Analysis phase sequence of group conductors for 500 kV extra high voltage affecting to magnetic field using Finite element method

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***Abstract*—** This paper presents a partial differential equation mathematical model for analysis and simulation of phase sequence conductors affecting to magnetic field. An extra high voltage transmission line of 500kV of four circuits with four bundle conductors is considered. Finite Element method is the technique for solving the numerical results. This paper focused on analyzes a magnetic field at the height of 1-10 meters under group conductors and compare with ICNIRP standard. Moreover, analyze around the group conductors in the area of 15-55 meters above ground. The results showed that considering at 1 meter above ground, the minimum magnetic field is not over than stated in the ICNIRP standard.

Keywords- Finite Element Method, Magnetic Fields, Transmission System, Phase Sequence

I. INTRODUCTION

Power transmission system in Thailand is divided into four levels of voltage, which are low voltage, medium voltage, high voltage and extra high voltage. Each voltage level has different values of flowing current and tower structures. For Thailand's extra high voltage (EHV) 500 kV is the only one. Three types of EHV transmission tower have been designed for single circuit, double circuits and four circuits.The 500 kV line with structure of four bundles and four circuits is considered in this paper. The simulation technique was achieved by Finite Element Method (FEM) via MATLAB program for solving an equation in form partial differential equation.

The FEM is one of the most popular numerical methods for computer simulation [1]. The key advantages of FEM over other numerical methods in engineering applications is its ability to handle nonlinear, time-dependent and circular geometry problems. Therefore, this method is suitable for solving the problem involving magnetic field.

This paper analyze phase sequence schemes are divided into 8 cases affecting to magnetic fields by considering under group of conductors comparing to the ICNIRP standard at height of 1-10 meters above ground. Moreover, analyzed around phase sequence conductors with height of 15-55 meters cover the group conductors. All of case studies scheme are compared and showed in Table I and Table II.

TABLE I. STUDY CASES1-4 OF PHASE CONDUCTORS SEQUENCE SCHEME

Case study							
1		2		3		4	
A1	A2	A1	A2	A1	A2	A1	A2
B1	B2	B1	B2	B1	B2	B1	B2
C1	C2	C1	C2	C1	C2	C1	C2
A3	A4	A3	B4	A3	C4	A3	A4
B3	B4	B3	C4	B3	A4	B3	C4
C3	C4	C3	A4	C3	B4	C3	B4

TABLE II. STUDY CASES5-8 OF PHASE CONDUCTORS SEQUENCE SCHEME

Case study							
5		6		7		8	
A1	A2	A1	A2	A1	B2	A1	C2
B1	B2	B1	B2	B1	C2	B1	A2
C1	C2	C1	C2	C1	A2	C1	B2
A3	B4	A3	C4	A3	C4	A3	A4
B3	A4	B3	B4	B3	A4	B3	C4
C3	C4	C3	A4	C3	B4	C3	B4

II. MODELLING OF MAGNETIC FIELDS INVOLVING POWER TRANSMISSION LINE

A Mathematical Model of Magnetic Fields (H) radiating around transmission line is usually expressed in the standard two dimensions wave equation (Helmholtz's equation) as shown in Eq.(1) [11]:

$$\nabla^2 \mathbf{H} - (\frac{1}{v^2})(\frac{\partial^2 \mathbf{H}}{\partial t^2}) - \mu\sigma(\frac{\partial \mathbf{H}}{\partial t}) = 0 \quad (1)$$

This paper has considered the system governing by using time harmonics mode and representing the magnetic fields in complex form therefore,

$$\frac{\partial \mathbf{H}}{\partial t} \approx j\omega H \quad \text{and} \quad \frac{\partial^2 \mathbf{H}}{\partial t^2} \approx -\omega^2 H$$

where ω is singular frequency.

From Eq.(1), by substituting the complex magnetic fields, Eq.(1) can be transformed to an alternative form as follows [4 -6].

$$\frac{\partial^2 H}{\partial x^2}+\frac{\partial^2 H}{\partial y^2}+(\mu\varepsilon\omega^2 - j\mu\sigma\omega)H=0 \qquad (2)$$

III. POWER TRANSMISSION LINE SYSTEM

The power transmission system is considered as a system that having flow current in normal conditions. The tower structure also varies according to its corresponding the circuit's quantities. In this paper, the characteristics of 500 kV four circuit transmission lines, with four bundled conductors were taken into account and considered when the conductors were placed only in a vertical position. Its designed distance between the same phase conductors is 0.475 m. and the distance between two difference phase conductors, line conductors and overhead ground conductors, is illustrated in Fig. 1. With the structure, the simulation results were based on static mode.

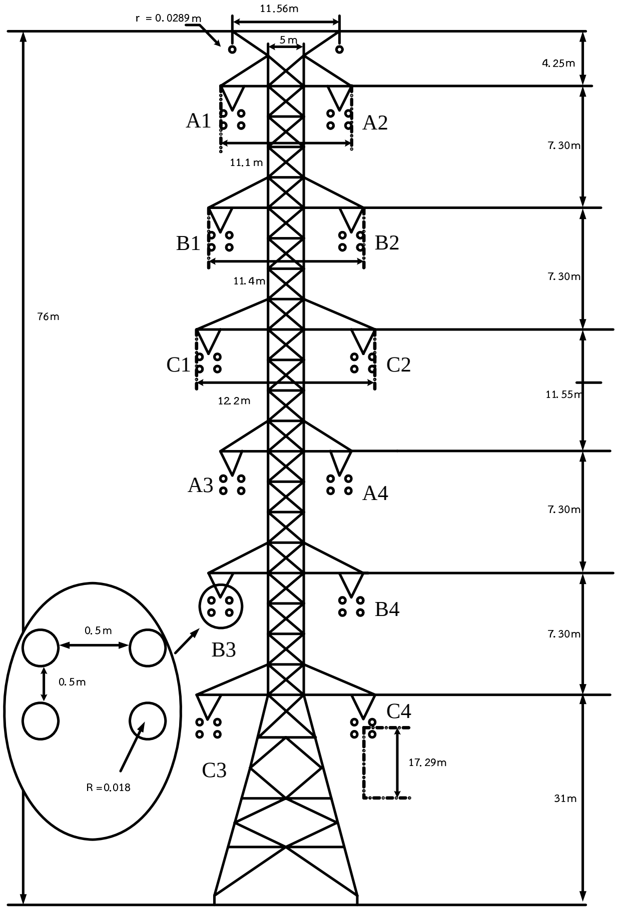


Figure 1. 500-kV four circuits, four bundled conductors power transmission line structure

IV. FINITE ELEMENT METHOD

A. Decretization

Finite Element Method (FEM) is one of the numerical techniques used for calculating approximately solutions of differential equations by divided the problem boundary into different elements and create a certain equation of each element based on its relative differential equation. The working region for modeling magnetic fields using FEM is defined by Fig. 2, which are decretized by using linear triangular elements

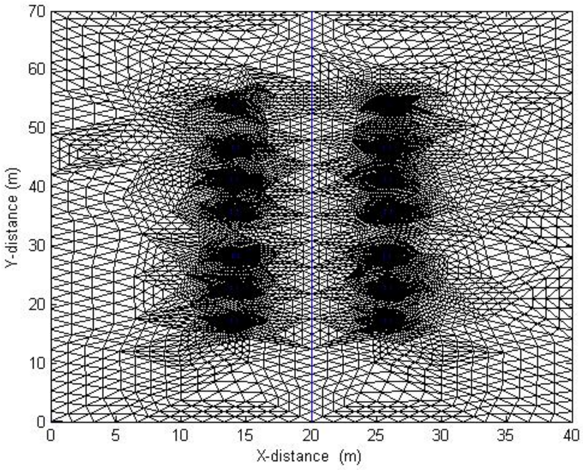


Figure 2. Discretization of 500-kV four circuits, four bundles

B. Finite Element Formulation

An equation governing for each element is derived from the Maxwell's equations directly by using Galerkin approach, which it is applied the particular weighted residual method for which the weighting functions are the same as the shape functions. According to the method, the electric field is expressed as follows.

$$H(x,y)=H_iN_i+H_jN_j+H_kN_k \qquad (3)$$

where N_n , $n = i, j ,k$ is the element shape function and the H_n , $n = i, j ,k$ is the approximation of the magnetic field at each node (i, j ,k) of the elements, which is

$$N_n=\frac{a_n+b_nx+c_ny}{2\Delta_e}$$

where Δ_e is the area of the triangular element and,

$$a_i = x_jy_k - x_ky_j\,, \quad b_i = y_j - y_k\,, \quad c_i = x_k - x_j$$
$$a_j = x_ky_i - x_iy_k\,, \quad b_j = y_k - y_i\,, \quad c_j = x_i - x_k$$
$$a_k = x_iy_j - x_jy_i\,, \quad b_k = y_i - y_j\,, \quad c_k = x_j - x_i\,.$$

Method of weighted residue with Galerkin approach is then applied to the differential equation, Eq.(2), where the integrations are performed over the element domain Ω [2-3,7,9-10].

$$\int_{\Omega} N_n \left(\frac{\partial}{\partial x}\left(\frac{1}{\mu}\frac{\partial E}{\partial x} \right) + \frac{\partial}{\partial y}\left(\frac{1}{\mu}\frac{\partial E}{\partial y} \right) \right) d\Omega$$

$$- \int_{\Omega} N_n \left(j\omega\sigma - \omega^2 \varepsilon \right) E \, d\Omega = 0$$

, in the compact matrix form is

$$[M + K]\{E\} = 0 \qquad (4)$$

$$M = \left(j\omega\sigma - \omega^2 \varepsilon \right) \int_{\Omega} N_n N_m d\Omega$$

$$= \frac{\left(j\omega\sigma - \omega^2 \varepsilon \right) \Delta_e}{12} \begin{bmatrix} 2 & 1 & 1 \\ 1 & 2 & 1 \\ 1 & 1 & 2 \end{bmatrix}$$

$$K = \nu \int_{\Omega} \left(\frac{\partial N_n}{\partial x}\frac{\partial N_m}{\partial x} + \frac{\partial N_n}{\partial y}\frac{\partial N_m}{\partial y} \right) d\Omega$$

$$= \frac{\nu}{4\Delta_e} \begin{bmatrix} b_i b_i + c_i c_i & b_i b_j + c_i c_j & b_i b_k + c_i c_k \\ & b_j b_j + c_j c_j & b_j b_k + c_j c_k \\ Sym & & b_k b_k + c_k c_k \end{bmatrix}$$

Where; ν is the material reluctivity ($\nu = 1/\mu$).

For one element with containing 3 nodes, the expression of the FEM approximation is a 3×3 matrix. With the account of all elements in the system of *n* nodes, the system equation is sizable as the *n*×*n* matrix.

V. BOUNDARY CONDITIONS AND SIMULATION PARAMETERS

The basic principle of magnetic field calculation for finding the values of magnetic fields around transmission conductors subjected to phase sequence conductors were employed in this paper [8]. In this work, All Aluminum Conductor (AAC) was used for testing and values of magnetic fields around the conductors for all of study cases followed in table III. and IV

TABLE IIII. MAGNETIC FIELD AT OUTER CONDUCTORS OF CASES 1-4

CASES	1	2	3	4
A1	568.2/-1.1	569.9/-1.1	569.1/-0.9	568.2/-1.0
B1	551.7/-64.3	551.2/-64.5	552.8/-64.5	552.7/-64.4
C1	534.5/-121.5	533.8/-121.6	534.7/-121.6	533.8/-121.6
A2	568.2/-1.1	572.1/-1.1	570.5/-0.8	568.2/-0.9
B2	551.7/-64.3	547.8/-64.9	554.6/-65.0	554.2/-64.5
C2	534.5/-121.5	529.9/-119.9	518.8/-121.1	530.1/-121.8
A3	564.8/-1.5	556.5/-1.3	558.8/-2.1	564.9/-1.7
B3	550.6/-64.4	555.8/-63.2	543.7/-63.3	554.1/-64.0
C3	530.4/-121.0	536.5/-121.6	538.0/-120.8	536.3/-120.7
A4	564.8/-1.5	563.3/-60.7	570.9/-121.0	564.6/0.6
B4	550.6/-64.4	549.0/-124.0	553.1/-4.0	549.2/-115.7
C4	530.4/-121.0	532.6/-0.8	533.2/-61.1	533.2/-59.1

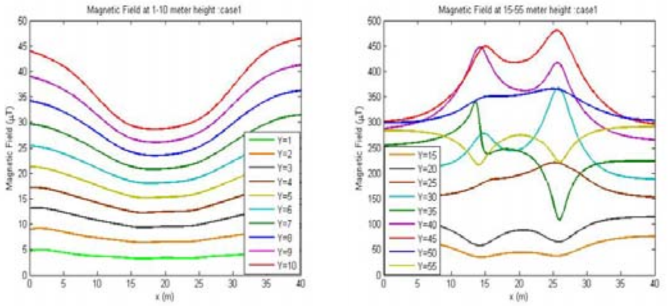
TABLEIV. MAGNETIC FIELD AT OUTER CONDUCTORS OF CASES 5-8

CASES	5	6	7	8
A1	569.1/-1.1	569.9/-1.0	560.8/-0.7	560.0/-0.7
B1	551.1/-64.4	551.9/-64.5	558.0/-63.3	551.8/-63.3
C1	534.5/-121.6	534.7/-121.6	540.8/-122.2	541.6/-122.2
A2	570.6/-1.2	572.1/-0.8	566.8/-61.6	564.1/-61.6
B2	547.5/-64.6	552.4/-65.2	541.7/-124.0	553.7/-124.0
C2	534.3/-120.2	518.8/-120.6	537.7/0.3	526.7/0.3
A3	558.5/-1.2	556.8/-2.0	558.9/-2.2	565.0/-2.2
B3	556.3/-63.9	549.7/-62.9	542.8/-63.5	544.2/-63.5
C3	530.5/-121.3	538.2/-121.5	537.1/-120.6	534.6/-120.6
A4	563.4/-58.6	570.9/-118.9	560.7/-119.9	579.1/-119.9
B4	553.2/-4.18	550.3/-56.1	559.5/-3.9	543.1/-3.9
C4	530.4/-119.0	532.7/-1.2	531.8/-61.5	533.1/-61.5

Characteristics of AAC in this are relative permittivity (ε_r) = 3.5, conductivity (σ) = 0.8x10^7 and relative permeability (μ_r) = 1.00091.

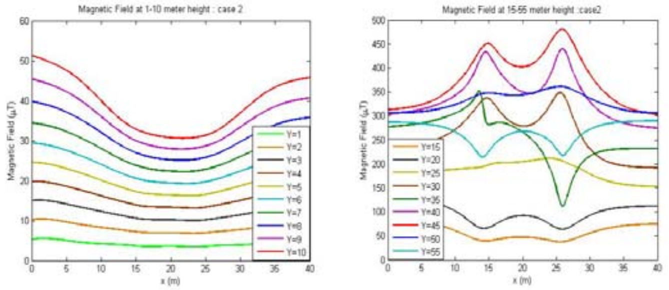
VI. SIMULATION RESULT

The FEM-based algorithm for analyzing the effects of magnetic fields was developed and coded in MATLAB by compared the amount of magnetic field dispersion at the ground and around conductors. The magnetic field simulation for eight study cases results divided two areas are as follows;



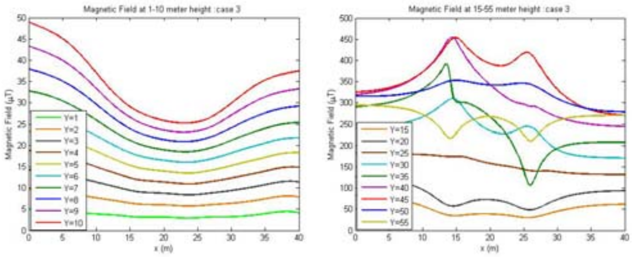
a) under group conductors b) around group conductors

Figure 3. Magnetic field distribution of case 1



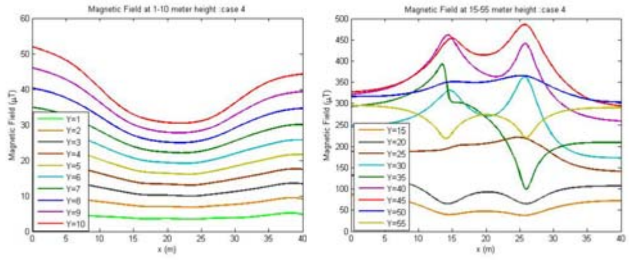
a) under group conductors b) around group conductors

Figure 4. Magnetic field distribution of case 2



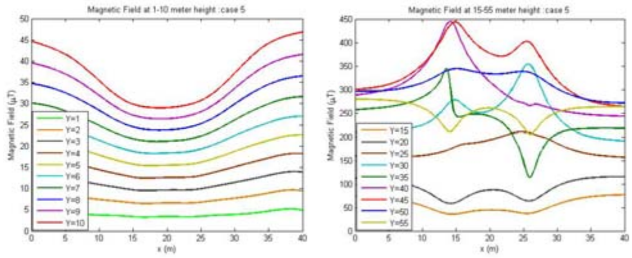
a) under group conductors b) around group conductors

Figure 5. Magnetic field distribution of case 3



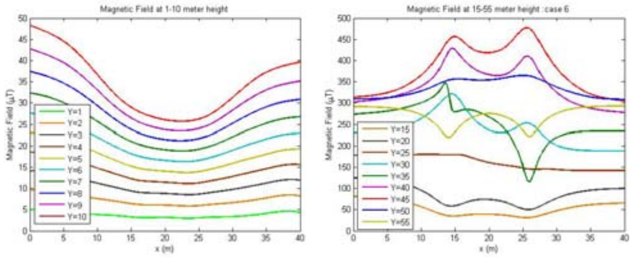
a) under group conductors b) around group conductors

Figure 6. Magnetic field distribution of case 4



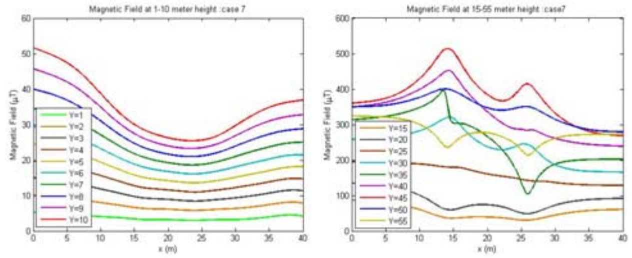
a) under group conductors b) around group conductors

Figure 7. Magnetic field distribution of case 5



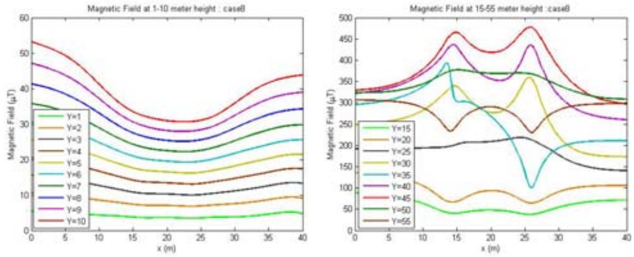
a) under group conductors b) around group conductors

Figure 8. Magnetic field distribution of case 6



a) under group conductors b) around group conductors

Figure 9. Magnetic field distribution of case 7



a) under group conductors b) around group conductors

Figure 10. Magnetic field distribution of case 8

Fig. 5 – 10 showed the magnetic field distribution; a) under group conductors and b) around group conductors all of study cases respectively. The figures indicated that the magnetic field distribution were difference depended on phase sequence scheme. The magnetic fields under group conductors were similar all of study cases and increasing when the distance near the group conductors. Beside of cases 3, 4, 6, 7 and 8 are similarly pattern. However, beside of cases 1 and 5 are the similar pattern. On the other hand, it is considered around group conductors, that the magnetic field distribution within sequence phase area are both of additive and subtractive characteristic. Analysis for this area is shown in Table V.

TABLE V. MAGNITUDE OF MAGNETIC FIELD (μT) ALL OF STUDY CASES AT BOTH OF UNDER AND AROUND PHASE CONDUCTORS

height	Cases							
(m)	1	2	3	4	5	6	7	8
1	3.99	4.26	3.74	4.24	4.02	3.80	3.83	4.28
2	7.71	8.24	7.22	8.20	7.77	7.32	7.38	8.27
4	14.78	15.82	13.79	15.73	14.92	13.98	14.09	15.87
6	21.83	23.36	20.33	23.23	22.04	20.60	20.76	23.43
8	29.03	31.06	27.03	30.89	29.31	27.40	27.61	31.15
10	36.35	38.88	33.84	38.66	36.68	34.33	34.57	38.98
15	55.48	59.28	51.60	58.93	55.91	52.46	52.78	59.40
20	91.57	97.42	84.15	97.08	91.88	85.76	86.17	97.75
25	177.26	186.22	158.20	187.07	176.02	161.64	161.97	187.97
30	240.09	261.89	232.16	258.69	242.71	236.69	237.67	261.79
35	235.50	253.02	253.89	254.55	235.56	252.65	258.24	256.09
40	338.22	341.84	321.96	351.47	303.05	340.91	327.31	345.89
45	373.24	376.84	358.27	381.24	342.97	379.38	376.29	383.97
50	329.37	330.00	322.06	333.66	311.10	334.34	342.21	344.78
55	268.28	266.17	262.24	270.49	253.68	270.92	276.13	282.74

A comparative all of cases for defined the lowest of magnetic field for both of under group conductors and around conductors as seen in figure 11 and figure 12 respectively.

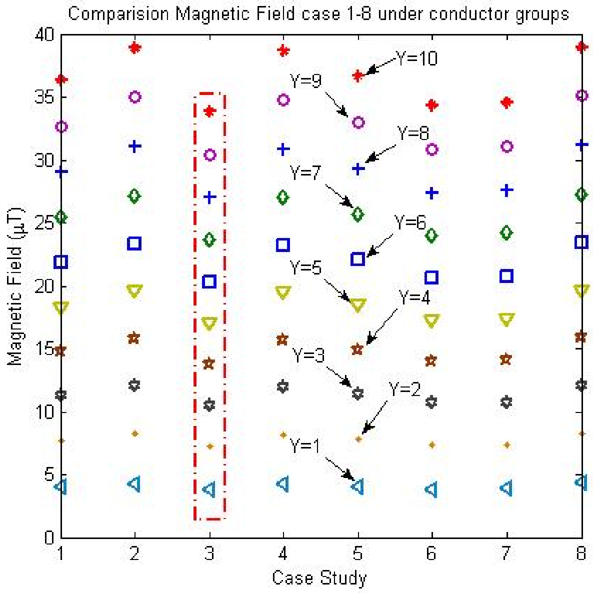


Figure 11. Magnetic field distribution under group of conductors (height of 1-10 meters) all of study case

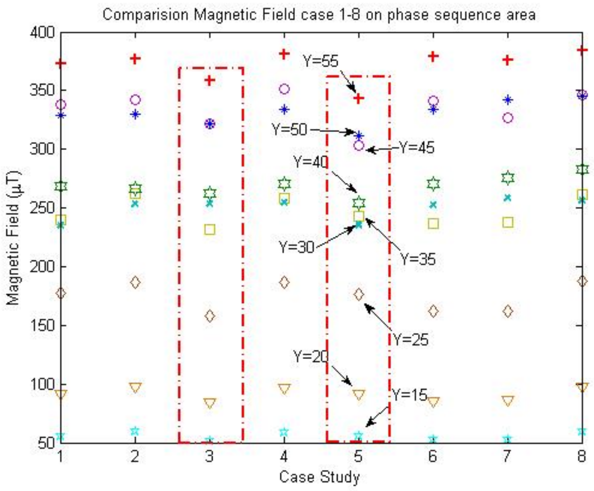


Figure 12. Magnetic field distribution around group of conductors (height of 15-55 meters) all of study case

Fig. 11 and Fig. 12 have shown that the magnetic field distribution considered under group of conductors and around group of conductors respectively. It is found that, the magnetic field in the third case at the 1 m above ground is the lowest value of 3.74 µT and it is not over than 100 µT which it is defined in ICNIRP standard. And around the conductors (30 m) for the same case gave the lowest magnetic field with its value is 232.16 µT.

VII. CONCLUSIONS

This paper proposed an analysis of the magnetic field distribution of 500 kV in the structure of four circuits and four bundles transmission line system. The finite element method for analyzing the effects of magnetic fields was developed and determined the values of magnetic field at the ground and around conductors. The results indicated that the magnetic field for both of under group conductors and around group conductors in third study case has the lowest values that are 3.74 µT and 232.16 µT respectively. Moreover, the result also shows that the magnetic field at 1 meter above ground for all of phase sequence study cases are not over than as stated in the ICNIRP standard.

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