula above, i、j=1, 2,..., m,..., n, corresponding to different discrete nodes, where m is the number of conductor discrete nodes, n is the number of discrete nodes of calculation model, and N_i together with N_i is the interpolation function. φ_i is the node potential in which θ_i is the destiny of node surface, e and e' are respectively the number of field unit and source unit, l_e represents the line integral path of field unit and $S_{e'}$ is the surface integral area of source unit. If making some corresponding modification to the integral path and electric charge destiny in the formula (2), we can get the other 3 kinds of discrete forms. Making vectors:

$$B=\left[\lambda_1,\ \lambda_{2,},\ldots,\ \lambda_m,\ \theta_{m+1},\ \theta_{m+2},\ldots,\ \theta_n\right]^T$$

$$u=\left[\varphi_1,\ \varphi_{2,},\ldots,\ \varphi_m,\ \varphi_{m+1},\ \varphi_{m+2},\ldots,\ \varphi_n\right]^T$$

And the matrix

$$A_{ij}=4\pi\varepsilon\sum_e\int_{l_e}N_j N_i\,dl \tag{3}$$

$$C_{ij}=\sum_e\sum_{e'}\int_{l_e}N_j\int_{S_{e'}}\frac{N_i}{P}dS'dl \tag{4}$$

In the formulas above, λ_1, λ_2,..., λ_m and φ_1, φ_2,..., φ_{n1} are respectively the linear density and electric potential of conductor node charge; θ_{m+1}□□θ_{m+2},..., θ_n and φ_{m+1}, φ_{m+2},..., φ_n are respectively surface density and electric potential of conductor node charge on the equipment's surface. Then the formula (1) can be written as follows:

$$CB=Au \tag{5}$$

Under the condition of knowing the device and the conductor potential, the surface density θ and the line destiny λ of conductor equivalent charge can be obtained. We can simulate different conditions of UHV transmission lines according to the formula and after obtaining θ and λ, can use the integral formula of the electric field to get the electric field intensity of any space point

$$E=\frac{1}{4\pi\varepsilon}\sum_{e'}\left[\iint_{S_{e'}}\frac{\theta(r-r')dS}{|r-r'|^3}+\int_{l_{e'}}\frac{\lambda(r-r')dl}{|r-r'|^3}\right] \tag{6}$$

III. Calculation and Analysis of Power Frequency Electric Field Around the UHV Transmission Line

A. Parameters of 1000kV AC UHV transmission line

China's 1000kV UHV demonstration project Jindongnan-Nanyang- Jingmen transmission line is all set up in single loop. Its full-length is 654 kilometers, transmission capacity is 600kVA, system nominal voltage is 1,000KV and its maximum operating voltage is 1,100KV. Setting up such a program has far-reaching influence on national energy security and reliable power supply. At present, UHV transmission line systems of our country mainly include single loop (IVI horizontal arrangement, VVV horizontal arrangement, IVI triangle arrangement and VVV triangle arrangement) and the common-tower double loop (I series vertical arrangement and V series vertical arrangement).

B. The factors influencing the power frequency electric field

According to the power frequency electric field calculation formula, the charge number on the wire surface, the distance between wires and other factors directly determine the electric field strength of the points in space [5]. Apart from the voltage of both sides, the number of charge on wire surface has relation to the arrangement, types and sizes of the tower wire. Therefore, further researches are needed about the relationship between the distribution of power frequency electric field under the transmission line and several factors as the arrangement of wires, the over-ground height, the split spacing and the sub wire radius.

1) Influence of arrangement of wires

a) Different Arrangement of Single Loop

Supposing the over-ground height of the phase conductor h=22m, with the height 1.3m and the distance from the center wire 100m, the electric field distribution curve under four different arrangement of wires can be presented as follows:

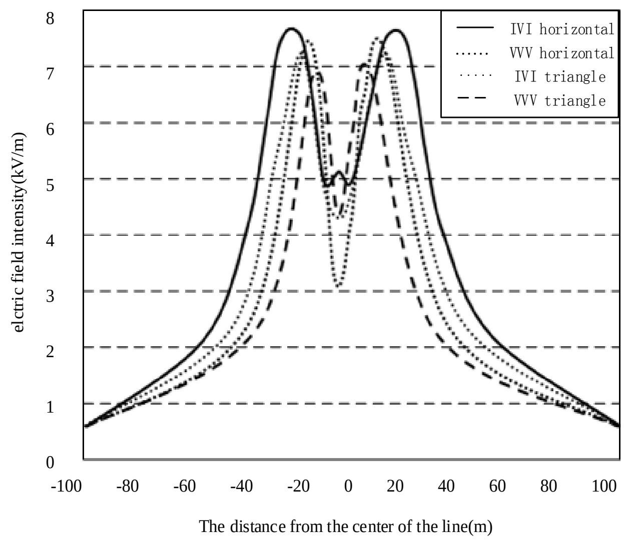


Fig. 1. The power frequency electric field of different arrangement of single loop

As can be seen from Fig.1, regardless of the arrangement, the electric field strength all reaches the maximum below the phase conductor and gradually weakens to both sides. Although the maximum field strength of IVI triangle arrangement is a little more than that of VVV horizontal arrangement, but the corresponding high field strength area of surpassing 4kV/m is smaller than the latter. In general, no matter what the maximum power frequency electric field and the corresponding high field strength area of under 4kV/m is, VVV triangle arrangement is always better than the other three arrangement. Therefore, using triangle arrangement can reduce the maximum field strength of the electric transmission line as well as the area under the cover of high field strength, thus reduces the construction risk and hidden danger.

b) Different Phase Sequence Arrangement of Double Loop

Double circuit arrangement of UHV AC can be subdivided into four types: positive and reverse phase sequence vertical arrangement of I and V. Supposing the over-ground height of the phase conductor h=22m, with the height 1.3m and the distance from the center wire 100m, the electric field distribution curve under four different arrangement of wires can be presented as follows:

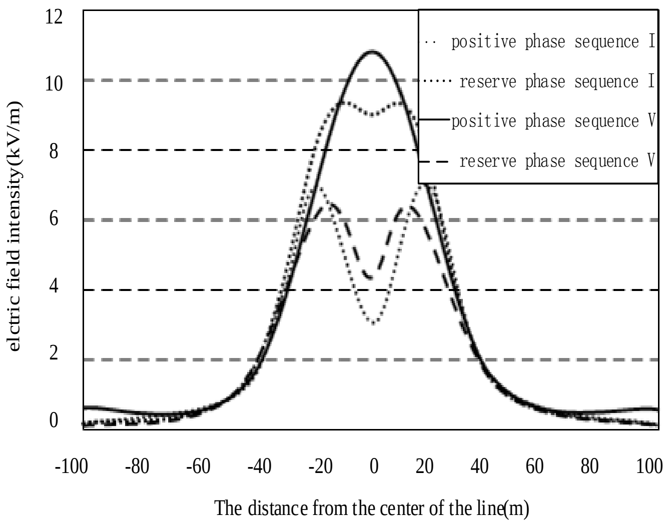


Fig. 2. The power frequency electric field of different arrangement of double loop

As we can see from Fig.2, the maximum field intensity of reverse phase sequence I is 2.2kV/m less than that of positive phase sequence [6-9]. The maximum field intensity of reverse phase sequence V is 4.5kV/m less than that of positive phase sequence. No matter using vertical arrangement of I or V, the maximum field intensity and the areas under high field strength of reverse maximum field strength are much lesser than those of positive maximum field strength. Therefore, in double circuit arrangement, using reverse phase sequence arrangement is an effective way to reduce the line strength and the area under high field strength.

2) The influence of conductor over-ground height

The changes of the power frequency electric field of UHV transmission line under different conductor over-ground height will be analyzed taking IVI horizontal arrangement for example. Supposing the conductor over-ground height h are 20m, 22m, 24m and 26m, the distribution curves of the power frequency electric field 1.3m above the ground can be presented as follows:

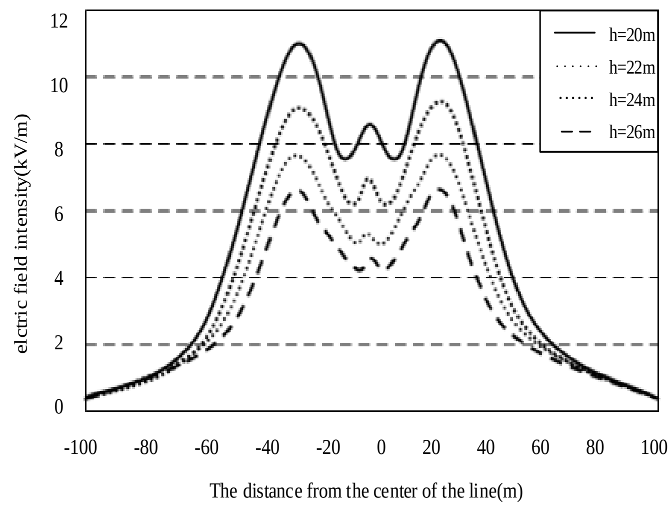


Fig. 3. The power frequency electric field of different conductor over-ground height

As we can see from Fig.3, the electric field intensity of transmission line becomes more and more weak with the increasing conductor over-ground height [10-12]. When the conductor over-ground height increases from 20m to 22m, the maximum electric field intensity reduces by 1.93kV/m. if the conductor over-ground height increases 2m each time, the maximum field intensity will reduces 1.45kV/m and 1.07kV/m in turn. Therefore, the decreasing amplitude of the electric field intensity is weaker. When the conductor over-ground height h is not so high, increasing the height has obvious influence on reducing the electric field intensity. With the increasing h, the economic input will gradually increase in order to reduce the same electric field intensity. Thus, we must take all the relevant factors into consideration when designing the lines and choose the appropriate conductor over-ground height.

3) The Influence of Split Spacing

The changes of the power frequency electric field of UHV transmission line under different split spacing will be analyzed using IVI horizontal arrangement as an example. As is known that the phase conductor of 1000kV UHV transmission line has

8 division structure, supposing the over-ground height of the phase conductor h is 22m and the split spacing are 0.3m, 0.4m, 0.5m and 0.6m, the distribution curves of the power frequency electric field 1.3m above the ground is presented in the following figure. As can be seen, the power frequency electric field intensity of UHV transmission lines decreases with decreasing split spacing. The maximum electric field intensity decreases from 0.42 to 0.54kV/m while the split spacing reduces every 0.1m. Therefore, reducing the conductor split spacing can decrease the electric field intensity of the transmission lines.

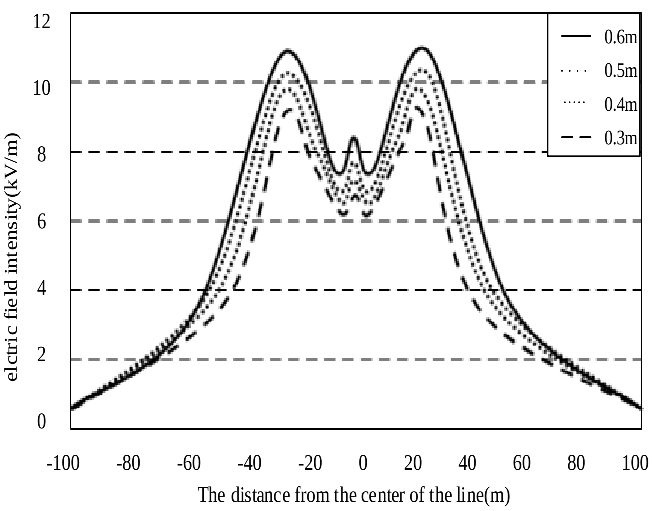
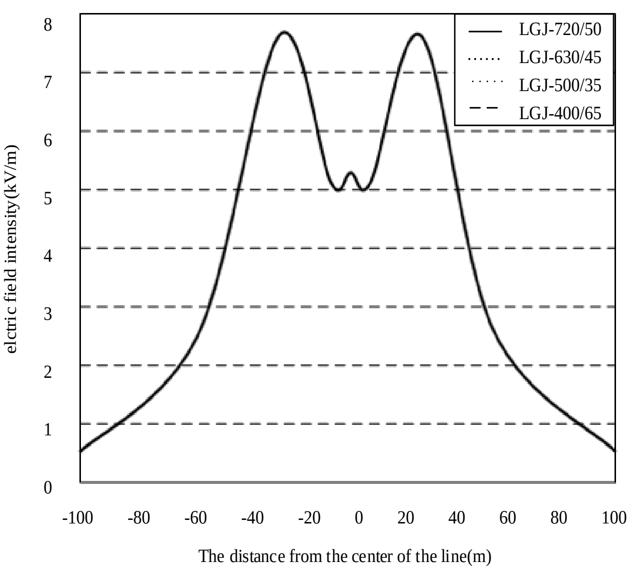
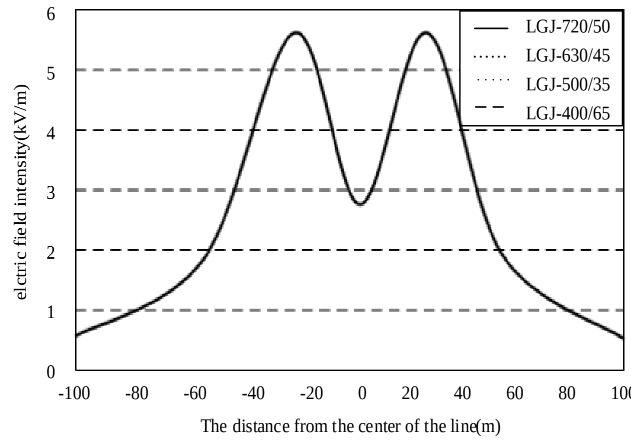


Fig. 4. The power frequency electric field of different split spacing



(a) IVI horizontal arrangement



(b) IVI triangle arrangement

Fig. 5. The power frequency electric field of different sub conductor radius

4) The influence of sub conductor radius

The relationship between conductor radius and the electric field strength will be analyzed using four types of sub conductor: LGJ-720/50, LGJ-630/45, LGJ-500/35 and LGJ-400/65. In IVI horizontal arrangement and IVI triangle arrangement, supposing the conductor over-ground height h=22m, the distribution curves of the power frequency electric field 1.3m above the ground is presented in the following figure. As is shown in the figure, the influence of different conductor radius on the power frequency electric field under the transmission lines can be ignored in the two different arrangement [13].

IV. Conclusion

Using boundary element method to simulate and calculate the power frequency electric field of the 1000kV UHV AC transmission line and analyze the distribution of electric field under different conditions, the following conclusions can be drawn:

A. *Different factors have different effects on the power frequency electric field distribution of UHV transmission lines. The conductor arrangement, the over-ground height and the split spacing all have a certain influence on the electric field while the influence of the sub conductor radius on the power frequency electric field can be nearly ignored. Adopting triangle arrangement in single loop and reverse phase sequence arrangement in double loop all have great influence on reducing the ground field strength. The over-ground height of phase conductor has great effect on the field strength and the higher the over-ground height is, the smaller the ground field strength will be. However, simply raising the conductor height will definitely increase the investment and difficulty of the project. Therefore, in order to decrease the ground field strength and reduce the construction cost as much as possible, we must choose the reasonable conductor over-ground height.*

B. *The influence of the splited conductors of UHV transmission lines on the power frequency electric field mainly depends on the conductor radius while the equivalent radius is mainly decided by the conductor split spacing. The electric field intensity will decrease with the decreasing split spacing. The sub conductor radius basically has no influence on the power frequency electric field.*

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