ISSN (Print) : 2320 – 3765
ISSN (Online): 2278 – 8875

International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering

(An ISO 3297: 2007 Certified Organization)

Vol. 4, Issue 8, August 2015

Analytical Expression of Electric Field Strength under Three – Phase Line

Juozapas Arvydas Virbalis[1], Povilas Marciulionis[2], Robertas Lukocius[3], Ramunas Deltuva[4], Gabija Nedzinskaite[5]

Department of Electronics Engineering, Kaunas University of Technology,Studentu St. 48–241, LT-51367 Kaunas, Lithuania[1]

ABSTRACT: The electric field strength near a high voltage power transmission line can be greater than maximum permissible values. Therefore it is important to know the limits of these areas. It is presented in the paper that the expressions and calculations of the electric field strength at any observation point near the three-phase line dependently both on geometrical parameters of the line and coordinates of the observation point. The 2D approach is used for obtaining expressions which we can calculate electric field strength in any point near the line. The analytically calculated values are compared with the numerically calculated ones.

KEYWORDS: Electric field strength, electric field distribution, three phase line, method of mirror images, effective value.

I.INTRODUCTION

The main source of industrial frequency – 50 Hzelectric field is the three phase transmissionline. The strength of electric field in any point near the line depends on the distance from the line wires and on thelinevoltage. Some authors have provided calculation methods and values of the electric and magnetic fields, corona losses [1–4, 17]. It is clear from the results that electric field could have greater values at the high voltage power lines. There is a lack of analytical methods to calculate effective value of three phase line electric field without using expensive computer programmes and big computer memory capacities. Calculation of the real electric or magnetic field values is difficult solution because of soil parameters. Some of the authors shown soil model described it dependence from humidity, soil structure [5–7, 15]. We used simpler model with ideal ground potential in this paper.

Near three phase high voltage lines can be the zones in which electric field strength is greater than maximum permissible values and can disruptand endangerthe health of workerswho operate andmaintainelectrical equipment [8, 9]. The territory of the open switch–gear is dangerous especially because there the height of line wires is lower and electric field gains greatest values. Consequently, it is extremely important to know the strength of the electric field at height of up to 2 m in the switch-gear territory.

For the industrial frequency electric field strength calculation the methods of electrostatic fields can be used because the dimensions of switch-gear are beyond comparison with the length of the 50 Hz frequency wave. We used the method of images for the ground influence evaluation [10, 11].
Conventional methods consist of calculation instant value of the field strength initially, evaluating phase difference in wires of the line in the observation point as function of observation point position and line voltage [10-12]. These computations take a long time and needs a handiwork.

We expressed the effective value of electric field strength in the observation point without instant values. We have provided a direct formula for calculation effective value of electric field strength immediately. Validation of the computation is carried out with numerical calculation with finite element method programme Comsol Multiphysics in conventional method. The novelty of the work is analytical expression which enables to determine effective values of the electric field strength under three-phase power line evaluating induced charges not only in respect of the earth but also of the other wires simultaneously. The application of this work is faster calculation of the effective electric field values and calculation not only for the wires placed in one plane but also for other distributions of the wires

ISSN (Print) : 2320 – 3765
ISSN (Online): 2278 – 8875

International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering

(An ISO 3297: 2007 Certified Organization)

Vol. 4, Issue 8, August 2015

II.ELECTRIC FIELD STRENGTH GENERATED UNDER THREE-PHASE POWER LINE

Geometry of the power line and observation point above the ground is presented in the Fig. 1. Thelineconsists of threeequalandparallel to the groundstretchedconductors. Wires of the line have linear charges densities τ_i (i=A, B, C). Real wires have little sag. We suppose that wires are straight and perform the analysis for line arranged in the height h equal to distance to the ground to the point of the real wires maximal sag [10]. Therefore two dimensional problems can be solved.
The distance of the three-phase conductors from the earth's surface is the same and equal to h. Then the distance from the images will approximately be $h'=h$. Height of theobservation point$M$of isy_M. We assume that the ground is plane and smooth. The linear charge densities images of any line have the same values and opposite signs: $\tau_A'=-\tau_A$, $\tau_B'=-\tau_B$and $\tau_C'=-\tau_C$.
The value of the electric field strength E_i (i=A, B, C, A', B', C') is generated by any of the charges with densities τ_i or τ_i' can be calculated using the following equation [12]:

$$E_i = \frac{\pm\tau_i}{2\pi\varepsilon_r\varepsilon_0}\cdot\frac{1}{r_i}; \qquad (1)$$

where ε_0 =8,85·10^{-12} F/m – dielectric constant, ε_r – relative dielectric constant; r – the distance between the charge and the observation point.

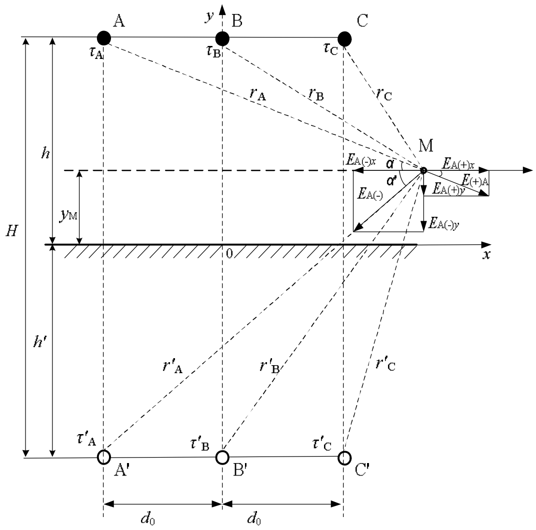

Fig. 1.Linear charge densities and their mirror images of the three phase power line. Components of the electric field strength generated at the point M by different linear charge densities.

The field is two dimensional because it equals along the line and there is no variation at the z axis.

III.CALCULATION OF THE ELECTRIC FIELD STRENGTH EFFECTIVE VALUE AT THREE PHASE LINE

Vector of the electric field strength generated by the three-phase line (Fig. 1) can be expressed as follows:

$$\boldsymbol{E} = \boldsymbol{E}_A + \boldsymbol{E}_B + \boldsymbol{E}_C; \qquad (2)$$

where$\boldsymbol{E}_A$, $\boldsymbol{E}_B$, $\boldsymbol{E}_C$the electric field strength generated by phases conductors A, B, C linear charges and its images.
Because the field is two-dimensional we express the x and y components of electric field strength, E_x and E_y, in the observation point M separately. Any field strength component is created by the positive and by the negative charge. Components created by wire linear charge we note as $E_{(+)}$ and created by image charge we note as $E_{(-)}$. Therefore, we can write:

$$E_x = E_{x(+)} + E_{x(-)}, \qquad (3)$$

$$E_y = E_{y(+)} + E_{y(-)} \qquad (4)$$

ISSN (Print) : 2320 – 3765
ISSN (Online): 2278 – 8875

International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering

(An ISO 3297: 2007 Certified Organization)

Vol. 4, Issue 8, August 2015

and

$$E = \sqrt{E_x^2 + E_y^2} \,. \tag{5}$$

Value of electric field strength at point M generated of the phase wires A, B, Caccording to the (1) can be expressed as follows:

$$E_{\mathrm{A}(+)} = \frac{\tau_{\mathrm{A}}}{2\pi\varepsilon_0\varepsilon_r r_{\mathrm{A}}} \text{ and } E_{\mathrm{A}(-)} = \frac{-\tau'_{\mathrm{A}}}{2\pi\varepsilon_0\varepsilon_r r'_{\mathrm{A}}}, \tag{6}$$

$$E_{\mathrm{B}(+)} = \frac{\tau_{\mathrm{B}}}{2\pi\varepsilon_0\varepsilon_r r_{\mathrm{B}}} \text{ and } E_{\mathrm{B}(-)} = \frac{-\tau'_{\mathrm{B}}}{2\pi\varepsilon_0\varepsilon_r r'_{\mathrm{B}}}, \tag{7}$$

$$E_{\mathrm{C}(+)} = \frac{\tau_{\mathrm{C}}}{2\pi\varepsilon_0\varepsilon_r r_{\mathrm{C}}} \text{ and } E_{\mathrm{C}(-)} = \frac{-\tau'_{\mathrm{C}}}{2\pi\varepsilon_0\varepsilon_r r'_{\mathrm{C}}}; \tag{8}$$

where $r_{\mathrm{A,B,C}}$ are the distances from the point M to the phases A, B, C and $r'_{\mathrm{A,B,C}}$ to the its images. $\tau_{\mathrm{A,B,C}}$ and $\tau'_{\mathrm{A,B,C}}$ are linear charge densities generated on the phases A, B, C wires and its images, correspondingly.

Values of the components x and y of the electric field strength $E_{\mathrm{A}(+)}$ and $E_{\mathrm{A}(-)}$, $E_{\mathrm{B}(+)}$ and $E_{\mathrm{B}(-)}$, $E_{\mathrm{C}(+)}$ and $E_{\mathrm{C}(-)}$ from the Fig. 1 can be calculated as follows:

$$E_{\mathrm{A}(+)\mathrm{x}} = E_{\mathrm{A}(+)} \cos\alpha_{\mathrm{A}} \text{ and } E_{\mathrm{A}(-)\mathrm{x}} = E_{\mathrm{A}(-)} \cos\alpha'_{\mathrm{A}}, \tag{9}$$

$$E_{\mathrm{A}(+)\mathrm{y}} = E_{\mathrm{A}(+)} \sin\alpha_{\mathrm{A}} \text{ and } E_{\mathrm{A}(-)\mathrm{y}} = E_{\mathrm{A}(-)} \sin\alpha'_{\mathrm{A}}, \tag{10}$$

Angles α_i, i=A, A',are showed in the Fig. 1. Accordingly with Fig. 1 values of the angle:

$$\alpha_A = \arctan\frac{d_0 + x_{\mathrm{M}}}{(h - y_{\mathrm{M}})},\ \alpha'_A = \arctan\frac{d_0 + x_{\mathrm{M}}}{(h + y_{\mathrm{M}})}, \tag{11}$$

Distances between linear charge and observation point M r_i, i = A, A' can be calculated as follows:

$$r_A = \sqrt{(h - y_{\mathrm{M}})^2 + (x_{\mathrm{M}} + d_0)^2},\ r'_A = \sqrt{(h + y_{\mathrm{M}})^2 + (x_{\mathrm{M}} + d_0)^2},$$

where$h$ – distance between power line wires plane and the observation point M;d_0– distance between wires of phases A and B same as between wires of phases B and C, y_{M} and x_{M} are in x and y coordinates. Calculations for phase B and C are performed in the same way.

Accordingly to equations (3) and (4) the components E_x and E_y can be calculated as follows [10]:

$$E_{\mathrm{x}} = E_{\mathrm{A}(+)\mathrm{x}} + E_{\mathrm{A}(-)\mathrm{x}} + E_{\mathrm{B}(+)\mathrm{x}} + E_{\mathrm{B}(-)\mathrm{x}} + E_{\mathrm{C}(+)\mathrm{x}} + E_{\mathrm{C}(-)\mathrm{x}}, \tag{12}$$

$$E_{\mathrm{y}} = E_{\mathrm{A}(+)\mathrm{y}} + E_{\mathrm{A}(-)\mathrm{y}} + E_{\mathrm{B}(+)\mathrm{y}} + E_{\mathrm{B}(-)\mathrm{y}} + E_{\mathrm{C}(+)\mathrm{y}} + E_{\mathrm{C}(-)\mathrm{y}}. \tag{13}$$

Substituting equations (6) – (10) we can write:

$$E_x = \frac{1}{2\pi\varepsilon_r\varepsilon_0}(\tau_{\mathrm{A}}C_{\mathrm{A}} + \tau_{\mathrm{B}}C_{\mathrm{B}} + \tau_{\mathrm{C}}C_{\mathrm{C}}), \tag{14}$$

$$E_{\mathrm{y}} = \frac{1}{2\pi\varepsilon_r\varepsilon_0}(\tau_{\mathrm{A}}S_{\mathrm{A}} + \tau_{\mathrm{B}}S_{\mathrm{B}} + \tau_{\mathrm{C}}S_{\mathrm{C}}) \tag{15}$$

Where $C_{\mathrm{A}} = \frac{\sin\alpha_{\mathrm{A}}}{r_{\mathrm{A}}} - \frac{\sin\alpha_{\mathrm{A}'}}{r'_{\mathrm{A}}}$ and $S_{\mathrm{A}} = \frac{\cos\alpha_{\mathrm{A}}}{r_{\mathrm{A}}} + \frac{\cos\alpha_{\mathrm{A}'}}{r'_{\mathrm{A}}}$.

Potentials of the wires V_i(i=A, B, C)can be related with charge densities τ_i (i=A, B, C) by Maxwell's equations which we can express in matrix:

$$[\tau_i] = [\beta_i] \cdot [V_i], \tag{16}$$

where:

$$\tau_i = \begin{vmatrix} \tau_{\mathrm{A}} \\ \tau_{\mathrm{B}} \\ \tau_{\mathrm{C}} \end{vmatrix},\ \beta_i = \begin{vmatrix} \beta_{11} & \beta_{12} & \beta_{13} \\ \beta_{21} & \beta_{22} & \beta_{23} \\ \beta_{31} & \beta_{32} & \beta_{33} \end{vmatrix},\ V_i = \begin{vmatrix} V_{\mathrm{A}} \\ V_{\mathrm{B}} \\ V_{\mathrm{C}} \end{vmatrix},$$

ISSN (Print) : 2320 – 3765
ISSN (Online): 2278 – 8875

International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering

(An ISO 3297: 2007 Certified Organization)

Vol. 4, Issue 8, August 2015

where β_{kn}(k=1, 2, 3; n=1, 2, 3) are capacitance coefficients. They can be expressed via coefficients of the potential α_{kn} (k=1, 2, 3; n=1, 2, 3) evaluating $[\boldsymbol{\beta}]=[\boldsymbol{\alpha}]^{-1}$ as follows:

$$\beta_{kn}=\frac{\det\alpha_{kn}}{\det\alpha}. \tag{17}$$

Potential coefficients are expressed via the geometrical parameters [11]. Coefficients $\alpha_{11}=\alpha_{22}=\alpha_{33}$ can be found from the following equation:

$$\alpha_{11}=\frac{1}{2\pi\varepsilon_r\varepsilon_0}\cdot\ln\frac{2\cdot h}{r}; \tag{18}$$

coefficients $\alpha_{12}=\alpha_{21}=\alpha_{23}=\alpha_{32}$ can be found as follows:

$$\alpha_{12}=\frac{1}{2\pi\varepsilon_r\varepsilon_0}\cdot\ln\frac{a_{AB'}}{a_{AB}}; \tag{19}$$

where $a_{AB}=a_{BC}$ is the distance between the wire phases A and B, whereas $a_{AB'}$ is the distance between the phase A wire and the image B' of the phase B wire.
Coefficients $\alpha_{13}=\alpha_{31}$ can be calculated in this way:

$$\alpha_{13}=\frac{1}{2\pi\varepsilon_r\varepsilon_0}\cdot\ln\frac{a_{AC'}}{a_{AC}}; \tag{20}$$

where a_{AC} is the distance between the wire phases A and C, whereas $a_{AC'}$ is the distance between the phase A wire and the image C' wire of the phase C. All coefficients are counted in the same way to get coefficient matrix.
Potentials of the wires can be expressed as follows [10]:

$$\begin{cases} V_A=U_m\sin\omega t; \\ V_B=U_m\sin\left(\omega t-120^0\right); \\ V_C=U_m\sin\left(\omega t+120^0\right). \end{cases} \tag{21}$$

where U_m is amplitude of phase voltage.
Effective value of the electric field could be found from:

$$E_{rms}=\sqrt{\frac{1}{T}\int_0^T E^2(t)dt}= =\sqrt{\frac{1}{T}\int_0^T E_x^2(t)dt+\frac{1}{T}\int_0^T E_y^2(t)dt}; \tag{22}$$

Substituting equation (14) to spread the electric field strength in to x direction:

$$E_x^2=\tau_A^2C_A^2+\tau_B^2C_B^2+\tau_C^2C_C^2+2\tau_AC_A\tau_BC_B+ +2\tau_AC_A\tau_CC_C+2\tau_BC_B\tau_CC_C \tag{23}$$

Linear charge density from the equation (23) could be written:

$$\tau_A^2=\left(\beta_{11}V_A+\beta_{12}V_B+\beta_{13}V_C\right)=\beta_{11}^2V_A^2+ +\beta_{12}^2V_B^2+\beta_{13}^2V_C^2+2\beta_{11}V_A\beta_{12}V_B+ +2\beta_{11}V_A\beta_{13}V_C+2\beta_{12}V_B\beta_{13}V_C \tag{24}$$

It is clear from the equations (24, 25, 31) that only voltage depends from time. To calculate E_{rms} in the equation (23) variables V must be found with integration.

$$V_A^2=\frac{1}{T}\int_0^T U_m\sin^2\varpi t dt=0{,}5U_m^2; \tag{25}$$

$$V_AV_B=\frac{1}{T}\int_0^T U_m^2\sin\varpi t\sin\left(\varpi t-120\right)dt=-0{,}25U_m^2 \tag{26}$$

ISSN (Print) : 2320 – 3765
ISSN (Online): 2278 – 8875

International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering

(An ISO 3297: 2007 Certified Organization)

Vol. 4, Issue 8, August 2015

It must be noted that $V_A^2 = V_B^2 = V_C^2 = 0{,}5U_m^2$ and $V_A V_B = V_A V_C = V_B V_C = -0{,}25U_m^2$. Calculations of linear charge density and potentials of the wires to the other phases are performed in the same way.

Substituting equations (22) – (26) and considering that $\beta_{11} = \beta_{31}$, $\beta_{23} = \beta_{32} = \beta_{12} = \beta_{21}$ and $\beta_{13} = \beta_{31}$ we can write final equation for three phase power line (fig. 1):

$$E_{rms} = \frac{U_m}{\sqrt{2}} \sqrt{\begin{matrix}((C_A^2 + S_A^2 + C_C^2 + S_C^2) \cdot K_{\beta A} + (C_B^2 + S_B^2) \\ \cdot K_{\beta B} + (C_A C_B + C_B C_C + S_A S_B + S_B S_C) \\ \cdot K_{\beta AB} + (C_A C_C + S_A S_C) \cdot K_{\beta AC})\end{matrix}}, \tag{27}$$

where coefficients:

$$K_{\beta A} = (\beta_{11}^2 + \beta_{12}^2 + \beta_{13}^2 - \beta_{11}\beta_{12} - \beta_{11}\beta_{13} - \beta_{12}\beta_{13});$$

$$K_{\beta B} = (\beta_{21}^2 + \beta_{22}^2 + \beta_{23}^2 - \beta_{21}\beta_{22} - \beta_{21}\beta_{23} - \beta_{22}\beta_{23});$$

$$K_{\beta AB} = (\beta_{22} - \beta_{21}) \cdot (2\beta_{22} - \beta_{31} - \beta_{11});$$

$$K_{\beta AC} = 2(\beta_{11} - \beta_{12}) \cdot (\beta_{13} - \beta_{12}) - (\beta_{11} + \beta_{13})^2.$$

IV.RESULTS AND DISCUSSION

All calculations are carried out with Matlab program package. Calculations are executed with amplitude of phase voltage U_m=1 V, all other values of the electric field effective value could be found by multiplying with desired value of power line potential.

Model (Fig. 1) is assumed as electric power line in open switch-gear station where electric field values may be exceeded. Distance from the surface of the earth's to the wires is 6.5 m. Distance between the wires is 4.5 m. Height of the observation point M is 1.8 m. Frequency is 50 Hz. Calculations are made from –10 to 10 meters from the centre of the coordinates. Results are shown in Fig. 2.

Effective value of the electric field strength could be calculated in any point of the field with this method.

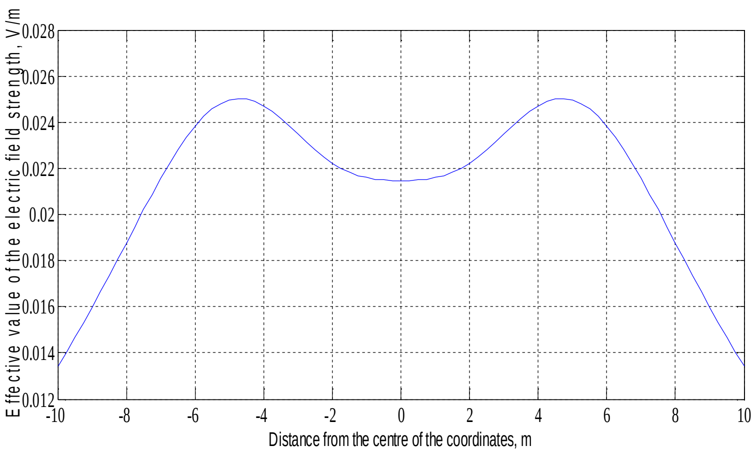

Figure 2.Effective values of the electric field strength

It is clear from the Fig. 2 that the highest values of electric field are reached under A and C phase (Fig. 1) wires and the values are equal. The smallest values in the power line zone is reached in the middle wire B. Electric field effective values steadily decreases receding from the power line.

Validation of the computation is carried out with numerical calculation with finite element method programme package Comsol Multiphysics in conventional method, using electrostatic module. Calculations are performed every 10 degrees with varying boundary conditions of power line wires potentials. Potentials are calculated from (21) equations. Total effective value of the electric field is determined by Eq. 28:

ISSN (Print) : 2320 – 3765
ISSN (Online): 2278 – 8875

International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering

(An ISO 3297: 2007 Certified Organization)

Vol. 4, Issue 8, August 2015

$$E_{\text{rms}} = \sqrt{\frac{1}{T}\sum_{1}^{n} \mathrm{E}_n^2 \Delta t}; \tag{28}$$

Height of the observation point M is 1.8 m, distance from the centre of the coordinates is from -10 to 10 meters. Real electric field values are ten times higher because of the model was made 10 times smaller.

Validation of analytical calculation with numerical method was performed at the three important points which are located directly under the wires (x = -4.5, 0, 4.5 m). Analytical solution values is calculated without capacitance (coefficients α_{12}, α_{13}, α_{21}, α_{23}, α_{31}, α_{32} equal to zero) because of numerical calculation was performed without capacitance. Effective values of the electric field strength calculated without evaluating capacitance by analytical method is shown in Fig. 3.

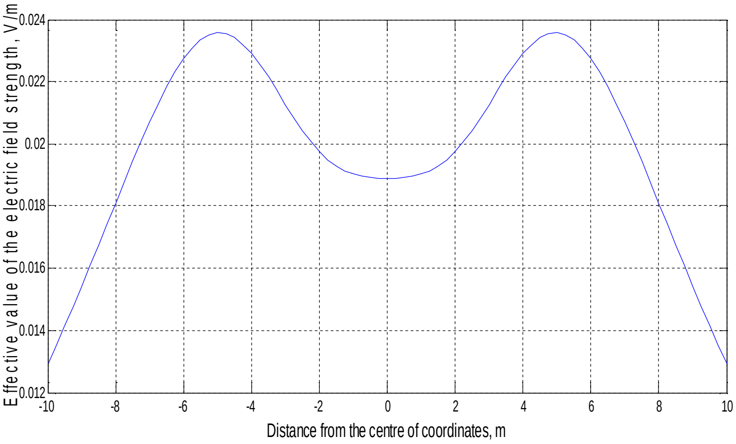

Figure 3.Effective values of the electric field strength calculated with analytical method without evaluating capacitance

The calculated effective values of the electric field with analytical method are 0.0235, 0.019, 0.0235. The values calculated by numerical method with (Eq. 28) are 0.0241, 0.0194, 0.0241. Percentage difference is 2.5 % and 2.1 % accordingly. Difference could be due to the numerical calculation are performed by 10 degrees and analytical expression is made by assumption that linear charges are in the middle of the wire.

V.CONCLUSION

The expression for calculation of electric field strength created by power transmission line in any observation point has been obtained in the study. The electric field strength created by unite potential is expressed via the geometrical parameters of line and observation point coordinates.

The highest values of electric field are reached under A and C phase wires and these values are equal. The smallest value is reached under the middle wire B in the power line zone. The effective values of electric field steadily decrease to receding from the power line.

The advantage of this method is the calculations carried out simultaneously. As result of this, induction could be estimated as well. There are some limitations that the model only works in two dimensions and couldn't estimate influence of the pylons which are situated nearby. It is lacking of real soil influence evaluation for real model

REFERENCES

[1] J.R. Stewart, L.J. Oppel, R.J. Richeda. Corona and Field Effects Experience on an Operating Utility Six-Phase Transmission Line. IEEE Transactions on Power Delivery, Vol. 13, No. 4, October 1998, p. 1363-1369. [Online]. Available: http://dx.doi.org/10.1109/61.714509

[2] A. Semlyen, D. Shirmohammadi. Calculation of induction and magnetic field effects of three pase overhead lines above homogeneous earth. IEEE Transactions on Power Apparatus and Systems, Vol. PAS-101, No. 8 August 1982, p. 2747-2754. [Online]. Available: http://dx.doi.org/10.1109/TPAS.1982.317646

[3] C. P. Nicolaou, A. P. Papadakis, P. A. Razis, G. A. Kyriacou, John N. Sahalos. Simplistic numerical methodology for magnetic field prediction in open air type substations. Electric Power Systems Research 81, 2011, p. 2120– 2126. [Online]. Available: http://dx.doi.org/10.1016/j.epsr.2011.08.003

ISSN (Print) : 2320 – 3765
ISSN (Online): 2278 – 8875

International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering

(An ISO 3297: 2007 Certified Organization)

Vol. 4, Issue 8, August 2015

[4] Charalambos P. Nicolaou, Antonis P. Papadakis, Panos A. Razis, George A. Kyriacou, John N. Sahalos. Measurements and predictions of electric and magnetic fields from power lines. Electric Power Systems Research 81, 2011, p. 1107–1116. [Online]. Available: http://dx.doi.org/10.1016/j.epsr.2010.12.014

[5] Klemen Dezelak, Franc Jakl, Gorazd Stumberger. Arrangements of overhead power line phase conductors obtained by Differential Evolution. Electric Power Systems Research 81, 2011, p. 2164–2170. [Online]. Available: http://dx.doi.org/10.1016/j.epsr.2011.07.015

[6] Anastasia S. Safigianni, Christina G. Tsompanidou. Measurements of electric and magnetic fields due to the operation of indoor power distribution substations, IEEE TRANSACTIONS ON POWER DELIVERY, VOL. 20, NO. 3, JULY 2005. [Online]. Available: http://dx.doi.org/10.1109/TPWRD.2005.848659

[7] R.S. Alipio, M.A.O. Schroeder, M.M. Afonso, T.A.S. Oliveira, S.C. Assis. Electric fields of grounding electrodes with frequency dependent soil parameters, Electric Power Systems Research 83, 2012, p. 220– 226. [Online]. Available: http://dx.doi.org/10.1016/j.epsr.2011.11.011

[8] Magda Havas. Intensity of electric and magnetic fields from power lines within the business district of 60 Ontario communities. The Science of the Total Environment 298, 2002, p. 183–206. [Online]. Available: http://dx.doi.org/10.1016/S0048-9697(02)00198-5

[9] Le Ha Hoang, Riccardo Scorretti, Noël Burais, Damien Voyer. Numerical Dosimetry of Induced Phenomena in the Human Body by a Three-Phase Power Line. IEEE TRANSACTIONS ON MAGNETICS, VOL. 45, NO. 3, MARCH 2009, p. 1666- 1669. [Online]. Available: http://dx.doi.org/10.1109/TMAG.2009.2012771

[10] R. Deltuva, J. A. Virbalis, S. Žebrauskas. Analysis of Electric Field in 330 kV Overhead Transmission Line // Electrical and Control Technologies. – Kaunas: Technologija, 2011. – No. ISSN 1822-5934. – P. 255-259. [Online]. Available: http://www.red.pe.org.pl/articles /2012/7b/55.pdf

[11] M. Abdel-Salam, H. Abdallah, M.Th. El-Mohandes , H. El-Kishky. Calculation of magnetic fields from electric power transmission lines Electric Power Systems Research 49, 1999, p. 99–105. [Online]. Available: http://dx.doi.org/10.1016/S0378-7796(98)00078-9

[12] R. Deltuva, J. A. Virbalis.Protection against Electric Field of the Outdoor Switch-Gear Workplaces // Electronics and Electrical Engineering. – Kaunas: Technologija, 2011. – No. 6 (112). – P. 11-14. [Online]. Available: http://dx.doi.org/ 10.5755/j01.eee.112.6.435

[13] Marco A. O. Schroeder, Márcio M. Afonso, Tarcísio A. S. Oliveira, Sandro C. Assis. Computer Analysis of Electromagnetic Transients in Grounding Systems Considering Variation of Soil Parameters with Frequency. Journal of Electromagnetic Analysis and Applications, 2012, p. 475-480 [Online]. Available: http://dx.doi.org/10.4236/jemaa.2012.412066

[14] DIB Djalel, MORDJAOUI Mourad. Study of the influence high-voltage power lines on environment and human health (case study: The electromagnetic pollution in Tebessa city, Algeria) Journal of Electrical and Electronic Engineering 2014; 2(1). p. 1-8 [Online]. Available: http://dx.doi.org/10.11648/j.jeee.20140201.11