

Calculation of the ground hybrid electric field of $\pm 800\text{kV}$ EHV DC and 750kV UHV AC parallel transmission lines

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Abstract. Based on the method of time-domain upwind difference algorithm, the ground hybrid electric field is calculated. The typical tower is selected from the $\pm 800\text{kV}$ Hami-Zhengzhou DC transmission project and the 750kV Tianshui-Baoji double-loop transmission line project. In the paper, the minimum height above ground is determined when the individual AC and DC lines meet the electric field limits, respectively. Then the article analyzes the AC and DC parallel spacing and the width of the corridor, using the weighted method to determine the control values of hybrid electric field.

1. Introduction

With the increase in UHV DC transmission lines, the shortage of the power corridors becomes more and more serious, and the situation of parallel erection or public corridors of EHV DC lines and UHV AC lines has emerged^[1-3]. Ground electric field, audible noise and other electromagnetic environment problems in the engineering design become increasingly important. Especially for the UHV AC and EHV DC parallel transmission lines, due to the high voltage level, the ground electromagnetic environment is more complex and malicious. So the study on the ground electric field of AC and DC parallel transmission lines is particularly necessary^[4,5].

In recent years, Chinese scholars have done a lot of research on the parallel problem of AC and DC lines. In the 1990s, Lu Guoqing and others analyzed the feasibility, the distance and the field strength of the common corridor of AC/DC lines, and got some useful conclusions^[6]. Wu Guifang discussed the definition of electromagnetic environment limits for AC/DC parallel corridors^[7]. In the calculation method, Yang Yong extended calculation method on the single AC and unipolar DC hybrid power electric field proposed by Zhao Tiebin to the three-phase AC and bipolar DC hybrid electric field calculation, but this method cannot fully reflect the dynamic process of line electric field effect of the AC and DC parallel transmission lines^[1,8]. In this paper, a computation method basing on time-dependent upwind difference algorithm for the hybrid electric field under the AC and DC parallel transmission lines is proposed. The method can be applied to deal with the complex situation of bundle conductor, three-phase AC lines and bipolar DC lines. And a variable time-step discretization method is introduced to accelerate the computational process^[9].

And according to the situation of $\pm 800\text{kV}$ UHVDC and 750kV EHV AC parallel transmission line in Northwest china, the ground electric field is calculated selecting typical tower type. In this paper, the AC typical tower type is selected from the 750kV Tianshui ~ Baoji double return line project, and the DC typical tower type is selected from the $\pm 800\text{kV}$ Hami ~ Zhengzhou DC transmission project. All typical tower types are selected from actual engineering, so as to provide reference for engineering design and construction of AC and DC parallel lines.



2. The limited value of electric field

Controlling the ground electric field intensity under the high voltage line is related to the personal safety of the residents near the line, but also to reduce its biological effects, that is, the electrostatic induction of the human body and livestock under the transmission line, as well as steady state shock and transient electric shock. The problem of electric field effect is more prominent for the parallel transmission of UHVDC and EHVAC lines^[10,11]. Each country has formulated standards or regulations in accordance with its own conditions, limiting the power frequency electric field under the AC transmission lines and the the synthetic electric field under DC transmission lines.

For DC lines, the United States provides that the ground synthetic electric field strength should not be greater than 15kV/m^[12]. The industry standard implemented in 1991 in China High Voltage DC Overhead Transmission Line Technical Guidelines provides that "the ground nominal field limit near the residential floor is 3kV/m", and the limit is more strict comparing to most countries. And in 2013, the implementation of the national standard Code for Designing of ± 800 kV DC Overhead Transmission Line provides that "when the line near the houses, the undistorted synthetic electric field shall not exceed 15kV/m in the case of wet wires on the ground floor "^[13].

For the AC line, the International Commission on Non-ionizing Radiation Protection(ICNIRP) stipulates that the power frequency electric field limit is 5 kV/m. The demand on the electric field limit issued by the EU in 2004 to protect workers from all kinds of material damage are also based on the ICNIRP guidelines, which provides for a maximum of 5kV/m^[12]. The national standard Code for Designing of 110kV~750kV Overhead Transmission Line carried out by China in 2010 provides "when 500kV and above transmission lines across non-permanent residential buildings or adjacent houses, the undistorted electric field shall not exceed 4kV/m at the housing location of 1.5m from the ground ", so as to meet the requirements of environmental protection departments^[14].

However, there is no control value standard for the ground hybrid electric field in parallel with AC/DC lines in China. This paper refers to the China Electric Power Research Institute related research, using the weighted method to determine the AC and DC hybrid electric field control value^[15,16].

The weighted method is as follows:

$$\frac{\text{AC electric field strength}}{\text{AC electric field strength control value}} + \frac{\text{DC electric field strength}}{\text{DC electric field strength control value}} \leq 1 \quad (1)$$

As for the control value of AC and DC electric field, the following three control value combinations are adopted on the three conditions of residential area, agricultural cultivation area and non-agricultural farming area:

(1) Residence area. The electric field control value is: AC electric field control value is 4kV/m; DC electric field control value is 15kV/m;

(2) Agricultural farming area. The electric field control value is: AC electric field control value is 10kV/m; DC electric field control value is 30kV/m;

(3) Non-agricultural farming area. The electric field control value is: AC electric field control value is 13kV/m; DC electric field control value is 42kV/m;

3. Line parameters

3.1. DC line parameters

The typical tower type of ± 800 kV EHVDC transmission line is shown in Figure 1. The pole spacing is 20m, and the ground wire spacing is 24.5m. The Bipolar lines are horizontally arranged and the insulator strings are arranged in a V-string. The type of the bundle conductor is 6*JL/G3A-1000/45 with a diameter of 42.08mm.

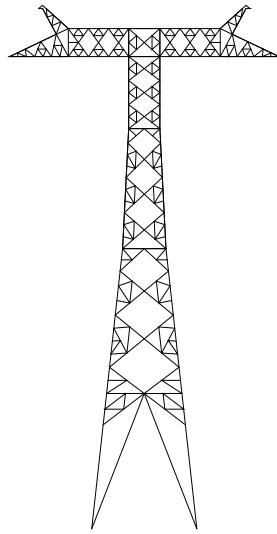


Fig 1. The typical tower type of + 800kV DC transmission line

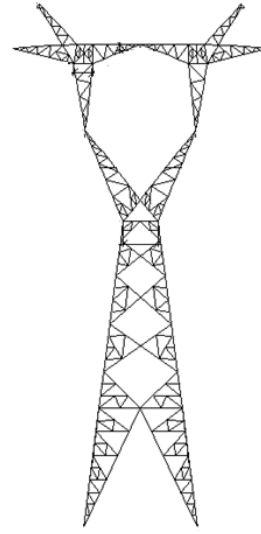


Fig 2. The typical tower type of 750kV AC transmission line

3.2. AC line parameters

The typical tower type of 750kV UHVAC transmission line is shown in Figure 2. The phase spacing is 18.2m, and the spacing of the ground lines is 32.4m. The type of the bundle conductor is 6*JL/G1A-400/50-54/7(LGJ-400/50) with a diameter of 27.6mm. One of the ground line is GJ-100, and the diameter is 13mm. Another is OPGW-120, and the diameter is 15.2mm.

4. Calculation of the ground hybrid electric field

In this paper, the method of finite element calculation is adopted to calculate the synthetic electric field of the DC line, and the idea of upflow difference is introduced into the solution^[17]; Based on the Abdel-Salam method, an improved algorithm for judging the corona and calculating the emission charge at each point of the conductor surface is applied to calculate the power-frequency electric field^[18]. The calculation of AC/DC parallel hybrid electric field adopts time-domain windward difference algorithm, suitable for bundle conductors and bipolar DC lines. And the computational efficiency is improved by the variable time-step discretization method^[9]. The methods have been validated in the previous articles, and the methods are used directly here.

4.1. Minimum earth height of AC and DC lines

The ground electric field of AC/DC parallel transmission line is not only related to the spacing of AC and DC transmission lines, but also to the height of AC and DC lines. In order to ensure that the ground hybrid electric field meets the limit values, the minimum ground height need to be determined to satisfy the ground electric field limit when the AC and DC lines are separately working. The maximum value of the ground electric field of the individual AC and DC transmission lines varying with the height of the conductor (the height off the ground of the point of the maximum arc sag) is calculated as shown in Fig. 3 and Fig.4.

For the 750kV AC transmission lines, the national standard minimum heights are 19.5m, 15.5m and 13.7m respectively, when the line through the residential area, agricultural farming area and non-agricultural farming area.

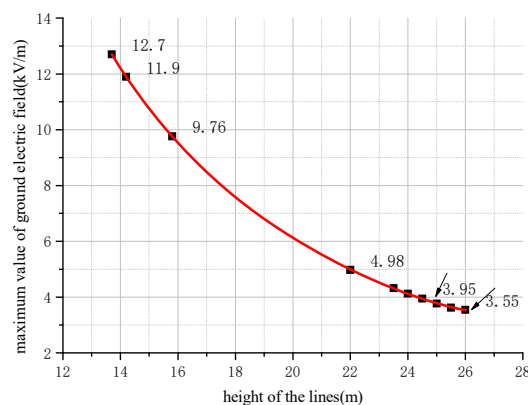


Fig 3. The diagram of maximum electric field strength of AC conductor at different heights

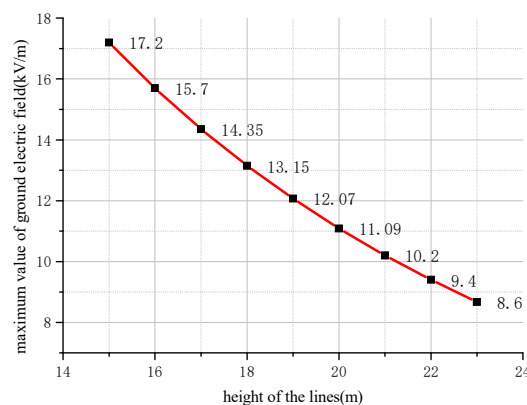


Fig 4. The diagram of maximum electric field strength of DC conductor at different heights

As can be seen from Fig. 3, the ground electric field is larger than the national limit when the line passes through the residential area and the height is 19.5m of the AC lines. When the height is 24.5m of the AC lines, the maximum value of the ground power frequency field is 3.95kV/m, less than the national standard limit; In the situation of agricultural farming area and the height of 15.5m, the ground electric field is larger than the national limit; In the situation of non-agricultural farming area and the height of 13.7m, the ground electric field is less than the national limit.

For the ± 800 kV DC transmission lines, the national standard minimum distances are 21m, 18m and 16m respectively, when the line through the residential area, agricultural farming area and non-agricultural farming area. As can be seen from Figure 4, the ground electric field meets the corresponding electric field control values when the height of DC lines was taken as the national standard minimum height.

Therefore, the height to the ground of the DC lines and the AC lines is set as follows:

- (1) Residential area. The height to the ground of the DC lines is set to 21m, and the AC wire 24.5m;
- (2) Agricultural farming area. The height to the ground of the DC lines is set to 18m, and the AC wire 15.8m;
- (3) Non-agricultural farming area. The height to the ground of the DC lines is set to 16m, and the AC wire 13.7m.

4.2. The distribution of hybrid electric field

The ground electric field of different AC/DC parallel spacing (the distance between the middle of the DC and AC lines) is calculated for three cases of residential area, agricultural farming area and non-agricultural farming area. Fig. 5 shows the distribution of the ground electric field when the distance between the lines is 90m, 60m and 50m corresponding to three cases above. The electric field strength in the figure is the absolute value.

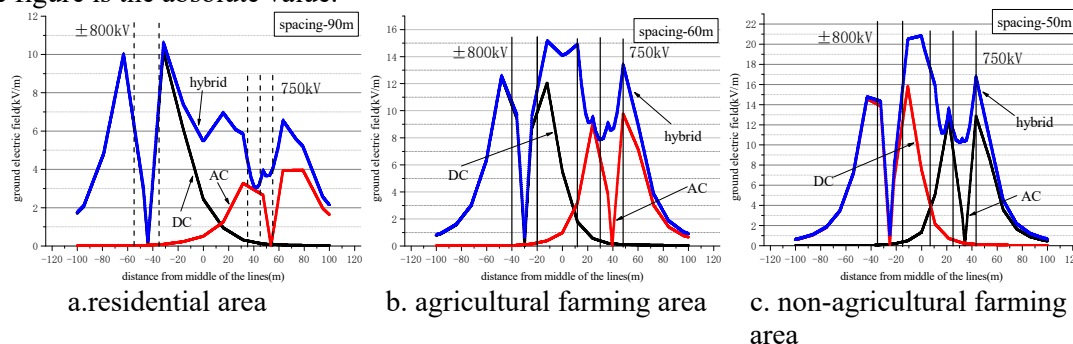


Fig 5. Instantaneous maximum value of the ground hybrid electric field of AC/DC parallel transmission lines

As can be seen from Figure 5, the distribution law of the ground hybrid electric field of AC/DC parallel lines has the following characteristics:

(1) The maximum values of the ground electric field of the single DC line are 11kV/m, 12kV/m and 16kV/m at the residential area, agricultural and non-agricultural farming areas, respectively, which are less than the electric field control limit;

(2) The maximum value of the ground electric field of the single AC line at the residential area, agricultural and non-agricultural farming areas, respectively, which approaches the limit but are less than it;

(3) Compared to a single DC line, the hybrid electric field below the DC line increases little; On the contrary, compared to a single AC line, the hybrid electric field below the AC line increases considerably. For the reason that the DC potential is higher than the AC potential, and the DC electric field has a large value at the AC line which is superimposed with the AC electric field;

(4) In the adjacent area of AC / DC parallel lines, the hybrid electric field is larger than that of individual DC and AC lines.

As can be seen from Figure 5, the ground electric field meets the corresponding limit requirements for individual AC and DC lines. However, for the hybrid electric field, the weighted method should be used for analysis because there is no corresponding national standard limit. Figure 6 shows the weighted normalized distribution.

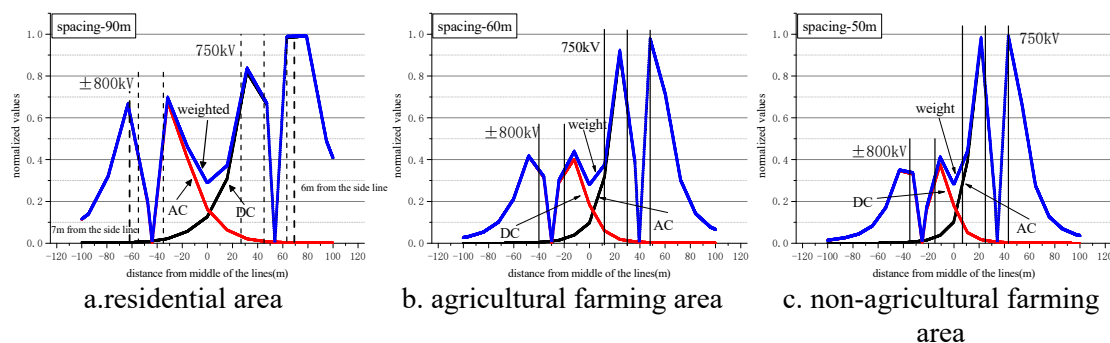


Fig 6. normalized value of ground hybrid electric field of AC/DC parallel transmission lines

When the spacing between AC and DC is decreased, the normalized value is also increased due to the mutual influence of AC and DC lines, and conversely, when the spacing increases, the normalized value decreases. So there is a minimum parallel spacing so that the normalized value is less than 1.

Fig. 6 shows the results of normalizing the values of the electric field in Fig5. In the Fig. 6, the normalized values of the AC electric field and the DC electric field just satisfy the condition of less-than 1. As can be seen from the Fig. 6, there is a great margin between the normalized value and the limit value of 1 at the DC line; and at the AC line, the normalized value is very close to the limit 1, and is also the main factor of limiting the spacing.

4.3. The width of Corridor

The DC ground electric field is much smaller than the limit of the national standard, when the height from the ground of DC lines is taken as the national standard. So the DC line has very little influence on the spacing of the line. Therefore, the influence of AC lines are mainly considered in calculation. The minimum spacing in the different regions is shown in Table 1 when the minimum height off the ground and the distance between AC lines and DC lines are given.

Table 1. calculation results of minimum distance between parallel lines of + 800kV DC line and 750kV single-circuit AC line

terrain classification	the minimum height of the line(m)		spacing(m)	The normalized value of the ground electric field (<1)
	DC	AC		

residential area	21	24.5	90	0.989
agricultural farming area	18	15.8	60	0.979
non-agricultural farming area	16	13.7	50	0.990

For the case of the lines passing through the residential area, the national standard states: in the case of no wind, the minimum horizontal distance between the side line and the building of the 750kV line is 6m, and the ± 800 kV line is 7m. The corresponding electric field should satisfy the limit.

In Fig. 6, the position off the DC side line 7m and the position off the AC side line 6m are shown, where the normalized value of the ground electric field is less than limit.

Considering the distance between the AC and DC lines, the spacing of lines and the minimum horizontal distance between the side line and the buildings, the minimum width of the corridor is 131.2m.

5. Conclusion

(1) The minimum ground height is calculated when the ground power frequency electric field of AC line meets the limit and the synthetic electric field on the ground of DC line satisfies the limit;

(2) The distribution of the ± 800 kV UHV DC and the 750kV EHV AC parallel ground electric field is calculated;

(3) The distribution of ground hybrid electric field of ± 800 kV UHV DC and 750kV UHV AC parallel transmission lines is calculated.

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