Research on Electromagnetic Environment Equivalent Parameters between Corona Cage and HVDC Transmission Lines by Finite Element Method

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Abstract —The corona effect of HVDC transmission lines affects the electromagnetic environment significantly. Corona characteristic parameters of the conductor surface of corona cage and HVDC transmission line are investigated in this paper. Finite element methods to calculate Static electric fields, compositive electric fields and ion current density of conduct surface are described. Deutsch assumption, a commonly used simplification in traditional compositive electric fields calculation methods is eliminated. The corona current is introduced to improve the stability and efficiency of calculation. The audible noise caused by conductor surface's corona are measured both in the corona cage and transmission line to verify the simulation results.

I. INTRODUCTION

Developments in the area of high voltage engineering during the last decades have shown that HVDC transmission of electric power over long distances offers some advantages over conventional ac transmission. In China, in order to meet the energy needs, several ±800kV HVDC transmission lines have been built, and some ±1000kV or above ones are in the future works. However, the overhead HVDC transmission lines affect the electromagnetic environment significantly. Especially, the corona effect produced by HVDC lines enhances the electrical field and forms a space charge distribution in a large range, which causes actual harm to the devices' and human bodies' safety in the vicinity. In addition, the influence of the corona discharge on power loss, noise and radio interference should also be thoroughly investigated before HVDC is commonly implemented.

Efforts have been made to simulate the ion flow field caused by corona effect in the vicinity of DC electrodes.

Janischewskyj and Gela [1] first applied finite element method (FEM) to simulate the corona in the simple coaxial cylindrical configuration. They accepted the Deutsch assumption, formulated and iteratively solved two separate partial differential equations for the electric potential and the space ion density.

Takuma et al. [2, 3] solved the corona problem in a wire-plane configuration assuming known ion density on the surface of the corona wire. A hybrid finite element method and charge simulation method (FEM-CSM) was applied to determine the potential distribution and the upwind FEM algorithm was used to estimate the charge density distribution.

Abdel-Salam et al. [4, 5] analyzed the wire to ground configuration using the FEM-CSM technique and the iterative technique introduced by Janischewskyj. Method of cell (MOC) combined with other numerical techniques used for solving the Poisson equation is very efficient and produces accurate results. But it is limited only to the simple structural lines.

This paper uses upwind FEM algorithm to solve the ion flow field. Deutsch assumption is removed. The corona onset judgment is made on each mesh point separately on the conductor surfaces. Suitable initial charge density values on the conductor surfaces are chosen to guarantee the computational stability. Non-reflective boundary condition is introduced to improve the computational efficiency.

II. CALCULATION METHOD

A. Mathematical Formulation

Assuming the ion flow field to be a 2D problem, the equations that constitute the mathematical description of the bipolar ionized field in air are:

Poisson's equation:

$$div\ \mathrm{grad}\Phi=(\rho^{-}-\rho^{+})/\varepsilon_0 \tag{1}$$

The positive and negative current density vectors:

$$\begin{aligned} \mathrm{j}^{+} &= \rho^{+}(-k^{+}grad\Phi+W) \\ \mathrm{j}^{-} &= \rho^{-}(-k^{-}grad\Phi-W) \end{aligned} \tag{2}$$

The current continuity condition:

$$\begin{aligned} \mathrm{divj}^{+} &= -R\rho^{+}\rho^{-}/e \\ \mathrm{divj}^{-} &= R\rho^{+}\rho^{-}/e \end{aligned} \tag{3}$$

The total current density vector:

$$\mathrm{j}=\mathrm{j}^{+}+\mathrm{j}^{-} \tag{4}$$

Where:

Φ electric potential(V), ρ^{+},ρ^{-} absolute values of positive and negative space charge density(C/m^2), $\mathrm{j}^{+},\mathrm{j}^{-}$, j positive, negative and total ion current density vector(A/m^2), k^{+},k^{-} positive and negative ion motilities(m^2/Vs) , W wind velocity vector(m/s), ε_0 permittivity of air, 8.854*10^{-12}F/m, e electron charge, 1.602*10^{-19}C, R coefficient of recombination, These differential equations must be solved for the potential Φ (or the electric field E) and the space charge densities ρ^{+} and ρ^{-}, as functions of the space coordinates.

B. *Proposed Approach of Solution*

Takuma [2,3] suggested an iterative algorithm to solve this system: first assume the charge density distribution on the conductors, then a hybrid FEM-CSM was applied to determine the potential distribution based on formula (1), after that, the upwind FEM algorithm was used to calculate the charge density distribution based on the combination of formula (1-4). The potential and charge density distribution are solved iteratively until the accuracy requirements are met.

With Takuma's method, the value of charge density on the conductor surface resulted from the experimental is required previously. We try to relax this requirement with Kaptzov's assumption. First, estimate the charge density on the conductor surface. The potential and charge density distribution are solved with iterative method. Then, Kaptzov's assumption is applied to check the surface condition. If the hybrid space electric field on the conductor surface is no more than the corona onset field, the iterative process terminates, otherwise, the surface charge density is modified. Fig. 1 illustrated this iterative process.

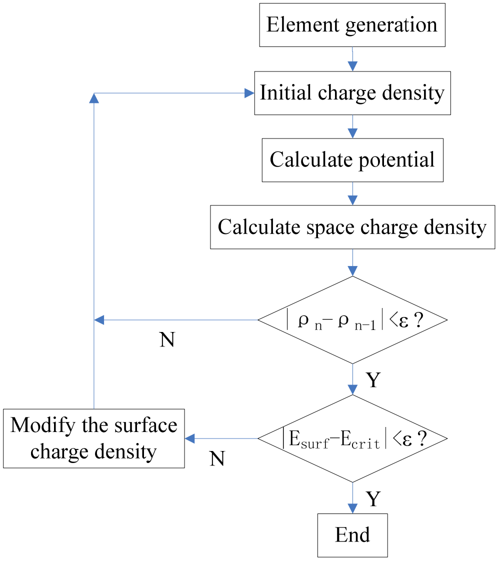

Fig. 1. Flowchart of the proposed approach

III. EQUIVALENT PARAMETERS

A. *Modeling and Calculation*

There is a big HVDC corona cage in EHVDC test base in Beijing, China. The length of the cage is 70m, the cross section of the cage is two 5m*5m square.

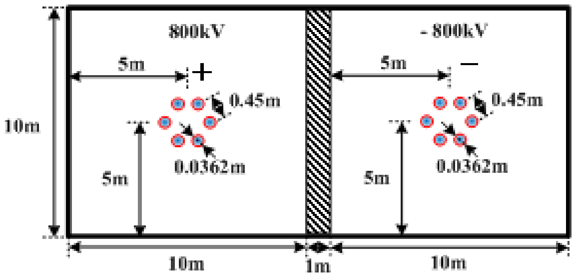

Fig. 2. Structure of double polar corona cage

There is a big HVDC corona cage in EHVDC test base in Beijing, China. The length of the cage is 70m, the cross section of the cage is two 5m*5m square.

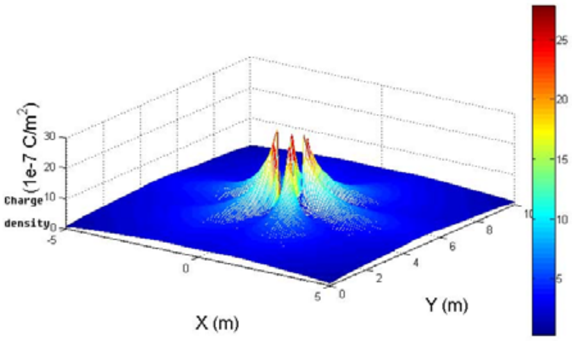

Fig. 3. Ion flow distributions in monopolar corona cage

B. *Analysis the Equivalent parameters*

Corona cages, as a powerful electromagnetic environment experimental tool, can simulation the mostly electromagnetic environment parameter. The surface static electric field can be used as equivalent parameter in the AC transmission line. Whereas the DC transmission line, there are ion flow on the surface of conductors, and the ion flow can influence the electric fields seriously. Static electric fields, compositive electric fields and ion current density of conduct surface are calculated at the conductor surface of corona cage and transmission line. The result will present in the full paper later. The audible noise of the conductor will validate the simulation results in the full paper.

IV. CONCLUSIONS

The modified finite element method is proved to be proper method for the ion flow fields simulation. And the compositive electric fields are the best equivalent parameter for corona cage and transmission line.

V. REFERENCES

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