Analysis of Ion Current Passing Through the Human Body under HVDC Lines with 3D Finite Element Method

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Abstract — As more and more HVDC projects are constructed in China, the electromagnetic environment problem is widely concerned, of which the ion current passing through human body under the HVDC lines is very important, but it has not been analyzed sufficiently with numerical algorithm as reported. In this paper, based on 3D upstream finite element method, a method to calculate the ion current passing through human body under HVDC lines is proposed. As an ion current effect, the potential of human body with different resistance to the ground is analyzed.

I. INTRODUCTION

Because of the advantage of high voltage direct current (HVDC) transmission system [1], more and more HVDC projects are constructed in China. Two ±800 kV UHVDC transmission systems have been put into operation in China, 2010.

When people stand under the HVDC lines, there will be ion current passing through the human body. The ion current is a very important environment target for HVDC projects. If the resistance to the ground is large, there will be a high potential of the human body, and people will be easy to suffer electric shock when touching something grounded. It is very benefit for projects that the ion current passing through body is calculated accurately.

Many methods have been proposed to analyze the ionized field of the HVDC transmission lines [1]-[5]. But the research before mainly focused on 2D ionized field, 3D problem including human body under HVDC lines has rarely been reported. As the UHVDC voltage levels reach ±800 kV, in order to ensure the ion current satisfy the environment limit value and keep economical, there is an urgent need to analyze the ion current of body under HVDC transmission lines to control it within a reasonable limits by calculations and adjustments in engineering design stage. Then 3D ionized field solution method is needed.

Similar to upstream finite element method (upstream FEM) in 2D problem [2], [4], based on the 3D upstream FEM, a method to analyze the ionized field of human body under HVDC transmission lines is proposed. Based on a reasonable calculation domain simplification method, the calculation consume is reduced a lot, and the accuracy is almost not affected. Then the method is easily implemented with PC. The ion current passing through human body is analyzed. Of human body, the relationship of the ion current, the potential, and the resistance to the ground is analyzed.

II. METHODOLOGY AND ANALYSIS

A. Basic Equations

For bipolar HVDC transmission lines, the potential φ, the ionized field $\boldsymbol{E}_s$, and the positive and negative ion current density $\boldsymbol{j}_+$, $\boldsymbol{j}_-$ can be defined as follows[2].

$$\nabla^2\varphi = -(\rho_+ - \rho_-)/\varepsilon_0 \tag{1}$$

$$\boldsymbol{E}_s = -\nabla\varphi \tag{2}$$

$$\nabla\cdot\boldsymbol{j}_+ = -r\rho_+\rho_-/\mathrm{e} \tag{3}$$

$$\nabla\cdot\boldsymbol{j}_- = r\rho_+\rho_-/\mathrm{e} \tag{4}$$

Where ρ_+ and ρ_- are positive and negative space charge density, r is the ion recombination coefficient, e is the charge of the electron,.

B. A 3D Solution Method

Coupled of equation (1)-(4), the governing equations are nonlinear, and iterative calculation method is adopted. Upstream finite element method (upstream FEM) has good ability in 2D ionized field calculation [2], [4]. Based on the similar idea, 3D upstream FEM is adopted, and as reported the method has not been used by other researchers. The calculation procedure is spread from 2D upstream method, and in 3D method, the tetrahedron element is adopted. Node *N* and its upstream element is shown as Fig. 1.

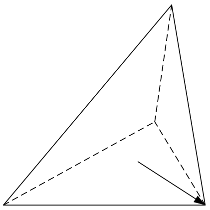

Fig. 1 Node *N* and its upstream element

Calculating 3D ionized field problem under HVDC lines directly, will cost enormous amount of computation. Fortunately, when a person stands under the HVDC lines, because the volume of a person is so small compared to the structure of HVDC lines, the potential and space charge density far away from the person will change little with the person existing or not. So with an enough calculation region, it’s reasonable to assume the potential and space charge density on the boundary will not change with the person existing or not. Then the boundary condition could be determined by 2D ionized field calculation.

The calculation human body model is shown as Fig. 2, called model 1. The height of model 1 is 1.80 m. The head model is a sphere with radius 0.1 m. Of the body, the thickness is 0.2 m. Of the upper part, the height is 0.64m, and the width is 0.5 m. The lower part height is 0.9 m， and the width is 0.4 m. Considering ±800 kV UHVDC lines, the height of the lines is 18 m, the lines have two 6×1.538 cm bundled conductors with the bundle spacing 0.45 m. The spacing between the negative and positive lines is 22 m. First, the ionized field below HVDC lines is calculated with 2D upstream FEM [4]. When model 1 is located under the negative lines, the calculation region is shown as Fig 3.

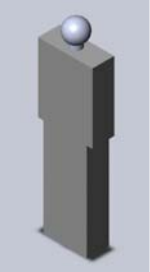

Fig. 2 Human body model

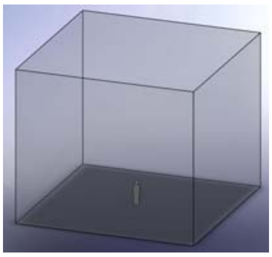

Fig. 3 Calculation region schematic diagram

To choose a suitable boundary for calculation, two block regions 14m×14m×14m and 14m×14m×12m are considered, where the height is 14m and 12m individually. On the top of model 1, the difference of the ionized field is less than 0.2% with the two regions. So the two calculation regions have little different influence on the calculation, and the calculation region 14m×14m×12m is enough for accuracy.

C. Results and Analysis

Usually, there is a grounded resistance of human body, then to obtain the ion current passing through human body, the problem is a coupled problem of ionized field and electric circuit, and the calculation resume is enormous. To reduce the calculation, we could assume the potential of human body is some value, then the ion current is easily obtained, and the resistance could be calculated. The relationship of the potential, ion current and grounded resistance is easily obtained. Assuming the potential Φ of model 1 is 0，-1 kV，-2 kV …，until -20 kV，the ion current passing through model 1 with the -Φ is shown as Fig.4, and the relationship of -Φ and the grounded resistance R is shown as Fig. 5.

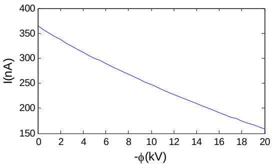

Fig. 4 Relationship of the potential and ion current of model 1

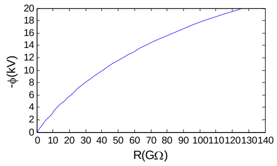

Fig. 5 Relationship of the potential and the grounded resistance of model 1

From Fig. 4, as the potential varies from 0 to -20 kV, the ion current decreases. If the potential is 0, the ion current passing through model 1 is 365.1 nA. People will feel nothing with the current passing through the human body. While without model 1, on the ground the ion current density is 54.4 nA/m^2. By the estimated formula in [6], the ion current passing from model 1 is 326.1 nA/m^2. So the results agree with each other well. The calculation results are trustworthy.

From Fig 5, it could be found that if R is less than 10 GΩ, the voltage of model 1 to the ground increases approximately linearly with R. The oral resistance of shoes for people is 3MΩ to 1GΩ [6], so when people stand under the HVDC lines, the voltage of human body to the ground changes only hundreds volts. People would not feel electric shock when touching something grounded. But the resistance of electrical insulation boots may reach 500 GΩ [6], if people stand under HVDC lines with it, the voltage may be more than 20 kV, then people should not touch grounded objects to void electric shock.

The relative experiment is being prepared and the results will be shown in the full paper.

III. CONCLUTIONS

The ion current passing through human body under the HVDC lines is concerned widely. The ionized field calculation domain simplified method is reasonable and the result is trustworthy compared with estimated formula. The relationship of ion current, the grounded resistance, and potential of human body model is analyzed. According to the results, people will not suffer electric shock with ordinary shoes under The UHVDC lines.

IV. ACKNOWLEDGMENT

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