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Simplified approach of maximum electric field distribution on the ground near HVAC–HVDC shared tower transmission lines

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Abstract: This study extends the superposition method proposed by the Electric Power Research Institute to calculate electric field distribution on the ground near high voltage alternating current-high voltage direct current (HVAC-HVDC) shared tower transmission lines under ultra high voltage (UHV). Maximum electric field on the ground can be easily superposed by electric field when two circuits act separately, and when one circuit acts, thhe other circuit is regarded as ground wires. The ac field is calculated by method of images. The dc field is calculated by a finite element method (FEM). A precise time-domain FEM is used to calculate the hybrid electric field for comparison. Dispersion between results of superposition and time-domain FEM confirms that the superposition method is less time consuming and can satisfy engineering precision.

1 Introduction

Sharing tower by different types of lines is a focused measure to fit the increasing demand for power transmission. However, in the case of HVAC–HVDC shared tower transmission lines, electric fields and space charges generated by two lines will influence each other; the total electric field consists of three parts: dc electrostatic field, ac power frequency field, and electric field generated by space charges that are affected by the former two fields. Wei *et al.* [1], of Tsinghua University, proposed a time-domain upwind difference discrete method to calculate the electric field and ion flow density around HVAC–HVDC shared tower transmission lines. Although the method is accurate, the total electric field is time-variant and non-linear, leading to computational difficulties and massive computing time. In an engineering project, actually, the accuracy can be sacrificed slightly to barter for the efficiency.

The Electric Power Research Institute (EPRI) proposed a simple superposition method [2, 3] in 1986 that the electric field around parallel HVAC–HVDC transmission lines can be obtained by a linear superposition of electric field when two circuits act separately, and when one circuit acts, the other circuit is regarded as ground wires. The method was summarised by a series of experiments in which the highest voltage was 800 kV ac and 400 kV dc. Compared with the time-domain upwind difference discrete method, this method is simple and time saving. However, this method is based on a parallel situation. When two circuits share a tower, the effect of interaction increases. Whether this method is applicable requires further study. If this method can be further applied to the situation of sharing tower and higher voltage, it will have a great effect on improving the efficiency of engineering design nowadays.

2 Validation

The superposition method proposed by EPRI shows that the maximum electric field distribution on the ground can be obtained by a linear superposition of maximum electric field when two circuits act separately, and when one circuit acts, the other circuit is regarded as ground wires. This method considers that there is no interaction impact between two circuits.

2.1 Model 1

A model comprising a single-circuit 1000-kV HVAC transmission line and a bipolar ±800-kV HVDC transmission line is built. The line parameters are taken from actual lines: 1000-kV Mengxi–Tianjinnan HVAC transmission lines and ±800-kV Zhalute–Qingzhou HVDC transmission lines. The line parameters are presented in Table 1. The relative position of the line is set such that the ac circuit is below, the dc circuit is above, and the arrangement of ac three phases is horizontal. The locations of the wires are shown in Fig. 1.

The ac field is calculated by method of images (the dc line is regarded as ground wires). The dc field is calculated by a finite element method (FEM) [4–20] (the ac line is regarded as ground wires). The superposition result is the sum of the maximum ac field and dc field. A time-domain FEM is used to calculate the hybrid electric field for comparison. The comparison results are shown in Fig. 2.

The black solid line in Fig. 2 shows the maximum dc field when the ac wires are ground wires, and the grey dotted line shows the maximum ac field when the dc wires are ground wires. The grey solid line shows the superposition results. It is close to the time-domain calculations (the black dotted line). The maximum value in time-domain results is 24.3977 kV/m, and the maximum value in superposition results is 24.889 kV/m; the difference is very small.

2.2 Model 2

Different from Model 1, the arrangement of ac three phases is triangular in Model 2. The locations of the wires are shown in Fig. 3, and the comparison results are shown in Fig. 4.

The maximum value in time-domain results is 21.3764 kV/m, and the maximum value in superposition results is 21.2827 kV/m; the difference is very small.

Table 1 Line parameters of Model 1

No.	Project	Type	Diameter, mm	Splitting number	Splitting distance, mm
1	±800 kV HVDC	JL/G3A-1250/70	47.35	8	550
2	1000 kV HVAC	JL/G1A-630/45	33.80	8	400

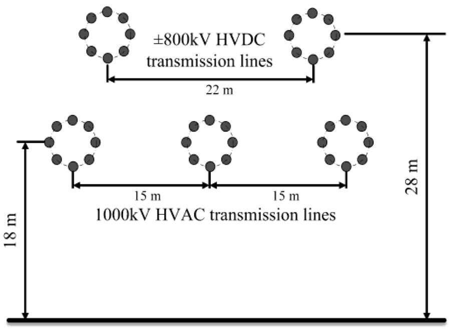

Fig. 1 *Wire location of Model 1*

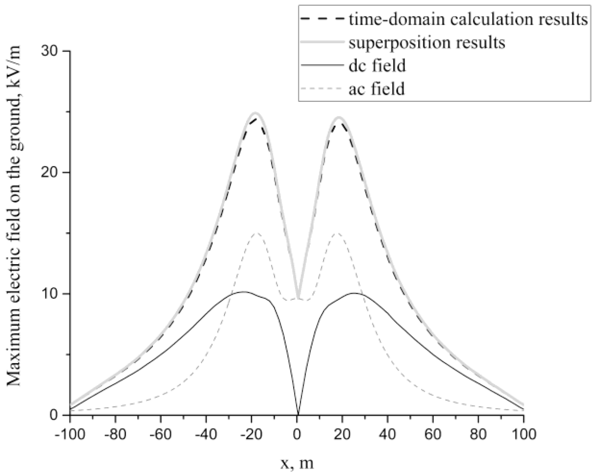

Fig. 2 *Comparison results of Model 1*

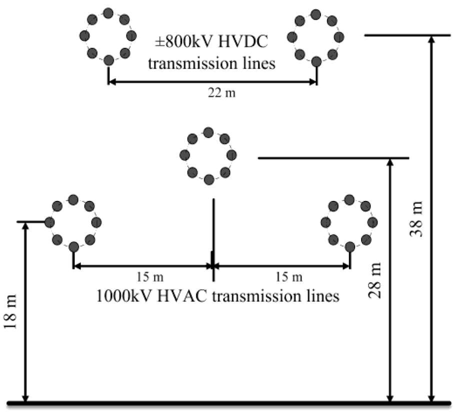

Fig. 3 *Wire location of Model 2*

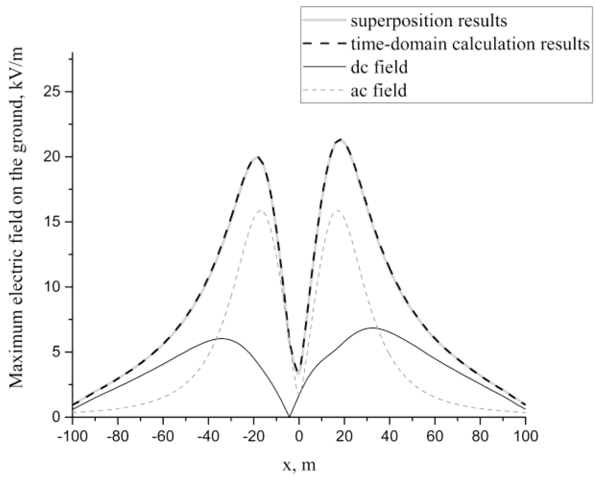

Fig. 4 *Comparison results of Model 2*

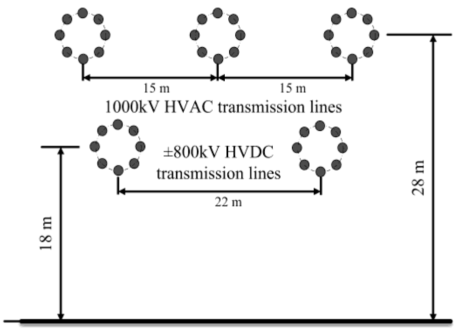

Fig. 5 *Wire location of Model 3*

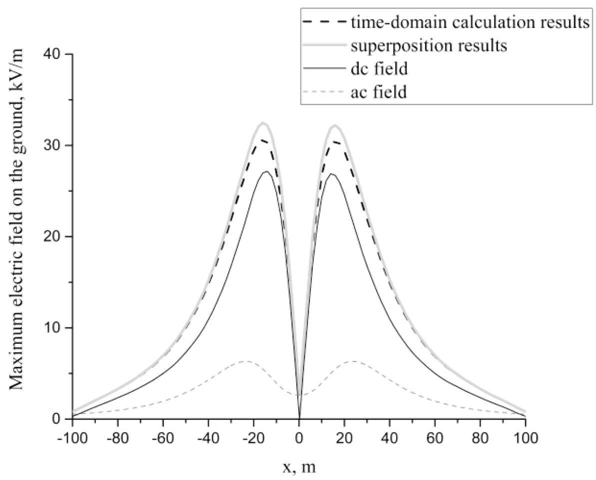

Fig. 6 *Comparison results of Model 3*

2.3 Model 3

Different from Model 1, the position of ac wires and dc wires is reversed. In Model 3, the ac line is the above and the dc line is below. The locations of the wires are shown in Fig. 5, and the comparison results are shown in Fig. 6.

The maximum value in time-domain results is 30.6261 kV/m, and the maximum value in superposition results is 32.4642 kV/m; the difference is 6%, which still satisfies the engineering requirements.

2.4 Model 4

Different from Model 3, the ac three-phase arrangement is triangular in Model 4. The locations of the wires are shown in Fig. 7, and the comparison results are shown in Fig. 8.

The maximum value in time-domain results is 32.3108 kV/m, and the maximum value in superposition results is 34.2715 kV/m; the difference is 6%, which still satisfies the engineering requirements.

2.5 Model 5

In fact, it is more likely to change one circuit of two-circuit shared tower lines to dc line. In Model 5, the left side of the tower is a dc line, and the right side of the tower is an ac line. The locations of the wires are shown in Fig. 9, and the comparison results are shown in Fig. 10.

The maximum value in time-domain results is 33.6667 kV/m, and the maximum value in superposition results is 36.3787 kV/m; the difference is 8%, which still satisfies the engineering requirements.

2.6 Model 6

At the other extreme, the dc line and two-circuit ac lines are on the same tower. Since the ac tower is generally built high, a case that the dc line is below is considered. The locations of the wires are shown in Fig. 11, and the comparison results are shown in Fig. 12.

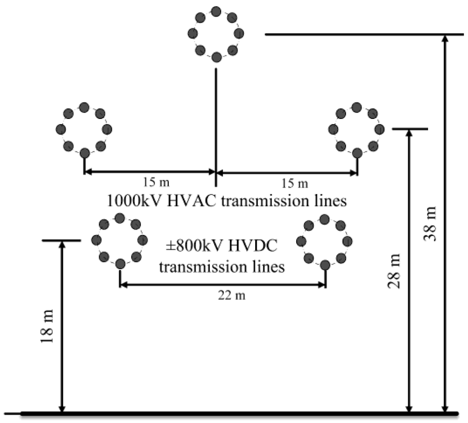

Fig. 7 *Wire location of Model 4*

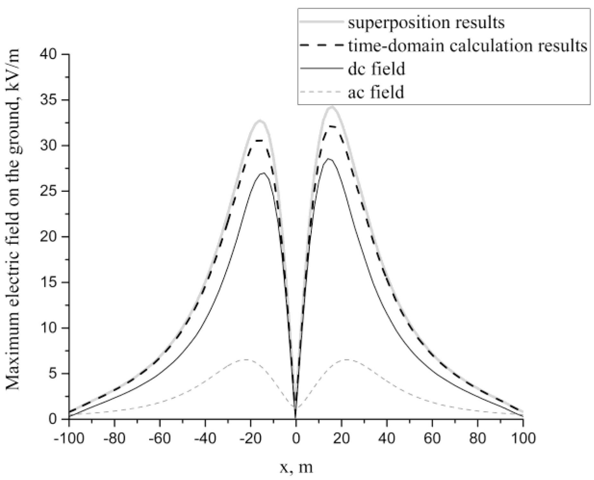

Fig. 8 *Comparison results of Model 4*

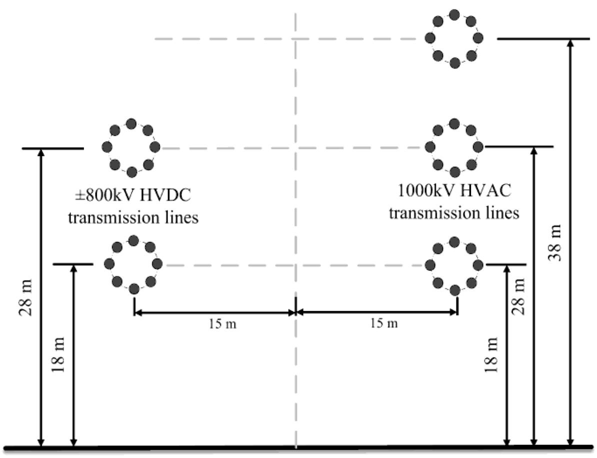

Fig. 9 *Wire location of Model 5*

The maximum value in time-domain results is 33.8724 kV/m, and the maximum value in superposition results is 36.6218 kV/m; the difference is 8%, which still satisfies the engineering requirements.

2.7 Model 7

The above six cases are all analysed based on one kind of line parameter. Is this method suitable for different line parameters? Parameters of another line are taken from actual lines: 1000-kV Yaan–Wuhan HVAC transmission lines and ±800 kV Hami–Zhengzhou HVDC transmission lines. The line parameters are presented in Table 2. The wire location is the same as in Model 5, and the comparison results are shown in Fig. 13.

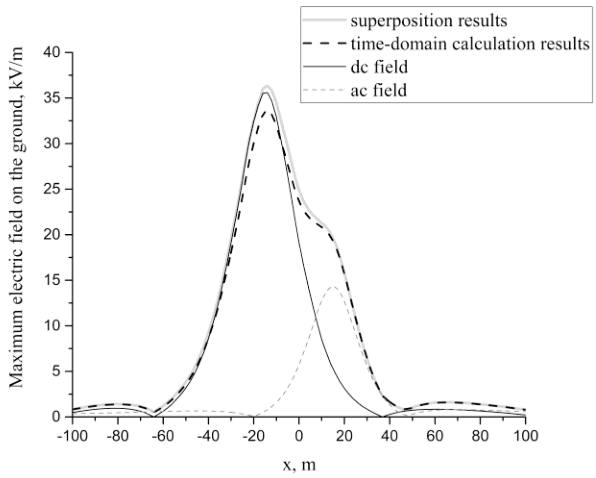

Fig. 10 *Comparison results of Model 5*

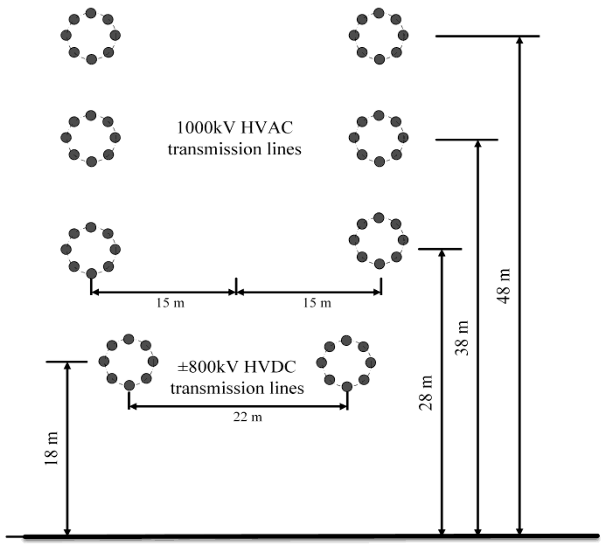

Fig. 11 *Wire location of Model 6*

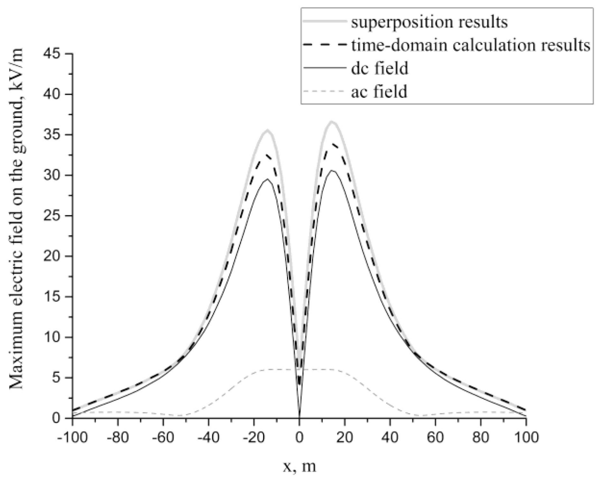

Fig. 12 *Comparison results of Model 6*

The maximum value in time-domain results is 42.9424 kV/m, and the maximum value in superposition results is 45.3614 kV/m; the difference is 5.6%, which still satisfies the engineering requirements.

3 Conclusions

In the above seven cases, the factors such as the relative positive of ac and dc wires, the number of ac circuits, and the line parameters

Table 2 Line parameters of Model 7

No.	Project	Type	Diameter, mm	Splitting number	Splitting distance, mm
1	±800 kV HVDC	JL/G3A-1000/45	42.08	6	450
2	1000 kV HVAC	JL/G1A-630/45	33.80	8	400

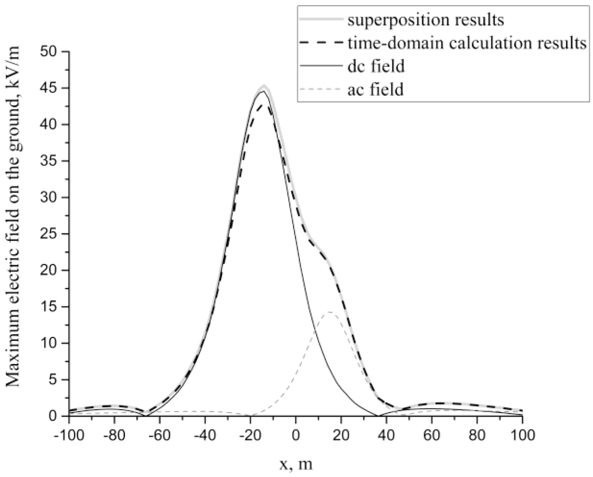

Fig. 13 *Comparison results of Model 7*

are analysed. The comparison between the superposition method and time-domain method is obtained through simulation.

We can see that under the UHV voltage, for the ac-dc shared tower, the superposition method proposed by EPRI can still be used to calculate the maximum electric field on the ground, and the error is <10%, which satisfies the engineering design requirements.

The conclusion of this paper provides a theoretical basis for simplifying the calculation of hybrid fields and improving the efficiency of the power design department.

4 Acknowledgments

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5 References

[1] Wei, L., Bo, Z., Jinliang, H., *et al.*: 'Calculation of the ion flow field of AC–DC hybrid transmission lines', *IET Gener. Trans. Distrib.*, 2009, **3**, (10), pp. 911–918

[2] High Voltage Transmission Research Center (A Research Facility of the Electric Power Research Institute): '*Hybrid transmission corridor study*' (New York Power Authority, New York, 1991)

[3] Clairmont, B.A., Johnson, G.B., Zaffanella, L.E.: 'The effect of HVAC–HVDC line separation in a hybrid corridor', *IEEE Trans. Power Deliv.*, 1989, **4**, (2), pp. 1338–1350

[4] Wei, L., Bo, Z.: 'Ion flow field calculation of multi-circuits DC transmission lines'. Proc. Int. Conf. High Voltage Engineering and Application, Chongqing, China, 2008, pp. 245–248

[5] Mazen, A., Zakariya, A.: 'A finite-element analysis of bipolar ionized field', *IEEE Trans. Ind. Appl.*, 1995, **31**, (3), pp. 477–483

[6] Jie, L., Jun, Z., Jihuan, T., *et al.*: 'Analysis of electric field, ion flow field, and corona loss of same-tower double-circuit HVDC lines using improved FEM', *IEEE Trans. Power Deliv.*, 2008, **24**, (1), pp. 482–483

[7] Feng, T., Zhanqing, Y., Rong, Z., *et al.*: 'Resultant electric field reduction with shielding wires under bipolar HVDC transmission lines', *IEEE Trans. Mag.*, 2014, **50**, (2), pp. 221–224

[8] Tadasu, T., Tsutomu, T., Tadashi, K.: 'Calculation of ion flow fields of HVDC transmission lines by the finite element method', *IEEE Trans. Power Appar. Syst.*, 1981, **PAS-100**, (12), pp. 4802–4810

[9] Zhenguo, W., Tiebing, L., Xuebao, L.: 'Predictive analysis of ion flow field at the ground level under HVAC and HVDC hybrid transmission lines'. Proc. IEEE Conf. Electrical Insulation and Dielectric Phenomena, Des Moines, USA, October 2014

[10] Xiangxian, Z., Xiang, C., Teibing, L., *et al.*: 'A time-efficient method for the simulation of ion flow field of the AC–DC hybrid transmission lines', *IEEE Trans. Mag.*, 2012, **48**, (2), pp. 731–734

[11] Han, Y., Jinliang, H., Bo, Z., *et al.*: 'Finite volume-based approach for the hybrid ion-flow field of UHVAC and UHVDC transmission lines in parallel', *IEEE Trans. Power Deliv.*, 2011, **26**, (4), pp. 2809–2820

[12] Bo, Z., Han, Y., Jinliang, H., *et al.*: 'Computation of ion-flow field near the metal board house under the HVDC bipolar transmission line', *IEEE Trans. Power Deliv.*, 2013, **28**, (2), pp. 1233–1234

[13] Qiang, S., Jian, W., Haiping, L., *et al.*: 'Analysis of coupling characteristics of hybrid electric field I the 750 kV HVAC and ±800 kV HVDC parallel transmission line'. Proc. IEEE 5th Int. Symp. Electromagnetic Compatibility, Beijing

[14] Ming, Y., Kuffel, E.: 'A new algorithm for calculating HVDC corona with the presence of wind', *IEEE Trans. Mag.*, 1992, **28**, (5), pp. 2802–2804

[15] Maruvad, P.S., Wasyl, J.: 'Analysis of corona losses on DC transmission lines: part II—bipolar lines', *IEEE Trans. Power Appar. Syst.*, 1969, **PAS-88**, (10), pp. 1476–1491

[16] Yongzan, Z., Xiang, C., Tiebing, L., *et al.*: 'High efficiency FEM calculation of the ionized field under HVDC transmission lines', *IEEE Trans. Mag.*, 2012, **48**, (2), pp. 743–746

[17] Guodong, H., Jiangjun, R., Zhiye, D., *et al.*: 'Highly stable upwind FEM for solving ionized field of HVDC transmission line', *IEEE Trans. Mag.*, 2012, **48**, (2), pp. 719–722

[18] Davis, J.L., Hoburg, J.F.: 'HVDC transmission line computations using finite element and characteristics method', *J. Electrostat.*, 1986, **18**, (1), pp. 1–22

[19] Janischewskyj, W., Cela, G.: 'Finite element solution for electric fields of coronating DC transmission lines', *IEEE Trans. Power Appar. Syst.*, 1979, **PAS-98**, (3), p. 1000

[20] Jihuan, T., Jun, Z., Jie, L., *et al.*: 'Calculation of total electric field and ionic current density of double-circuit HVDC transmission lines', *Power Syst. Technol.*, 2008, **32**, (2), pp. 61–65