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An Investigation on Electric Field Distribution around 380 kV Transmission Line for Various Pylon Models

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***Abstract*—**In this study, electric field distribution analyses for three pylon models are carried out by a Finite Element Method (FEM) based software. Analyses are performed in both stationary and time domains to observe instantaneous values along with the effective ones. Considering the results of the study, different line geometries is considerably affecting the magnitude and distribution of electric field although the line voltages are the same. Furthermore, it is observed that maximum values of instantaneous electric field obtained in time domain analysis are quite higher than the effective ones in stationary mode. In consequence, electric field distribution analyses should be individually made for each different line model and the limit exposure values or distances to residential buildings should be defined according to the results obtained.

***Keywords*—**Electric field, energy transmission line, finite element method, pylon.

I. Introduction

TODAY, the large part of the supplied energy is transmitted by high voltage overhead lines. Generally, the most commonly used voltage levels for transmission systems are 154 kV, 220 kV and 380 kV [1]. However, higher voltage levels for transmission systems are still needed due to increasing energy demand. In addition to this, designing new types of coordination and arrangements for existing overhead lines also became a current issue for energy transmission. These studies come along with some technical problems such as insulator designs, conductor dimensions, pylon structures, mechanical calculations and etc. In addition to these, investigating the electric field distribution around high voltage transmission lines for human health become more of an issue.

Energy transmission is one of the most important and basic study fields of power systems. It becomes a need to use high voltages to decrease power losses and transmit energy efficiently to the residential areas. In recent years, by the reasons of increasing research studies and technological developments in high voltage equipment, transmission voltage rating is aimed to reach higher levels [1]. Additionally, there are some studies in progress about increasing the performance of existing lines and providing the system and public safety.

In early days, transmission lines could have been placed far from residential areas due to low population density. But today, they are accepted as a part of the living spaces and the public [2]. For this reason, investigating the electric field around overhead lines becomes an important matter for human health and safety [3], [4]. In literature, there are several research studies on analyzing electric field distributions by measurements and numerical methods [5]-[7]. In addition, induced current on human body due to electric field exposure and its biological effects are investigated [2], [8]. As a consequence, analysis of electric field distribution around commonly used 380 kV transmission lines for various line geometries is a considerable issue. Besides, results of the study could be a reference work for the further studies on biological effects of the electric field on human health.

In this work, electric field analyses are performed for three types 380 kV transmission line models. Thus, it is aimed to identify the electric field distribution for different pylon models. Analyses are made in both stationary and time domain to investigate effective and instantaneous values respectively by using COMSOL Multiphysics software.

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II. Finite Element Method

Basic approach of the FEM is to find the solution that minimizes energy equation. In order to solve a problem of this kind with FEM, five steps should be followed,

- Geometry of problem, materials and boundary conditions must be defined
- Meshing
- Writing equations for all elements in mesh
- Combining all elements in solution domain
- Solving the acquired equations

Within the scope of this study, V=V(x,y,z) is defined electrical potential, the solution of static electrical field problem requires a quadric homogenous differential solution. Equation (1) is defined as “Laplace Equation”.

$$\Delta V = \frac{\partial V^2}{\partial x^2} + \frac{\partial V^2}{\partial y^2} + \frac{\partial V^2}{\partial z^2} \quad (1)$$

FEM solves this equation by the principle of minimizing the electrical energy equation in solution domain as,

$$W = z\iint \left\{ \frac{1}{2} \cdot \left[\varepsilon_x \left(\frac{\partial V}{\partial x} \right)^2 + \varepsilon_y \left(\frac{\partial V}{\partial y} \right)^2 \right] \right\} \cdot dx \cdot dy \quad (2)$$

The solution that is found in this way is also desired solution of the Laplace equation [9]. In the solution, Cartesian coordinates can be used. Principally, mentioned area is divided into finite elements called “discretizing the area”. Generally, triangle finite element is used for discretizing. Thereafter by using boundary conditions, known potentials and material properties, lateral polynomial approach functions, equations of the elements and general equation of the problem

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is derived. Acquired equation is a big dimensional matrix with many zeroes. By solving this linear equation system with an iterative numerical solution method, node potential of triangle elements are obtained. Depending upon potential values and element's potential approach functions, potentials and electrical field values can be calculated in any point of the area [9].

III. Exposure Limits and Standards

Several studies have been published about the effects of electric field on human health. Electric field exposure levels depend on many factors such as distance from the electric field source, exposure duration, strength and frequency of the electric field. Therefore, limit values for electric fields at different frequencies are specified by the International Commission on Non-Ionizing Radiation Protection (ICNIRP) [10]. These values are given in Table I for occupational and general public exposure.

TABLE I
Reference Levels for Occupational Exposure to Time Varying Electric Fields (Unperturbed RMS Values)

Exposure	Frequency Range	Electric Field Strength E (kV/m)
Occupational	1 Hz – 8 Hz	20
	8 Hz – 25 Hz	20
	25 Hz – 300 Hz	500/f
	300 Hz – 3 kHz	500/f
	3 kHz – 10 Mhz	0.17
General Public	1 Hz – 8 Hz	5
	8 Hz – 25 Hz	5
	25 Hz – 50 Hz	5
	50 Hz – 400 Hz	250/f
	400 Hz – 3 kHz	250/f
	3 kHz – 10 MHz	0.083

IV. Simulation and Results

Electric field distribution around high voltage transmission lines can be calculated by numerical methods such as Finite Elements, Boundary Elements and Charge Simulation Method [2]. In this study, electric field is computed by COMSOL Multiphysics software based on FEM.

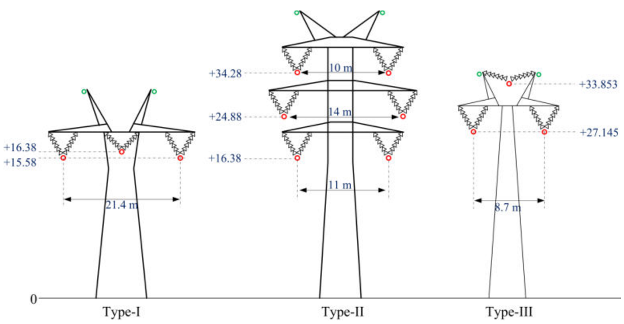

Fig. 1 Dimension of the three pylon models

The pylon models used in analyses are shown in Fig. 1. Type I and Type III is a single circuit pylon models with two bundles in each phase. Whole conductors are chosen as 954 MCM CARDİNAL. Type II is a double-circuit pylon model with three bundles and consist the same conductor. The distance of conductors closest to the ground in Type I and II is approximately 16 m. This distance can be change according to the geographical formations of the pylon's area. In practical applications, the distance of lowermost conductors can be greater than ones in this paper. However, the distance of conductors closest to the ground may drop down to levels given in this study because of the line sag between pylons. Therefore, the closest distance in practical applications is taken into consideration to observe the more critical results.

Type III pylon given in Fig. 1 is a new design for 380 kV transmission lines. It has a compact design and so occupies lesser space than the others. The closest conductor to ground of Type III pylon is arranged as 27 m to observe the effect of conductor distances to the ground on electric field distribution.

A. Stationary Domain Analyses

The simulation is firstly made for effective line voltages. Dielectric coefficient of air is selected as 1. The boundary conditions of the conductors are calculated as line-ground voltage. In the simulation, approximately two hundred triangle elements used and one hundred nodes are computed.

The minimum angle of the triangle finite element is chosen as 30 degree. The reference line for the data obtained is collected from 1 m. above from the ground. The electric field distribution results for the Type II pylon used in the software are given in Fig. 2.

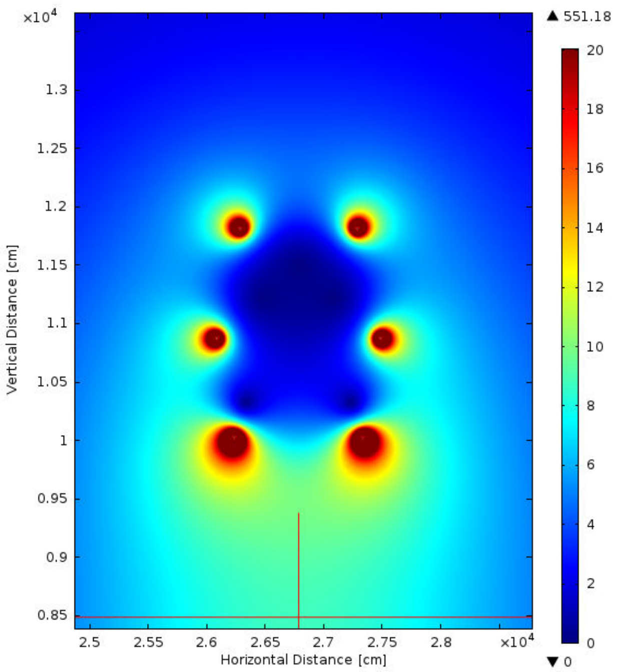

Fig. 2 Electric field distribution in kV/m around Type II pylon

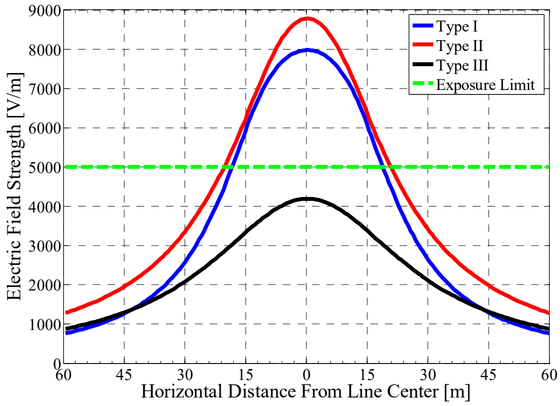

Fig. 3 Horizontal electric field distributions for three pylon model

The electric field distribution of three pylons at 1m above from the ground is given in Fig 3. As it is seen from Fig. 3 that, maximum electric field is occurred in the center of the transmission line for all pylon types. When it gets farther horizontally from the center, the effective electric field value is decreasing exponentially.

In this situation, the highest electric field is occurred in the center of the Type II pylon model. The reason is that the Type II pylon has more conductors than the others because of having three bundles. Principally, each conductor has a charge value due to its voltage level. More charges result in higher electric fields according to the Coulomb's law (3).

$$E \cdot q = \frac{q_1}{4\pi\varepsilon_0}\sum_{i=2}^{n}\frac{q_i}{r_{1i}^2}\hat{r}_{1i} \qquad (3)$$

The maximum electric field computed under Type II pylon is 8.72 kV/m. The obtained maximum electric field results of the Type I and II pylons are 8 kV/m and 4.19 kV/m respectively. For Type I and II pylon models, obtained maximum electric field values are exceeding the reference general public exposure value 5 kV/m given in standard. However, whole computed maximum electric field values are below the reference occupational exposure value 10 kV/m. It can be concluded from the results in Fig. 3 that the electric field around a transmission line is increasing with the increased number of conductors carried.

In addition to this analysis, vertical electric field distribution in the center of the line is also computed for all pylon models and shown in Fig. 4. The general overview of the Fig. 2 is that the computed electric field values of all pylon models are slightly increasing with the decreased distance to the conductor. The electric field results belong to the Type I and II pylon models are above the limit general public exposure value 5 kV/m. When it gets closer to the conductors, the electric field is increasing. For Type II pylon model, electric field cannot reach the general public exposure value even at 10 m above from the ground.

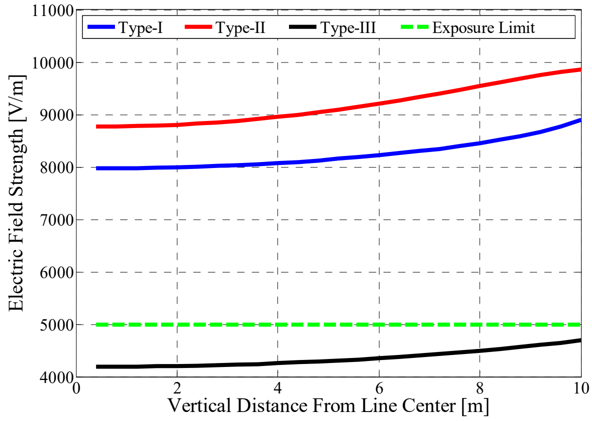

Fig. 4 Vertical electric field distributions for three pylon model

B. Time-Dependent Domain Analysis

In this section, analyses are carried out in time domain to observe the changes of electric field magnitude. According to the data obtained, mean values of electric field are calculated.

In a three phase power system, it is known that the voltage of the each phase is changing with time. The waveform of the alternative voltage is sinusoidal and has 50 Hz mains frequency. Also, there is 120° phase difference between each phase. In Fig. 5, change of the phase magnitudes with time in a 380 kV, 50 Hz system is given.

The boundary conditions for all transmission line models are defined as given in Fig. 5. Then instantaneous and mean values of electric field are computed and presented in Fig. 6. Only the result of the Type II pylon is given to obtain a clearer view for the results of electric field changes in time domain.

As it is seen from Fig. 6 that the electric field is alternating due to the phase difference between phases. The waveform of the electric field never becomes negative and appears similar as a fluctuant DC wave. The frequency of this signal is 100 Hz. Therefore, computed mean electric field values of all pylon models are indicated in Fig. 6.

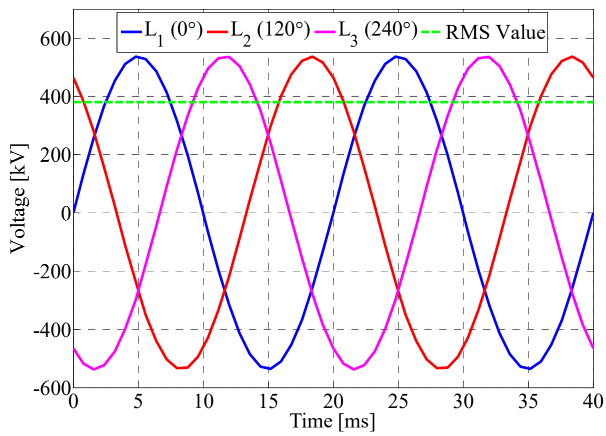

Fig. 5 The alternating voltages of a 380 kV, 50 Hz AC System

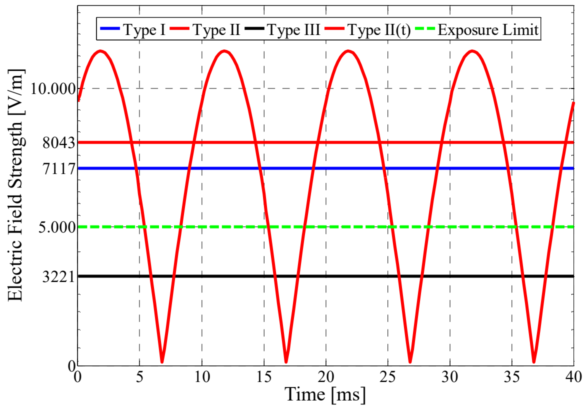

Fig. 6 Instantaneous and mean values of electric field in time domain analysis

The maximum and the mean electric field value of Type II pylon reaches to 11.35 kV/m. and 8.043 kV/m respectively. On the other hand, the mean electric field value obtained as 7.117 kV/m for Type I pylon and 2.279 kV/m for Type II. The computed mean electric field values in time domain analysis are slightly smaller than the ones in stationary section. However, their maximum values are quite high compared to the results in stationary domain analysis.

The overall electric field results obtained in both domains are summarized in Table II. The results show that, all maximum electric field values computed in time domain analysis are higher than the other ones. Additionally, the effective electric field values are changing due to the line geometry. For the transmission line models where conductors are closer to the ground, electric field becomes greater. Also, the number of conductors carried by transmission line is affecting the electric field value.

Although Type I and Type II line model have same height, the electric field occurred under the Type II pylon is higher because of having three bundle. Besides, the shape of the electric field distribution for all pylon models is quite similar as highest in the center of the line and decreasing while becoming distant horizontally.

TABLE II
MEAN AND MAXIMUM ELECTRIC FIELD RESULTS OF STATIONARY AND TIME DOMAIN ANALYSES

Analysis	Value	Type-I	Type-II	Type-III
Stationary Domain	Effective Electric Field (kV/m)	8	8.72	4.19
Time Domain	Maximum Electric Field (kV/m)	10.035	11.35	5.037
	Mean Electric Field Value (kV/m)	7.117	8.043	3.221

V. CONCLUSION

In this study, electric field analyses of three transmission line models at 380 kV are made by using COMSOL Multiphysics software. The analyses are made both in stationary and time domain to see the electric field difference for effective and time dependent boundary conditions. According to the results, it is concluded that electric field strength around a transmission line changes due to the parameters such as;

- Transmission line geometry,
- Conductor height,
- Number of conductors (bundle) in each phase,
- Boundary condition of conductors (effective or time dependent)

Generally in most common pylon models used in 380 kV transmission lines, the maximum electric field strength occurs in the center of line. Then it begins to decrease rapidly for farther horizontal distances. The shape of electric field distribution is generally obtained in this form for three phase transmission lines. The waveform of the electric field only changes with the position and arrangement of the phase conductors. Additionally, the instantaneous results of electric field for all pylon models are quite higher than the others. Thereby, the effects of the increase in electric field at time domain analysis should also be considered for human health. In conclusion, electric field around a transmission line may be harmful for human health depends on its strength. Therefore, electric field effects of each transmission line model should be analyzed individually by considering the mentioned parameters and living spaces should be organized accordingly.

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