Improved Calculation method of Electric Field and Power loss of EHV AC Bundled Conductors

Shuo JIN, Jiangjun Ruan, Zhiye DU, Member, IEEE, Guodong Huang
School of Electrical Engineering, Wuhan University, Wuhan 430072,China
duzhiye@126.com

Abstract—This paper presents an improved method for calculating power loss and the electric field at the ground level due to corona on EHV AC bundled conductors. The method is based on the charge simulation technique combined with the method of successive imaging, where the number and location of the simulation charges are not arbitrary. The charge emits from the corona conductors into the space nearby when the electric field on the conductor surface exceeds the onset value. The space ion and surface charges on each sub-conductor are simulated by a series of infinite line charges. The displacement of space ion is calculated during corona periods over both the positive and negative half cycles. Several examples of field calculation are carried out by the proposed method, including one with the present of ground wires. Taking each sub-conductor into consideration, the calculated electric field at the ground level and corona power loss have better convergence and agree well with the measurements than the results achieved using equivalent conductors.

Key words—*Charge simulation method; Corona; Power frequency electrical field; Bundled Conductors.*

I. INTRODUCTION

With the ever increasing voltage level and widely use of bundled conductors, corona is becoming a more and more important aspect to take into consideration when designing transmission lines. When the electric field in the near vicinity of high-voltage conductor(s) of power transmission lines becomes sufficient high, corona starts. Charges of the same sign as that of the wire potential are emitted into space and move away from the wire in the form of shells. The movement of space charges consumes energy, and the energy interrelated is used to represent the corona power loss on stressed conductor.

In direct current (DC) corona, the ion flow is uni-directional from the coronating wire to the ground plane. Unlike DC corona, in the case of ac corona, the space charges produced by corona are constrained to the vicinity of the conductor because of the periodic reversal of electric field. Within the region of the charge movement, the outgoing and returning space charges recombine with each other. Therefore, the analysis of AC corona is more complicated than DC corona analysis.

Though some experimental investigations were done on the corona EHV AC transmission lines, little theoretical work has been conducted due to the peculiar characteristics of AC corona, most of which use equivalent conductors to represent bundled conductors when analyzing. The equivalent simplification of conductors leads to fluctuated results in some occasions. Existing experimental achievements on AC corona loss of high voltage-level show that corona power loss is affected by many factors, such as conductor radius, meteorological condition, transmission line height, spacing between conductors and the conductor surface factor η.

Combined Charge Simulation Method (CSM) with the successive imaging method, this paper proposed an improved method for calculating the electric field on EHV bundled conductors with the affection of corona. The CSM is used to determine the simulation charges in inner conductor region with the voltage applied. The successive imaging method is also introduced to calculate the electric field caused by simulation charges. The onset field at corona initial stage is evaluated in the absence of ion space charge. When corona discharge is initiated, the resultant ion flow cannot be evaluated analytically, since the magnitude and distribution of the space charge are unknowns. Such a problem calls for a digital iteration computation as proposed in this paper. The computation is based on the following assumptions:

(i).the electric field on the surface of corona conductor is constant;

(ii).the corona power loss is mainly caused by the displacement of space charges;

(iii).only recombination is taken into consideration during the moving of charges.

This paper aims to:

(1).calculate the corona power loss on EHV bundled conductors;

(2).determine the ground-level electric field underneath the EHV transmission line.

II. METHOD

This paper proposed a new method for calculating the electric field of bundled conductors. This method takes the space charges into consideration when the corona occurs in the high voltage transmission lines.

CSM is used to determine the simulation charges and space charges emitted from the coronating conductor. According to traditional CSM, M infinite simulation line charges are set in inner conductor region of each conductor, accompanied by M boundary points at the relevant positions on the surface. Space charges produced by corona are also represented by infinite line charges. The underground images of charges are considered to keep ground plane at zero potential. The values of simulation charges Q_{con} are calculated by the following equation:

$$U = K_{con}Q_{con} + K_{space}Q_{space} \tag{1}$$

where U is the potentials array of boundary points which equal the voltages applied on each conductor, K_{con} and K_{space} are the potential coefficients matrix calculated by conductor simulation charges and space simulation charges at boundary points. Q_{space} is the space charges array, which is the equivalent charges emitted from surface of the conductor to the space around in coronating status.

When the surface electric field exceeds the onset values, corona starts and charges begin to be emitted. The successive imaging method is used when calculating the surface field of each conductor in order to get accurate values.

The power loss is calculated with the displacement distance of each space charge in each time step. And according to the superposition principle, the electric field intensity under EHV transmission lines due to the corona discharge can be obtained by adding the value produced by space charges to the value generated by the simulation charges in inner conductor region.

This method calls for an iterative procedure, as illustrated in Fig. 1.

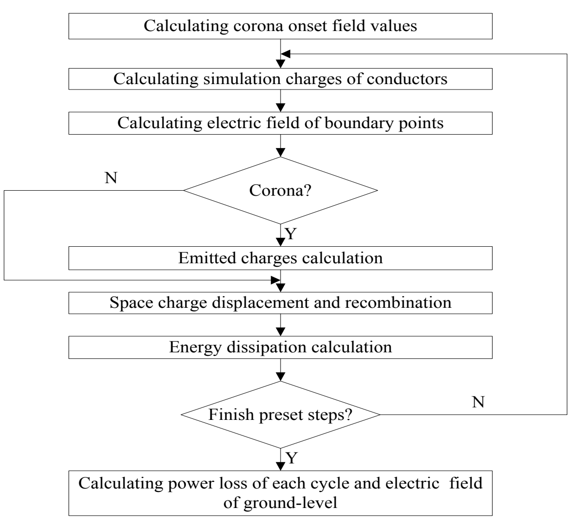
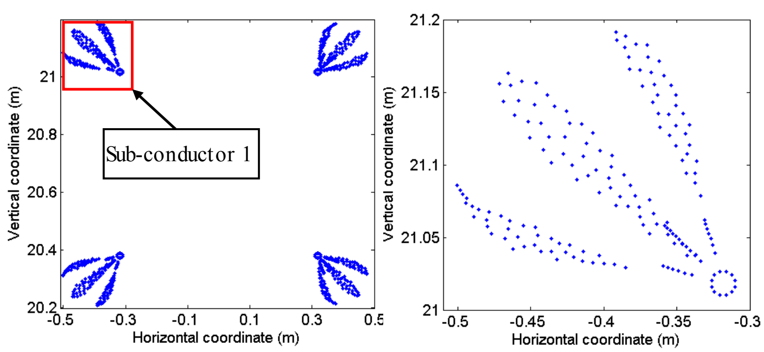


Fig. 1. Calculation flowchart of the ionized field



charge distribution of middle phase   zoom in map of sub-conductor 1

Fig. 2. Charge distribution map

Figure 2 shows simulation results due to the existence of the space charges surrounding the conductor, the ion emission is assumed discrete, dictates that each space line charge represents the charge over a volume element per unit length of the wire. The zoom in map indicated the displacement of space charge can be calculated in proposed method. Fig. 3 shows the ground level electric field calculation results of 500kV single-circuit transmission lines in the form of bundled conductors. Fig. 4 shows the power loss calculated with different surface factor η. When η=0.57, the power loss of unit length is 5W/m, which is close to the experimental data.

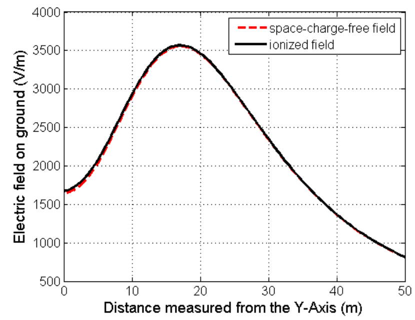


Fig. 3. Electric field (RMS value) at ground level

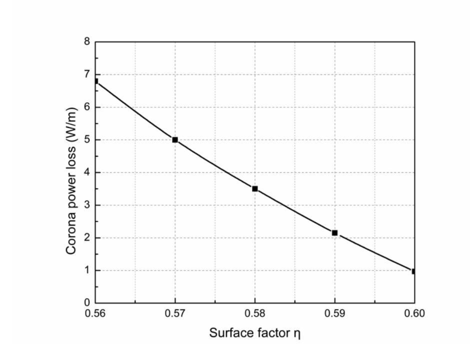


Fig. 4. Power loss calculated with different surface factor η

III. APPLICATION

The simulation results of 500 kV single-circuit quad bundled conductor transmission lines proved that this proposed method is reasonable and feasible. The simulation results of 500 kV double circuits EHV transmission lines are obtained with and without the ground lines separately. It is shown that the corona discharge enhances slightly the electric field at the ground level. The surface factor of wire affects significantly on the power loss in the calculation.

REFERENCE

[1] Clade J. J. , Gary C H, Lefevre C A. "Calculation of corona losses beyond the critical gradient in alternating voltage," *IEEE Transactions on Power Apparatus and Systems*, vol. PAS-88, no. 5, pp.695-703, May 1969.

[2] Abdel-Salam M, Shamloul D. "Computation of ion-flow fields of AC coronating wires by charge simulation techniques," *IEEE Transactions on Electrical Insulation*, vol. 27, no. 2, pp. 352-361, Apr. 1992.

[3] Mazen Abdel-Salam, Essam Zaki Abdel-Aziz. "Improved Calculation for Corona Loss on Three-phase Power Transmission Lines," *Industry Applications Society Annual Meeting*. vol. 3. Denver, CO, USA: IEEE, 1994, pp. 1601-1607.

[4] Li Wei, Zhang Bo, He Jinliang, Zeng Rou, Li Xiaolin, Wang Qi. "Corona Losses Calculation of UHV/EHV AC Transmission Lines," *Proceedings of the CSEE*, vol. 29, no. 19, pp. 118-224, 2009.

[5] Maruvada P. Saram, Wasyl Janischewskyj, "Electrostatic Field of a System of Parallel Cylindrical Conductors," *IEEE Trans. on Power Apparatus and Systems*, vol. PAS-88, no. 7, pp. 1069-1079, July 1969.