Calculation of Electric/Magnetic field under Power Transmission Line with Periodic Analysis, Dip Effect and Method of Image

JaeJoong Lee[1], Young-Seek Chung[2], and Hyun-Kyo Jung[3], *Senior, IEEE*

[1] Company Auxiliary Research Institute, Powernix Co.Ltd., Daejeon 34025, Korea, ljj@powernix.kr
[2]Department of Electronics Convergence Engineering, Kwangwoon University, Seoul 139-701, Korea, yschung@kw.ac.kr
[3]Department and Computer Engineering, Seoul National University, Seoul 151742, Korea, hkjung@snu.ac.kr

In this paper, the electric field and the magnetic field generated under the extremely low frequency (ELF) and high voltage power transmission line are calculated. The transmission line existing between the actual transmission towers is sagged due to the weight of the transmission line and the result is different from the result of the ideal straight line Also, when calculating the high-voltage transmission line, the image effect occurs due to the earth ground, and each grounded transmission tower made of a conductor is present on both sides, which affects the actual interpretation. The electric field and the magnetic field were calculated considering all of these effects, and the results were verified compared with the actual measured results. The moment method (MoM) and periodic boundary conditions were applied for the calculation of the two fields. The EMDEX II from Narda STS was used to measure these two fields in the area without any structures.

***Index Terms*— Dip effect, Electric field, Magnetic field, Method of moment, Numerical analysis, Periodic boundary condition, Power transmission**

I. Introduction

Double-circuit high voltage AC (HVAC) transmission lines is widely used to transfer the power from the power plant to the city. As the higher voltage is used, the higher the power transmission efficiency, the higher the voltage used in the transmission tower. In 1965, the first 735kV ultra high voltage transmission was made in Canada. In 2002, the first 765kV vertical array three phase double circuit transmission system in Asia was commercialized in Korea through the KEPCO [1]. As the transmission voltage gradually increases, the magnitude of the electric field and the magnetic field generated in the vicinity becomes larger. The quantitative interpretation of the electric field and the magnetic field is becoming more and more important because these fields can affect objects or humans in the environment [2][3].

II. Fields Calculation

A. Formulation

Since we deal with very low frequency problems, we use the basic potential equation from Coulomb's law as the governing equation in calculating the electric field. Here, we take the inner product on both sides and apply the method of moment to calculate the unknown source, so that the following matrix equation can be made.

$$\left\langle V(\mathbf{r}), g_m(\mathbf{r}) \right\rangle = \left\langle \frac{1}{4\pi\varepsilon_0} \int_{-W/2}^{W/2} \frac{\lambda(\mathbf{r}')}{R} dl', g_m(\mathbf{r}) \right\rangle \qquad (1)$$

The left hand side of the equation (1) is called voltage vector size of *N* by one and the right hand side can be divided into two matrices by applying a basis function to the charge density. The matrix including the integral equation excluding the unknown matrix becomes the potential coefficient matrix size of *N* by *N*. $g_m(\mathbf{r})$ is *m*-th basis function and *R* is distance from the source to observation point.

In the case of magnetic fields, the transmission line is approximated by the catenary equation, and the magnetic field is calculated by integrating it along this catenary equation. At this time, the three-dimensional Biot-Savart's law is the governing equations of this system. The matrix equation of the electric field is as follows.

$$[P]\{\lambda\} = \{V\} \qquad (2)$$

And the governing equations for the electric field and the magnetic field are as follows.

$$\mathbf{E}(\mathbf{r}) = \frac{1}{4\pi\varepsilon_0} \int_{-W/2}^{W/2} \frac{\lambda(\mathbf{r}')}{R^2} \hat{R} dl', \quad \mathbf{B}(\mathbf{r}) = \frac{\mu_0}{4\pi} \int_l \frac{\mathbf{I} dl \times \hat{\mathbf{r}}}{|\mathbf{R}(l)|^2} \qquad (3)$$

B. Ground Effect

The transmission lines that we calculate are on the earth ground and the image effects are generated. In this paper, the effect of ground is assumed to be PEC and applied to the electric field problem, and the image current due to the image effect is calculated using the complex image [4][5].

The matrix equation of the electric field due to earth effect is expanded as follows.

$$\begin{bmatrix} [P_{rr}] & [P_{ri}] \\ [P_{ir}] & [P_{ii}] \end{bmatrix} \begin{bmatrix} \{\lambda_r\} \\ \{\lambda_i\} \end{bmatrix} = \begin{bmatrix} \{V_r\} \\ \{V_i\} \end{bmatrix} \qquad (4)$$

λ_r is the line charge density of real transmission line and λ_i is the line charge density of image line which is negatively equal to the real line charge density. Applying this boundary condition, the size of the matrix equation could be reduced from *2N* by *2N* to *N* by *N*.

The image current for calculating the magnetic field flows opposite to the actual current, and if the line source is located at the height y, the position of the image current below the ground is expressed by the following equation.

$$y_{ic} = y + \delta(1-j) \qquad (5)$$

where δ is the skin depth of the earth.

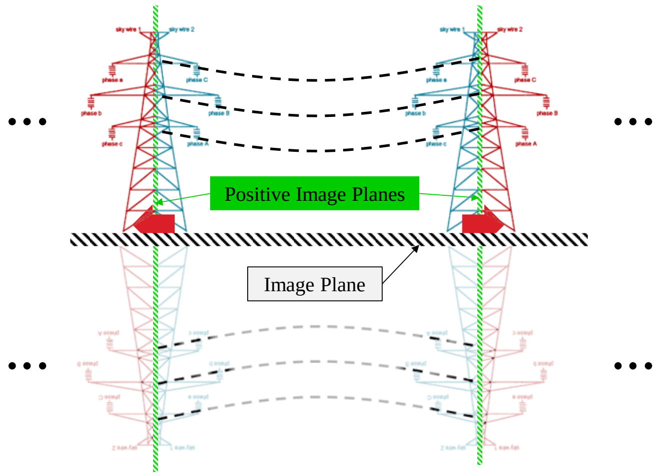

Fig. 1. Infinite arrangement of unit structure and its image effects.

C. *Periodic Structure*

The actual transmission line is located at a considerable distance from the power plant to the city. However, unlike the characteristics of electromagnetic waves that propagate through space, the effect of nearby lines is greatly reduced by distance in this problem, which is transmitted at 60 Hz. Therefore, we approach the problem by assuming that the unit structure of the place to be analyzed is infinitely repeated in both sides. The resulting matrix equation is infinite in size, but if we apply both sides of a unit structure to a positive image plane and apply a boundary condition, the size of the equation can be reduced to N by N again.

III. Result and Measurement

Measurements were made on three phase double circuit transmission lines with a height of 108 m in both transmission towers. The electric field and the magnetic field were measured at 1 m above ground using EMDEX II. The source voltage of the electric field is constant at 765kV and the source current of the magnetic field was used for the calculation using the current provided by the nearby substation at the time of measurement. At that time, the current changed from 1362A to 1438A, and the change was assumed to be linear. The results of the electric and magnetic fields compared to the simulation results are shown in Figure 2 and Figure 3 and plotted perpendicular to the x-axis in Figure 1.

IV. Conclusion

Extremely high voltage and low frequency electric fields / magnetic fields generated by transmission lines are more problematic as the transmission voltage increases, especially when passing through urban areas, nearby schools, and facilities. Accurate predictions of the electric field / magnetic field generated by these facilities are therefore an important indicator when resolving disputes or constructing other transmission facilities. In this paper, the electric field and the magnetic field generated under the transmission line were calculated and compared with the actual measurement results, the reliability was secured. Also, since the mathematical expression used in the calculation is a formula for interpreting the three-dimensional space, the electric field and the magnetic field can be accurately predicted for an arbitrary space on the three-dimensional space. And by analyzing only one periodic structure using appropriate boundary condition, it is possible to analyze the structure which exists infinitely. The novelty of this paper will be explained in detail later in the full paper.

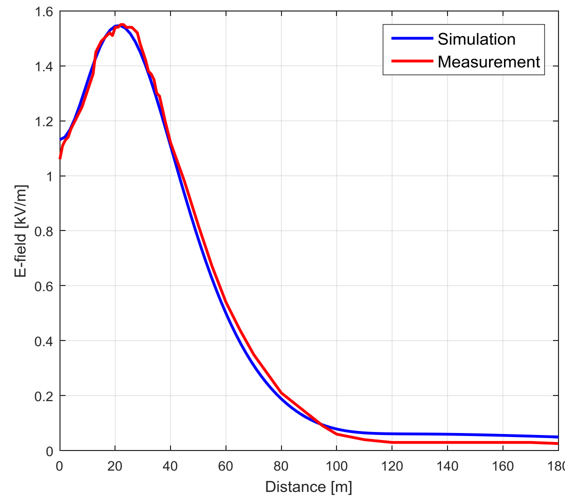

Fig. 2. The simulation versus measurement result of electric field.

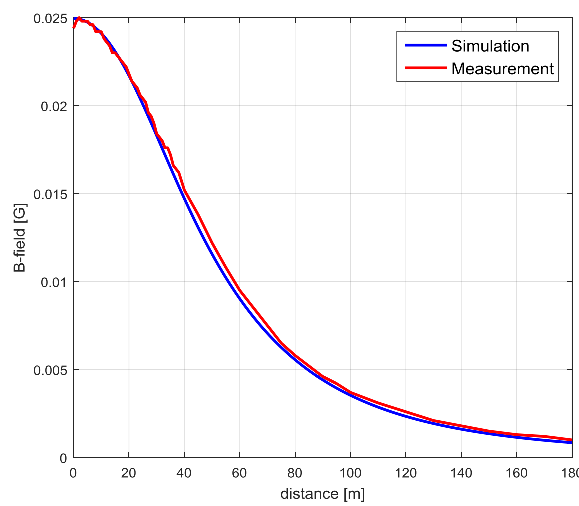

Fig. 3. The simulation versus measurement result of magnetic field.

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