Comparative study for the installation of overhead ground wire affecting the electric field of high voltage transmission lines

A. Isaramongkolrak, P. Kerdpradub, and K. Wungwattana

Abstract— **This paper presents a study comparing the distance and height of overhead ground wire that affects the distribution of the electric field of high voltage transmission towers, single circuit 500 kV voltage level, type 4 bundle is the highest of Thailand. The analysis focuses on the electric field distribution from the transmission line. When changing the overhead ground wire position to installation. By considering suitable location that makes the electrical field distribution around the ground were minimal. Consider for a height of 1 meter from the ground and to compare the electric field with standard ICNIRP This paper has been living a mathematical model of the electric field in the form of differential equations and, based on simulation results with Finite Element Method. It is being designed within the sliding wire overhead. A long scroll both horizontally and vertically. From the simulation results, it was found that the area overhead ground wire installed at a height of 50.484 meters from the ground and the horizontal distance from the center pillar on each side of 10.65 meters, the electric field is minimal which equals 7.5907 kV / m.**

Index Terms—**Electric Field, Finite Element Method, Over-head Ground wire, Transmission system**

I. Introduction

An overhead ground wire is one of key components in electric power transmission systems. It is a small metal conductor run between the tops of overhead power transmission towers. At each tower, the overhead ground wire is connected to ground through the tower metal frame. It exhibits the protection of high voltage conductors from lightning strokes. Beside the lightning protection, the overhead ground wire also influences electric field distribution around the power transmission lines caused by high voltage conductors. Finite Element Method is one of the most popular numerical methods used for computer simulation. The key advantage of this method over other numerical methods in engineering applications is the ability to handle nonlinear, time-dependent and circular geometry problems. Therefore, this method is suitable for solving the problem involving electric field effects around the transmission line caused by circular cross-section of high voltage conductor.

This paper has shown that a line conductor within an angle of 30 degrees with overhead ground wire from the Y to help protect conductors from lightning. However, for the electric field occur. Also be studied Simulation results and analysis in comparison with overhead ground wire installed in the electric field occur. In this paper study will compare the distance and height of a overhead ground wire makes the electric field are the minimum and less than the International Commission on Non-Ionizing Radiation Protection (ICNIRP) standard configured not exceeding 10 kV / m.

A. Isaramongkolrak is with the Electrical Power Engineering Department, Mahanakorn University of Technology, 140 Cheumsampan Road Kratumrai, Nongchok Bangkok 10530 Thailand (corresponding author to provide phone: 02-988-3650 ext 3304 ; fax: 02-988-4040; e-mail: arnon@ mut.ac.th).

P. Kerdpradub was with Mahanakorn University of Techonology. Bangkok, 10530 Thailand. He is now with the Department of Electrical Power Engineeing (e-mail: pornpus.k@srtet.co.th).

K. Wungwattana was with Mahanakorn University of Techonology, Bangkok, 10530 Thailand. He is now with the Department of Electrical Power Engineeing (e-mail: korakott08@gmail.com).

II. Transmission System

A. *500kV transmission structure*

High Voltage transmission towers structure of 500 kV single circuit transmission power in the form of a bundle. The transmission of data needed grounding conductors and overhead can be shown in Tables I and II, respectively

TABLE I
SPECIFICATION OF LINE CONDUCTOR OF 500KV SYSTEM

Size	795 MCM ACSR/GA "condor"
Size of diameter	27.73 mm.
Number of conductors	4 conductors per bundle
Maximum Sag.	13.98 m.

TABLE II
SPECIFICATION OF OVERHEAD GROUND WIRE OF 500KV SYSTEM

Size	3/8 "(EHS) Galvanized steel
Size of diameter	9.144 mm.
Number of conductors	1 conductors
Maximum Sag.	10.86 m.

. Size and structure, including bundle spacing. The conductor of the power system voltage 500 kV, with the size and details as Figure 1.

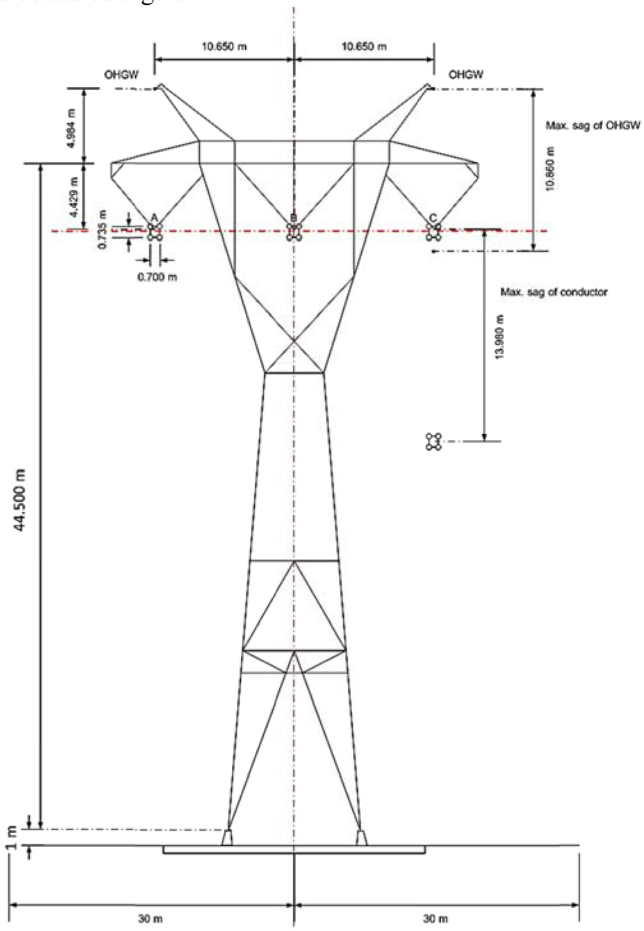

Fig. 1 Single circuit and 4 bundles of 500kV transmission System

B. Modeling of Electric Fields involving Electric Power Transmission Lines

A mathematical model of electric fields (**E**) radiating around a transmission line is usually expressed in the wave equation (Helmholtz's equation) as equation (1) [4], [5] derived from Faraday's law.

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

Where ε is the dielectric permittivity of media, μ and σ are the magnetic permeability and conductivity of conductors, respectively.

This paper has considered the system governing by using the time harmonics mode and representing the electric field in complex form, $\mathbf{E}=Ee^{j\omega t}$ [6] therefore,

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

Where ω is the angular frequency.

From equation (1), by substituting the complex electric field, equation (1) can be transformed to an alternative form as follows.

$$\nabla^2 E - j\omega\sigma\mu E + \omega^2\varepsilon\mu E = 0$$

When considering the problem of 2D in Cartesian coordinate (x,y), hence

$$\frac{\partial}{\partial x}\left(\frac{1}{\mu}\frac{\partial E}{\partial x}\right) + \frac{\partial}{\partial y}\left(\frac{1}{\mu}\frac{\partial E}{\partial y}\right) - \left(j\omega\sigma - \omega^2\varepsilon\right)E = 0 \quad (2)$$

Analytically, there is no simple exact solution of the above equation. Therefore, in this paper the finite element method is chosen to be a potential tool for finding approximate electric field solutions for the PDE described in equation (2) [7]-[9]

C. Finite Element Formulation

An equation governing each element is derived from the Maxwell's equations directly by using Galerkin approach, which is the particular weighted residual method for which the weighting functions are the same as the shape functions [11], [12]. According to the method, the electric field is expressed as

$$E(x,y) = E_i N_i + E_j N_j + E_k N_k \quad (3)$$

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

$$N_n = \frac{a_n + b_n x + c_n y}{2\Delta_e}$$

where Δ_e is the area of the triangular element and,

$$a_i = x_j y_k - x_k y_j, \quad b_i = y_j - y_k, \quad c_i = x_k - x_j$$
$$a_j = x_k y_i - x_i y_k, \quad b_j = y_k - y_i, \quad c_j = x_i - x_k$$
$$a_k = x_i y_j - x_j y_i, \quad b_k = y_i - y_j, \quad c_k = x_j - x_i.$$

The method of the weighted residual with Galerkin approach is then applied to the differential equation, refer to (2), where the integrations are performed over the element domain Ω.

$$\int_{\Omega} N_n\left(\frac{\partial}{\partial x}\left(\frac{1}{\mu}\frac{\partial E}{\partial x}\right)+\frac{\partial}{\partial y}\left(\frac{1}{\mu}\frac{\partial E}{\partial y}\right)\right)d\Omega - \int_{\Omega} N_n\left(j\omega\sigma-\omega^2\varepsilon\right)E\,d\Omega = 0$$

,or in the compact matrix form

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

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

$$K=\frac{1}{\mu}\int_{\Omega}\left(\frac{\partial N_n}{\partial x}\frac{\partial N_m}{\partial x}+\frac{\partial N_n}{\partial y}\frac{\partial N_m}{\partial y}\right)d\Omega = \frac{1}{4\mu\Delta_e}\begin{bmatrix}b_ib_i+c_ic_i & b_ib_j+c_ic_j & b_ib_k+c_ic_k\\ b_ib_j+c_ic_j & b_jb_j+c_jc_j & b_jb_k+c_jc_k\\ b_ib_k+c_ic_k & b_jb_k+c_jc_k & b_kb_k+c_kc_k\end{bmatrix}$$

For one element 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 an n×n matrix.

D. Boundary Conditions and Simulation Parameters

The boundary conditions applied here are zero electric fields at the ground. For the boundary conditions at outer perimeters of 12-single circuit power lines has applied with the research of [10], [13], which boundary conditions of electric field depends on the charge density. Each conductors per phase are calculated the charge density from maxwell's equations and assumed to be a balanced load condition. For slice conditions, every step to slice the overhead ground wire just to reference the angle of protective from lightning not less than 30 degree and not over 49 degree. For charge density calculation are follow equation (5)

$$[Q]=[P]^{-1}[V] \quad (5)$$

Where, Q is electric charge (Culomb) P is Maxwell's potential coefficient and V is system voltage (kV) and the electric charge from three phase power conductor can calculated in form of the matrix that is the effect of linkage the form of real part and imaginary part, Hence,

$$\begin{bmatrix}Q_{ra}\\Q_{rb}\\ \cdot\\ \cdot\\ \cdot\\Q_{rm}\end{bmatrix}=\begin{bmatrix}P_{aa}&P_{ab}&\cdot&\cdot&\cdot&P_{am}\\P_{ba}&P_{bb}&\cdot&\cdot&\cdot&P_{bm}\\ \cdot&\cdot&\cdot&\cdot&\cdot&\cdot\\ \cdot&\cdot&\cdot&\cdot&\cdot&\cdot\\ \cdot&\cdot&\cdot&\cdot&\cdot&\cdot\\P_{ma}&P_{mb}&\cdot&\cdot&\cdot&P_{mm}\end{bmatrix}^{-1}\begin{bmatrix}V_{ra}\\V_{rb}\\ \cdot\\ \cdot\\ \cdot\\V_{rm}\end{bmatrix}$$

$$\begin{bmatrix}Q_{ia}\\Q_{ib}\\ \cdot\\ \cdot\\ \cdot\\Q_{im}\end{bmatrix}=\begin{bmatrix}P_{aa}&P_{ab}&\cdot&\cdot&\cdot&P_{am}\\P_{ba}&P_{bb}&\cdot&\cdot&\cdot&P_{bm}\\ \cdot&\cdot&\cdot&\cdot&\cdot&\cdot\\ \cdot&\cdot&\cdot&\cdot&\cdot&\cdot\\ \cdot&\cdot&\cdot&\cdot&\cdot&\cdot\\P_{ma}&P_{mb}&\cdot&\cdot&\cdot&P_{mm}\end{bmatrix}^{-1}\begin{bmatrix}V_{ia}\\V_{ib}\\ \cdot\\ \cdot\\ \cdot\\V_{im}\end{bmatrix}$$

$$P_{aa}=\frac{1}{2\pi\varepsilon_0}\ln\left[\frac{4y_a}{D_{eq}(a)}\right]$$

$$P_{ab}=\frac{1}{2\pi\varepsilon_0}\ln\left[\frac{(x_a-x_b)^2+(y_a+y_b)^2}{(x_a-x_b)^2+(y_a-y_b)^2}\right]^{1/2}$$

Where, Deq is equivalent diameter per phase(m) , D is distance of bundle(m), N is number of bundle, d is diameter of conductor (m) y is vertical distance of conductor per phase(m) and x is horizontal distance of conductor per phase(m). The conductors used for test are Aluminum Conductor Steel Reinforced (ACSR) having the following properties: conductivity (σ) = 0.8×10^{7} S/m, the relative permeability (μ_r) = 300, and the relative permittivity (ε_r) = 3.5. It notes that the permittivity of free space (ε_0) = 8.854×10^{-12} F/m and the permeability of free space (μ_0) = $4\pi\times10^{-7}$ H/m [15].

For the design picture of slice step is follow in figure 2 and the outer parameter that calculation from Maxwell 's equation show that in table III

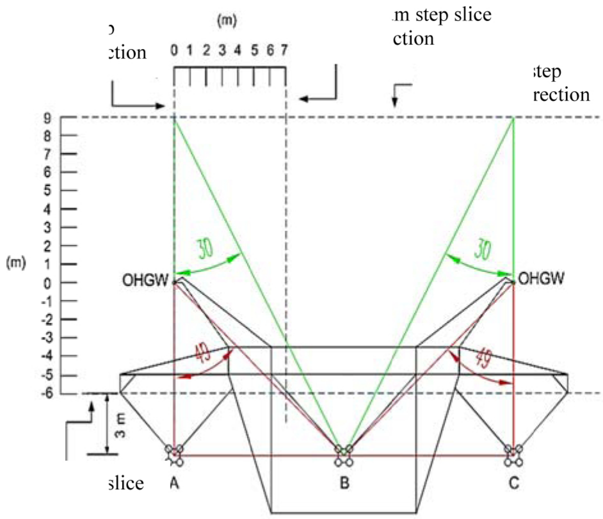

Fig. 2 Step of slice the overhead ground wire in Horizontal and Vertical direction

TABLE III
A MAXIMUM OF ELECTRIC FIELD OF SINGLE CIRCUIT AND FOUR BUNDLE OF 500KV AT MAXIMUM SAG

Phase Conductor	Electric Field (kV/m)
Phase A	317.2732
Phase B	349.9630
Phase C	317.2732
Overhead ground wire 1	3.8966
Overhead ground wire 2	3.8966

III. SIMULATION RESULTS

The simulation results in this paper divides simulation results as follow: By moving the installation location of Over-head ground wire compartment along the Y axis from the normal installation position each 0.5 meter up to 8 meter and a horizontal X axis to shift land lines installed each 0.5 meter causing total case is 28 cases. By simulation results are shown in the form of the numerical of electric field intensity in each case, Follow table IV-X

TABLE IV
AVERAGE ELECTRIC FIELD AT 1 METER HEIGHT AND INSTALLATION INCREASING THE OHGW AT Y=0 -1.5 METER AND STEP SLICE X EACH 0.5 METER

Y axis	OHGW1	OHGW2	Electric Fields (kV/m)			
			Y=0	Y=0.5	Y=1	Y=1.5
x axis	0.0	0.0	**7.591**	7.598	7.615	7.608
	0.5	-0.5	7.596	7.599	7.606	7.611
	1.0	-1.0	7.598	7.603	7.610	7.614
	1.5	-1.5	7.600	7.609	7.615	7.620
	2.0	-2.0	7.608	7.612	7.619	7.627
	2.5	-2.5	7.614	7.617	7.622	7.628
	3.0	-3.0	7.618	7.620	7.627	7.632
	3.5	-3.5	7.621	7.625	7.633	7.634
	4.0	-4.0	7.627	7.631	7.636	7.643
	4.5	-4.5	7.635	7.638	7.643	-
	5.0	-5.0	7.637	-	-	-

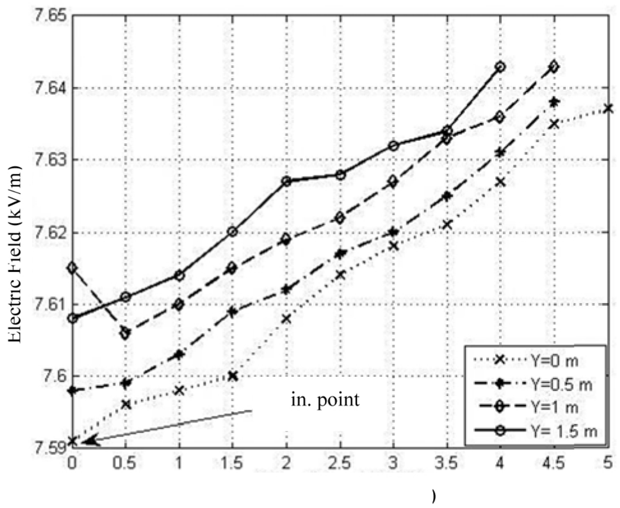

Fig. 3 Electric Field at 0 – 1.5 meter height increasing of Installation of overhead ground

TABLE V
AVERAGE ELECTRIC FIELD AT 1 METER HEIGHT AND INSTALLATION INCREASING THE OHGW AT Y=2 -3 METER AND STEP SLICE X EACH 0.5 METER

Y axis	OHGW1	OHGW2	Electric Fields (kV/m)			
			Y=2	Y=2.5	Y=3	Y=3.5
x axis	0.0	0.0	7.616	7.621	7.626	7.634
	0.5	-0.5	7.615	7.623	7.634	7.633
	1.0	-1.0	7.621	7.624	7.631	7.639
	1.5	-1.5	7.625	7.630	7.636	7.643
	2.0	-2.0	7.630	7.634	7.640	7.665
	2.5	-2.5	7.633	7.641	7.645	7.652

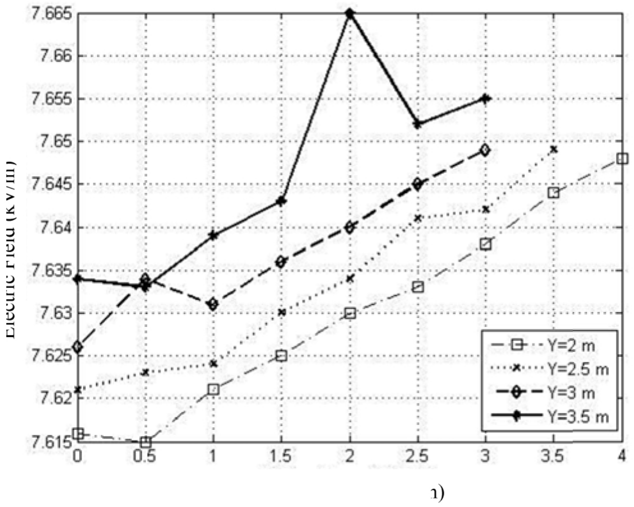

Fig. 4 Electric Field at 2 – 3.5 meter height increasing of Installation of overhead ground

TABLE VI
AVERAGE ELECTRIC FIELD AT 1 METER HEIGHT AND INSTALLATION INCREASING THE OHGW AT Y=4 -5.5 METER AND STEP SLICE X EACH 0.5 METER

Y axis	OHGW1	OHGW2	Electric Fields (kV/m)			
			Y=4	Y=4.5	Y=5	Y=5.5
x axis	0.0	0.0	7.641	7.646	7.653	7.660
	0.5	-0.5	7.643	7.650	7.656	7.662
	1.0	-1.0	7.647	7.651	7.659	7.666
	1.5	-1.5	7.651	7.656	7.662	7.669
	2.0	-2.0	7.654	7.661	7.666	7.675
	2.5	-2.5	7.658	7.665	-	-

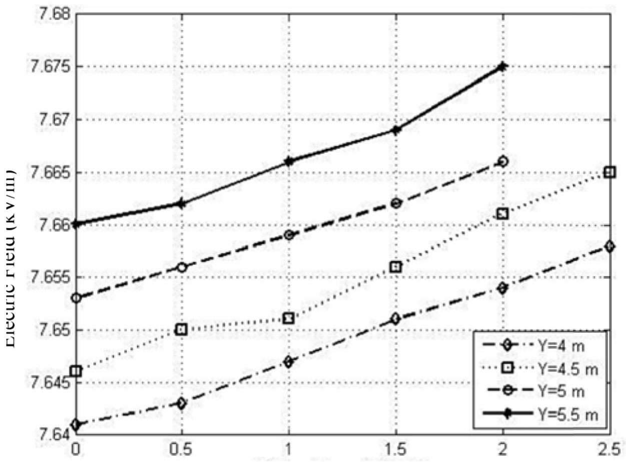

Fig. 5 Electric Field at 4 – 5.5 meter height increasing of Installation of overhead ground

TABLE VII
AVERAGE ELECTRIC FIELD AT 1 METER HEIGHT AND INSTALLATION INCREASING THE OHGW AT Y=6 -8 METER AND STEP SLICE X EACH 0.5 METER

Y axis	OHGW1	OHGW2	Electric Fields (kV/m)			
			Y=6	Y=6.5	Y=7	Y=8
x axis	0.0	0.0	7.641	7.646	7.653	7.660
	0.5	-0.5	7.643	7.650	7.656	7.662
	1.0	-1.0	7.647	7.651	7.659	7.666
	1.5	-1.5	7.651	7.656	7.662	7.669
	2.0	-2.0	7.654	7.661	7.666	7.675
	2.5	-2.5	7.658	7.665	-	-

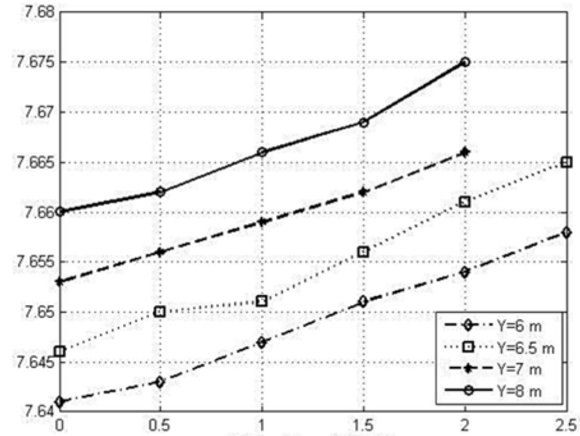

Fig. 6 Electric Field at 6 – 8 meter height increasing of Installation of overhead ground

TABLE VIII
AVERAGE ELECTRIC FIELD AT 1 METER HEIGHT AND INSTALLATION DECREASING THE OHGW AT Y=0.5 -2 METER AND STEP SLICE X EACH 0.5 METER

Y axis	OHGW1	OHGW2	Electric Fields (kV/m)			
			Y=-0.5	Y=-1	Y=-1.5	Y=-2
x axis	1.0	-1.0	7.595	-	-	-
	1.5	-1.5	7.600	7.595	-	-
	2.0	-2.0	7.603	7.600	7.598	-
	2.5	-2.5	7.606	7.602	7.600	7.595
	3.0	-3.0	7.610	7.606	7.605	7.599
	3.5	-3.5	7.616	7.611	7.609	7.603
	4.0	-4.0	7.621	7.616	7.611	7.609
	4.5	-4.5	7.626	7.622	7.619	7.614
	5.0	-5.0	7.634	7.628	7.624	7.619
	5.5	-5.5	7.642	7.637	7.633	7.629
	6.0	-6.0	-	-	7.656	7.652

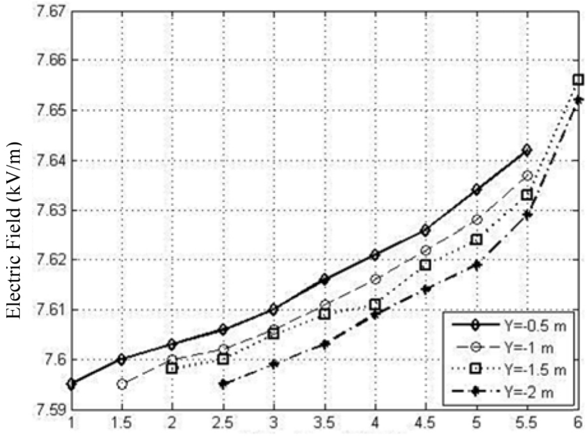

Fig. 7 Electric Field at 0.5 – 2 meter height decreasing of Installation of overhead ground

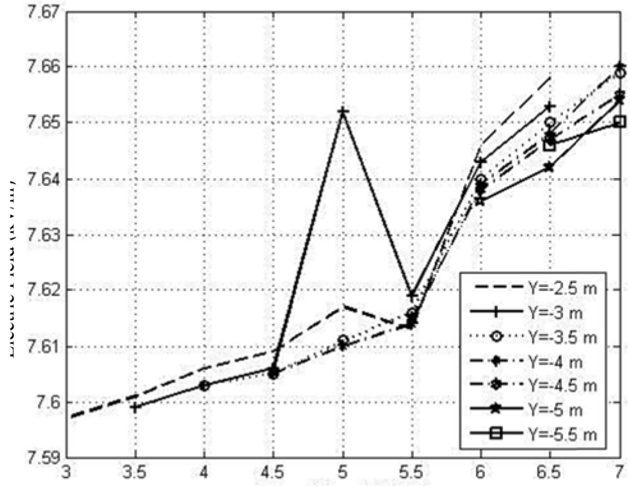

Fig. 8 Electric Field at 2.5 – 5.5 meter height decreasing of Installation of overhead ground

TABLE IX
AVERAGE ELECTRIC FIELD AT 1 METER HEIGHT AND INSTALLATION DECREASING THE OHGW AT Y=2.5 - 4 METER AND STEP SLICE X EACH 0.5 METER

Y axis	OHGW1	OHGW2	Electric Fields (kV/m)			
			Y=-2.5	Y=-3	Y=-3.5	Y=-4
x axis	3.0	-3.0	7.597	-	-	-
	3.5	-3.5	7.601	7.599	-	-
	4.0	-4.0	7.606	7.603	7.603	-
	4.5	-4.5	7.609	7.606	7.605	7.605
	5.0	-5.0	7.617	7.652	7.611	7.610
	5.5	-5.5	7.613	7.619	7.616	7.614
	6.0	-6.0	7.646	7.643	7.640	7.639
	6.5	-6.5	7.658	7.653	7.650	7.648
	7.0	-7.0	-	-	7.659	7.660

TABLE X
AVERAGE ELECTRIC FIELD AT 1 METER HEIGHT AND INSTALLATION DECREASING THE OHGW AT Y=4.5-5.5 METER AND STEP SLICE X EACH 0.5 METER

Y axis	OHGW1	OHGW2	Electric Fields (kV/m)		
			Y=-4.5	Y=-5	Y=-5.5
x axis	5.5	-5.5	7.615	-	-
	6.0	-6.0	7.638	7.636	-
	6.5	-6.5	7.647	7.642	7.646
	7.0	-7.0	7.655	7.654	7.650

IV. CONCLUSION

Numerical simulation analysis of the electric field for current installation position of OHGW on single circuit, 4 bundle conductors, and 500kV power transmission tower is at a height of 1 meter above ground, it is shown that the electric field is of about 7.5907kV/m. There is compared with distance and height of installing OHGW, which it is found that the electric field increase from current installation position. Also it may be concluded that the change in installing position, spacing, and height of OHGW line affects to the electric field. The simulation indicate that the electric field occurred at a height 1 meter above ground give minimum value of 7.5907kV/m at the position to move the line X=0 m and Y=9 m or installed at a height of 59.484 meter vertically from the ground with a distant of 10.65 meters each side of the center pole. In summary, the electric field at ground level increase when install OHGW higher than current position may be at 15.13%. However with reference to ICNIRP standard, the electric field intensity is not exceeding the ICNIRP which it is defined as not exceeding 10kV/m

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Arnon Isaramongkolrak received his B.E. and M.E. degree in Electrical Engineering from Suranaree University of Technology, Thailand in 2005 and 2010 respectively. Currently, he is a lecturer at Mahanakorn University of Technology. His research interests are application of electromagnetic Fields in power system and application of optimization in power system.

Pornpus Kerdpradub received his B.E. degree in Electrical Power Engineering from Mahanakorn University of Technology, Thailand in 2013. Currently, he is an engineer at SRT Electrified Train Co,. Ltd. His research interests are application of electromagnetic Fields in electic train.

Korakot Wungwattana received his B.E. degree in Electrical Power Engineering from Mahanakorn University of Technology, Thailand in 2013. Currently, he is an engineer at SRT Electrified Train Co,. Ltd. His research interests are application of electromagnetic Fields in electic train.