Resultant Electric Field Reduction with Shielding wires under Bipolar HVDC Transmission Lines

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***Abstract*— A Time domain method was adopted to solve DC ion flow field of bipolar transmission lines under which shielding wires were built to reduce the resultant electric field. The charge simulation method (CSM), finite element method (FEM) and finite volume method (FVM) were used to solve the space-charge-free electric field, ion flow field and current continuity equation respectively. This method was validated by measurement results derived from the shielding wire experiments. Meanwhile, experimental results were explained theoretically by the time domain solutions. Relationships between transmission line configurations and shielding wire schemes were evaluated based on calculation results.**

***Index Terms*— HVDC transmission, time domain**

I. INTRODUCTION

Reduction of resultant electric field which induced by corona discharges generated from HVDC transmission lines is one of the key issues in practical transmission line designs and constructions. Shielding wires could be installed below the poles in order to reduce the resultant electric field, and could be one important approach for transmission projects optimization.

Yuji Amano and Yoshitaka Sunaga have studied the shielding wire approach under double HVDC test lines [1]. However, only basic measurement results were provide. In order to get a better understanding of the shielding effectiveness under various arrangements of conductors, numerical calculations were performed.

Resultant electric field refers to combination of space-charge-free field and ion flow field around HVDC transmission lines. Various methods have been proposed to solve ion flow field directly [2]-[5]. Takuma T. proposed an upwind FEM method based on Kaptzov's assumption [2]. Wei Li proposed a dynamic method which can represents the physical process based on upwind FEM method [4]. But it can only suitable within very short time period. The author Han Yin improved Wei Li's method and proposed the method adopted here which can apply for calculating ion flow field of DC corona [6]. More information could be found in his another paper [6].

In the paper, the theory and procedures of the time domain method are stated. Test platform of shielding wires under full-scale HVDC test line is introduced, and the test procedures are briefly presented. Then, the validation of the method will be checked using the measurement data of resultant electric field. After that, the theoretical explanations of the measurement results obtained under various shielding wire heights will be offered based on numerical calculation process. Last, formula used to describe the relationship of configurations of test lines and conductor heights of shielding wires is proposed based on the calculation results.

II. TIME DOMAIN METHOD

Generally, the ion flow field is analyzed through solving the Poisson's equation (1) and current continuity equation (2) to (5) iteratively. Space-charge-free field is calculated by CSM, and space charge distribution will be obtained. Electric field induced by space charge is calculated by FEM. Current continuity equations are solved by FVM. Refine space charge density is obtained in this step. During the iterate process, strang operator splitting is introduced in order to decouple the problem caused by charge advection and recombination. The method ends when the ion flow current on the ground is stable.

$$\nabla^2 \Phi(t) = -[\rho^+(t) - \rho^-(t)] / \varepsilon_0 \tag{1}$$

$$\boldsymbol{j}^+(t) = \rho^+(t)[\mu^+ \boldsymbol{E}(t) + \boldsymbol{W}(t)] \tag{2}$$

$$\boldsymbol{j}^-(t) = \rho^-(t)[\mu^- \boldsymbol{E}(t) - \boldsymbol{W}(t)] \tag{3}$$

$$\frac{\partial \rho^+(t)}{\partial t} = -\nabla \cdot \boldsymbol{j}^+(t) - R\frac{\rho^+(t)\rho^-(t)}{e} \tag{4}$$

$$\frac{\partial \rho^-(t)}{\partial t} = \nabla \cdot \boldsymbol{j}^-(t) - R\frac{\rho^+(t)\rho^-(t)}{e} \tag{5}$$

In equations (1)-(5),$\Phi(t)$ is the electric potential, $\rho^+(t)$ and $\rho^-(t)$ are the positive and negative charge densities, ε_0 is the permittivity of free space, $\boldsymbol{j}^+(t)$ and $\boldsymbol{j}^-(t)$ are the positive and negative ion current densities, μ^+ and μ^- are the ionic mobility of positive and negative ions, $\boldsymbol{E}(t)$ is the electric field intensity, $\boldsymbol{W}(t)$ is the wind velocity, R is the recombination coefficient, and e is the electron charge.

The current continuity equations in time domain are solved by the following two equations:

$$\frac{\partial \rho^+(t)}{\partial t} S_i = -\sum_{x=j,k,m} \rho_{ix}^+(t)\boldsymbol{V}_{ix}^+(t) \cdot \boldsymbol{n}_{ix} L_{ix} - R\frac{\rho_i^+(t)\rho_i^-(t)}{e} S_i \tag{6}$$

$$\frac{\partial \rho^-(t)}{\partial t} S_i = -\sum_{x=j,k,m} \rho_{ix}^-(t)\boldsymbol{V}_{ix}^-(t) \cdot \boldsymbol{n}_{ix} L_{ix} - R\frac{\rho_i^+(t)\rho_i^-(t)}{e} S_i \tag{7}$$

Where, S_i is the area of the ith element, $\rho_{ix}^+(t)$ is the charge density of the edge between element i and x, $\boldsymbol{V}_{ix}^+(t)$ is the corresponding velocity of the edge, and L_{ix} is the edge length. Strang operator splitting is introduced to decouple equation (6) and (7).

III. EXPERIMENTAL PLATFOM

The 800m full-scale test line with conductors type of 6×LGJ-720/50 is comprised of 3 spans, as shown in Fig. 1.

The terminals of the test lines are left open ended. High voltage of ±800kV was applied to the positive and negative pole.

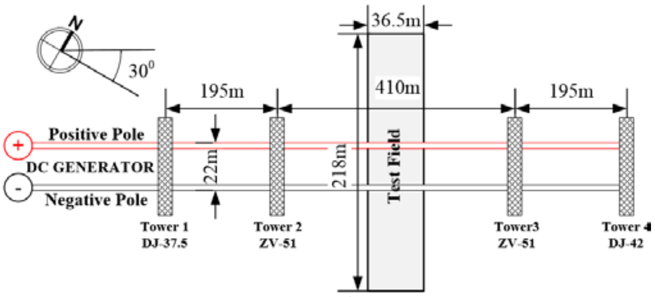

Fig. 1. Top view of the test lines

The experimental platform is shown as Fig.2. Shielding wires were located below the positive pole and supported by towers shown in Fig. 3. Resultant electric field on the ground was measured right below the middle of the test line with rotating field meters. Current on shielding wires was measured through 100Ω sampling resistors connected in series between each shielding wire and the ground with high speed digital oscilloscope. The visual corona discharges were recorded by ultraviolet camera.

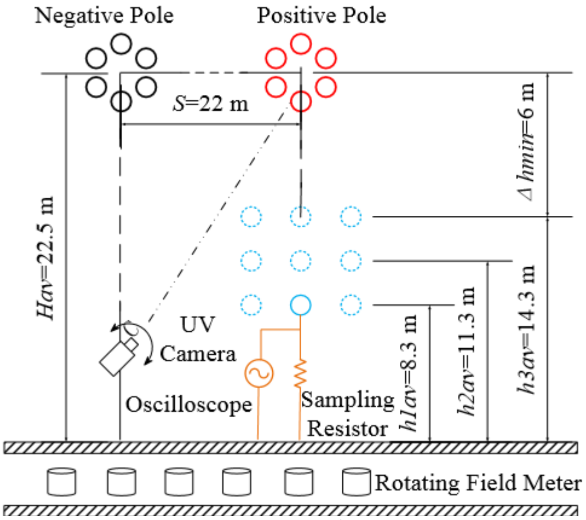

Fig.2. Test platform

Three cross arms are installed on each tower horizontally and symmetrically. Seven suspension points distribute uniformly along each cross arm. The minimum height of suspension point is 13m. The clearance of positive pole and the shielding wires is kept at least 6m.

Fig. 1. Shielding wire support tower

The type of the shielding wire is LGJ-300/70 with a radius of 1.26cm. During all tests, sags are kept at 7m. However, the number and arrangement of shielding wires could be adjusted in order to find the relationship of test line configurations and shielding wire schemes.

IV. TEST SHIELDING WIRE SCHEMES

Parameters of tested wire schemes are shown in Table 1. 1-wire and 3-wire configurations were tested.

Table 1 TEST SHIELDING WIRE SCHEMES

No. of wires	Cross arm	Support point
1	Lower	Beginning
3	Lower	Beginning\Middle\Last
3	Middle	
3	Upper	

V. VALIDATION

Comparisons of calculation and measurement results of resultant electric field on the ground are shown in Fig.4, and demonstrate the validity of the method.

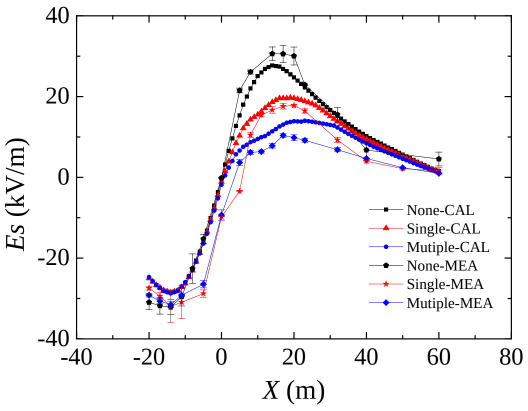

Fig. 2. Validation of the method

Comprehensive descriptions of the method and more detailed simulation results will be provided and discussed in the full paper. These results could offer better understanding of the shielding effectiveness and are helpful in determining optimal shielding wire configuration under specific HVDC transmission lines.

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