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Investigation of Electrical Potential and Electromagnetic Field for Overhead High Voltage Power Lines in Malaysia

R.K.Z. Sahbudin, S.A. Fauzi, S. Hitam and M. Mokhtar
Department of Computer and Communication System Engineering, Faculty of Engineering,
Universiti Putra Malaysia, 43400 Serdang, Selangor, Malaysia

Abstract: The exposure of human body to electric field and magnetic field could cause biological effects, including changes in functions of cells and tissues and subtle changes in hormone levels, which may or may not be harmful. The aim of this study was to analyze and compute the amount of electrical potential, electric field and magnetic flux density at a certain point and distance from the overhead high voltage power lines of 132 and 275 kV in Malaysia. An analytical calculus method is proposed in order to accomplish this study. The models of the power lines were constructed using the actual physical dimensions of the towers. The results show that the exposure levels of the electromagnetic fields to the public is low if they stay more than 30 m away from the power lines. For the live-line worker, the exposure to the high electric and magnetic field could endanger their body if they stay too close to the conductor. The evaluations of the electrical potential, electric field strength and magnetic flux density are done using the Matlab environment. Matlab's Graphical User Interface (GUI) techniques are developed as an easy and user-friendly tool to be used.

Key words: Electric field, magnetic field, power lines, exposure, live-line worker, Matlab

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INTRODUCTION

In Malaysia, most of the High Voltage Power Lines (HVPL) are 132 and 275 kV. There are different tower designs in Malaysia according to the vendor company, but mostly the specifications of the overhead power line design are as the Tenaga Nasional Berhad Malaysia (TNBM) requirements (R.W. Beck Inc., 2000). The construction of new overhead power lines, in particular, raise many issues of an environmental, legal and physical nature in relation to the vicinity through which those lines will pass and the effects that their construction and operation will have on the people living nearby (Said *et al*., 2004). The harmful effects of electromagnetic fields emanating from power lines have received growing attention worldwide in recent years. Similar to other countries, Malaysia has its fair share of public concern over the HVPL.

Overhead HVPL produces electromagnetic fields (EMF) (NIEHS-NIH, 2002). In order to determine the real effect or danger of EMF from the HVPL, the amount of potential voltage, electric field and magnetic field should be known specifically. The field profiles are actually depends on the tower configurations. Thus, the power line design engineers should design the overhead power lines that could provide the lowest and the desired field levels in the vicinity of the power line. The electric and magnetic field levels are not always the main consideration in the design of an overhead power line, but other parameters related to the geometry such as the conductor type, placement of shield wires and phase spacing play a significant part in the design in order to optimize its electrical performance and to minimize the cost (Pretorius, 2006).

This study was carried out in respond to the public concern of the EMF caused by the overhead power lines, 132 and 275 kV in Malaysia. There is no specific study to evaluate the amount of each potential voltage, electric field and magnetic field at a certain point that is for the near-field or far-field case from the overhead power lines, focusing on 132 and 275 kV which are commonly used in Malaysia. The study of the electrical potential at the overhead power lines is important in order to figure out the maximum electric voltages that are generated at the air space, while the EMF investigation is useful as a safety precaution to limit the exposure to the field especially to those who are living near the overhead power line (Gregory, 1996).

The method used to evaluate the electrical potential, electric field strength and the magnetic flux density are based on the analytical calculus (Marincu *et al*., 2005). The electrical lines are considered in steady state throughout the calculation of these fields.

Corresponding Author: R.K.Z. Sahbudin, Department of Computer and Communication System Engineering,
Faculty of Engineering, Universiti Putra Malaysia, 43400 Serdang, Selangor, Malaysia

HIGH VOLTAGE POWER LINES IN MALAYSIA

Figure 1 shows the power grids distribute electricity generated at the power station via high voltage lines. In areas where power needs to be distributed to consumers, transformers are used to convert this high voltage into a much lower voltage at the substation. Before entering the customer's house or premises, another transformer is used to drop the voltage down to more manageable levels. Normally power grids transmit electricity in three levels of voltages; High Voltage (HV), Medium Voltage (MV) and Low Voltage (LV). The range of voltages is (Malaysian Communications and Multimedia Commission, 2005):

- LV: 1 to 1 kV (240 V, single phase; 415 V, 3 phases)
- MV: 1 to 100 kV (11, 33 and 66 kV)
- HV: 100 kV upwards (132, 275 and 615 kV)

Figure 2 and 3 show the tower design with the actual physical dimensions for 132 and 275 kV, respectively, which are widely used in Malaysia. The black dots represent the conductor which is at each of the phase on both sides. The details of these tower specifications are depicted in Table 1. The 275 kV tower is taller than the 132 kV tower.

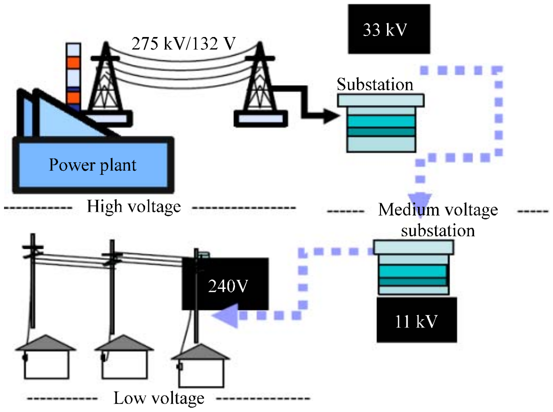


Fig. 1: The distribution of voltages over the power lines in Malaysia (Malaysian Communications and Multimedia Commission, 2005)

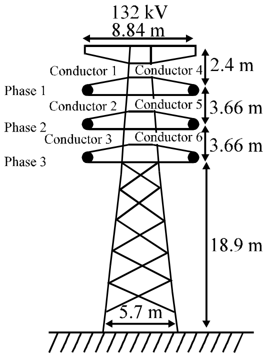


Fig. 2: 132 kV tower design (Abdul Kudus, 2006)

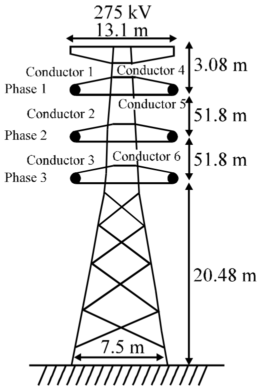


Fig. 3: 275 kV tower design (Abdul Kudus, 2006)

Table 1: Details of the towers (Abdul Kudus, 2006)

Tower type	132 kV tower	275 kV tower
System	Three phase	Three phase
Voltage	132 kV	275 kV
Frequency	50 Hz	50 Hz
Conductor diameter	24.16 mm	24.16 mm
Conductor type	ACSR	ACSR

ACSR is aluminium conductor steel reinforced

Experiment: The computation of the electrical potential, electric field strength and magnetic flux density around a three-phase high voltage 132 and 275 kV overhead power line has been carried out using the Matlab software. An analytical calculus method is proposed in this study as the results show a good agreement with the experiment measurement as presented by Marincu *et al.* (2005). The study was carried out in June 2009 for duration of 12 months.

Distance of current point P(X, Y) from overhead power lines: Figure 4 shows the distance between all the six conductors to the current point. In the calculation, r_{pk} is the distance between the phase k and the current point P and r'_{pk} is the distance between the electrical image of the phase k and the current point P. The r_{pk} for each phase can be determined using the following equations (Marincu *et al.*, 2005):

$$\text{For phase } k = 1: \sqrt{(X-d)^2+(h1-Y)^2} \qquad (1)$$

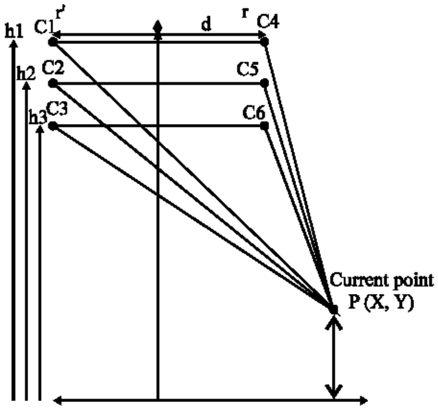


Fig. 4: The distance determination between the overhead of the power lines and current point

$$\text{For phase } k = 2: \sqrt{(X-d)^2 + (h2-Y)^2} \tag{2}$$

$$\text{For phase } k = 3: \sqrt{(X-d)^2 + (h3-Y)^2} \tag{3}$$

The r'_{pk} can be determined using the following equations (Marincu *et al*., 2005):

$$\text{For phase } k = 1: \sqrt{(d+X)^2 + (h1-Y)^2} \tag{4}$$

$$\text{For phase } k = 2: \sqrt{(d+X)^2 + (h2-Y)^2} \tag{5}$$

$$\text{For phase } k = 3: \sqrt{(d+X)^2 + (h3-Y)^2} \tag{6}$$

Electrical charge calculation on phase q_k: The electrical potential V and the electric field strength E depend on the electrical charges from the three-phase conductor, the geometrical design of the pillar and the lines. Using the Maxwell equations for capacities, the linear distributed electrical charge on the phase conductors is:

$$[U] = [p][q] \tag{7}$$

where, [U] is the phases potential matrix (toward the earth) and (p) is the potential coefficients matrix in the form of:

$$p_{ij} = a \ln \frac{D'_{ij}}{D_{ij}} \tag{8}$$

$$p_{ii} = a \ln \frac{D'_{ii}}{r_{oi}} \tag{9}$$

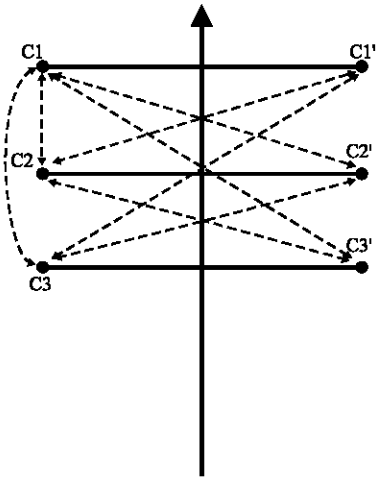


Fig. 5: The illustration distance between all conductor points at overhead power lines

Where:

D_{ij} = The distance between the conductor i and j

D'_{ij} = The distance between the conductor i and the image of the conductor j

r_{oi} = The radius of the conductor i

Fig. 5 shows the illustration of relationship between conductors to another conductor. The D_{ij} and D'_{ij} are illustrated in Fig. 5. Each conductor is assumed as a point charge and then the distance for each conductor to another conductor point can be measured.

To determine the

$$\begin{bmatrix} q_1 \\ q_2 \\ q_3 \end{bmatrix}$$

substitute the p_{ij} and p_{ii} into the matrix shown in Eq. 10.

$$\begin{bmatrix} p_{11} & p_{12} & p_{13} \\ p_{21} & p_{22} & p_{23} \\ p_{31} & p_{32} & p_{33} \end{bmatrix} \begin{bmatrix} q_1 \\ q_2 \\ q_3 \end{bmatrix} = \begin{bmatrix} U_1 \\ U_2 \\ U_3 \end{bmatrix} \tag{10}$$

$$\begin{bmatrix} a \ln \frac{D'_{ii}}{r_{oi}} & a \ln \frac{D'_{ij}}{D_{ij}} & a \ln \frac{D'_{ij}}{D_{ij}} \\ a \ln \frac{D'_{ii}}{D_{ij}} & a \ln \frac{D'_{ii}}{r_{oi}} & a \ln \frac{D'_{ij}}{D_{ij}} \\ a \ln \frac{D'_{ij}}{D_{ij}} & a \ln \frac{D'_{ij}}{D_{ij}} & a \ln \frac{D'_{ii}}{r_{oi}} \end{bmatrix} \begin{bmatrix} q_1 \\ q_2 \\ q_3 \end{bmatrix} = \begin{bmatrix} U_1 \\ U_2 \\ U_3 \end{bmatrix} \tag{11}$$

The conductor radius for both tower designs is 0.01208 m (Abdul Kudus, 2006).

Current (I) for each conductor: The current at the specific conductor of the overhead power lines is given as:

$$I_{rms} = \frac{V_{rms}}{Z_{o,line}} \tag{12}$$

$$Z_{o,line} = 60 \ln \frac{2h}{r} \tag{13}$$

$$V_{rms} = \frac{V_{max}}{\sqrt{2}} \tag{14}$$

Where:
h = Height of the conductor to the ground
V_{max} = The maximum voltage generated by the power lines
$Z_{o,\ line}$ = The impedance line for the transmission line
r = Radius of the conductor in meter

The real and imaginary part for the magnetic flux density obtained from the current is given as:

$$I e^{\frac{-j2p}{3}} \tag{15}$$

The real part is:

$$I \cos\left(\frac{-2p}{3}\right) \tag{16}$$

The imaginary part is

$$I \sin\left(\frac{-2p}{3}\right) \tag{17}$$

Potential voltage, electric field strength and magnetic flux density: In this study, the formulae based on analytical calculus method are applied to find the potential voltage at a current point from the overhead power lines. The potential voltage is:

$$V_p = a \sum_{k=1}^{n} q_k \ln \frac{r'_{pk}}{r_{pk}} \tag{18}$$

The electric fields strength at a current point P(X, Y) is given as:

$$E_{px} = a \sum_{k=1}^{n} q_k x_{pk} F_{pk} \tag{19}$$

$$E_{py} = a \sum_{k=1}^{n} q_k y_{pk} F_{pk} \tag{20}$$

$$E_p = \sqrt{(E_{px})^2 + (E_{py})^2} \tag{21}$$

where:

$$a = \frac{1}{2p\varepsilon_o} \tag{22}$$

$$\varepsilon_o = \frac{1}{4p \times 9 \times 10^9} \tag{23}$$

$$F_{pk} = \frac{1}{r_{pk}^2} - \frac{1}{r'^2_{pk}} \tag{24}$$

q_k is the electrical charge of the phase k, considered as a linear distribution. The magnetic fields calculation around the overhead power lines are given as:

$$B_{px} = -\beta \sum_{k=1}^{n} I_k \frac{Y_{pk}}{r_{pk}^2} \tag{25}$$

$$B_{py} = \beta \sum_{k=1}^{n} I_k \frac{X_{pk}}{r_{pk}^2} \tag{26}$$

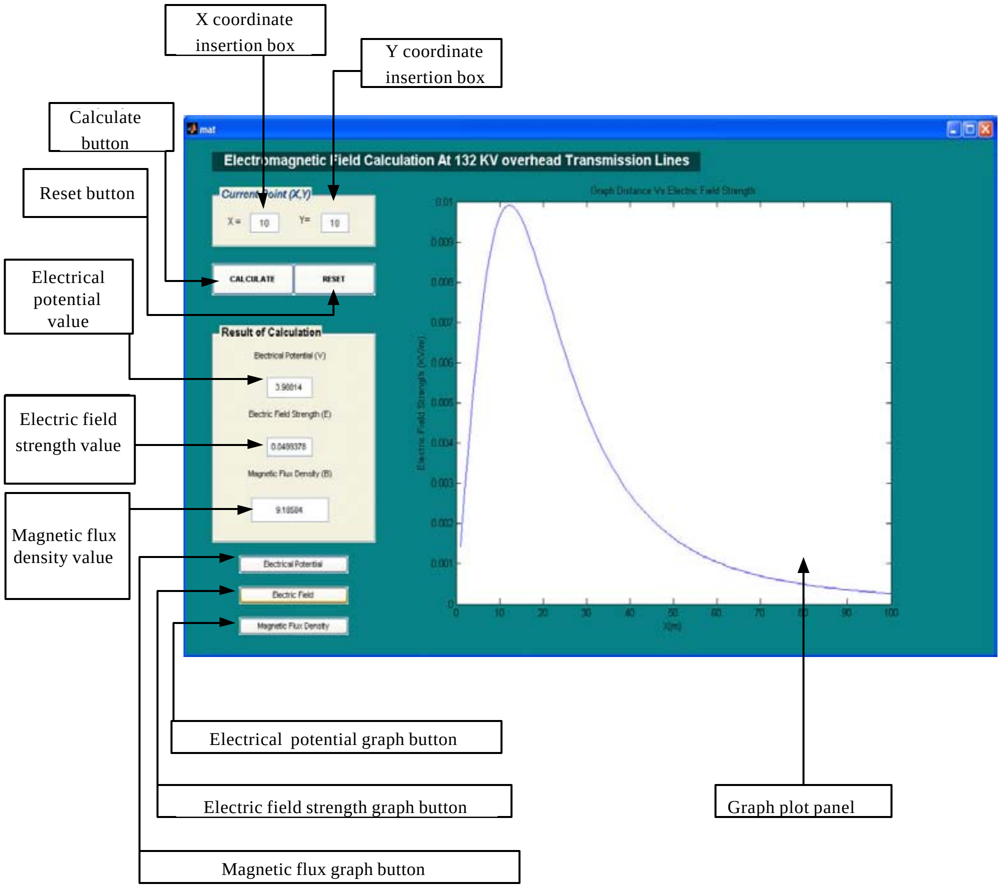
$$B_p = \sqrt{(B_{px})^2 + (B_{py})^2} \tag{27}$$

where, $\beta = \mu_0/2\pi$ and $\mu_0 = 4\pi \times 10^{-7}$ H/m . B_{px} is presented with real part value while B_{py} is the imaginary part value of current (I).

RESULTS AND DISCUSSION

A user-friendly window based for the evaluation of electrical potential and electromagnetic fields for overhead power lines has been developed and shown in Fig. 6. The inputs are the current point (X, Y). To obtain the results the calculate button should be pressed. To plot the graph, the user should select one of the three buttons at the bottom of the window.

The exposure of EMF for human standing near the power lines (on ground): A few assumptions were made in order to analyze the three component values which are the potential voltage, electric field strength and magnetic flux density. First, the value of Y was made to be 1 meter. The varying distance at the horizontal point is increase by 1 m.



Electromagnetic Field Calculation At 132 KV overhead Transmission Lines

Current Point (X,Y)

X= 10 Y= 10

Result of Calculation

Electrical Potential (V): 3.98814

Electric Field Strength (E): 0.0499378

Magnetic Flux Density (B): 9.18584

Fig. 6: Matlab graphic user interface

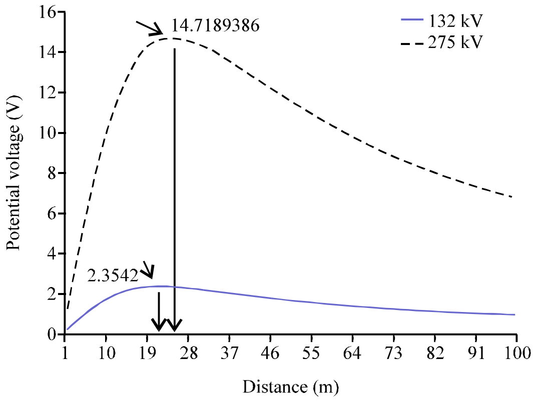


Fig. 7: Potential voltage versus distance

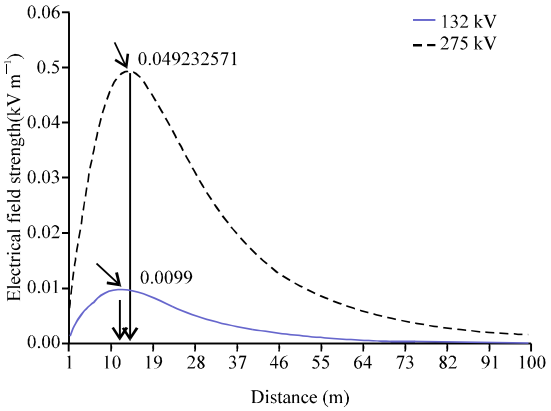


Fig. 8: Electric field strength versus distance

Figure 7 shows the potential voltage versus distance for both power lines, 132 and 275 kV. The curves for both 132 and 275 kV have the same pattern. The value of potential voltage increases up until it approaches the maximum value and then slowly diminishes. For 132 kV, the highest value of the potential voltage is 2.35 V at distance X = 21 m, whereas the highest value for 275 kV is 14.72 V at distance X = 24 m. The highest value of potential voltage for the 275 kV is 6 times greater than the highest value potential voltage of the 132 kV tower.

Figure 8 shows the electric field strength versus distance for both power lines, 132 and 275 kV. For

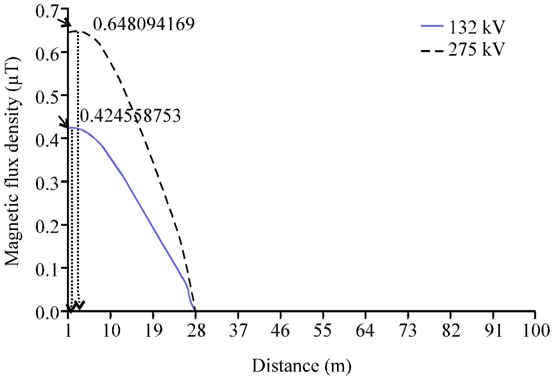


Fig. 9: Magnetic flux density versus distance

132 kV, the highest value of the electric field strength is 0.0099 kV m^{-1} at the distance X = 12 m. The highest value of electrical potential for 275 kV is 0.0492 kV m^{-1} at distance X = 14 m. The highest electric field strength for 275 kV is about 5 times greater than the highest electric field strength of the 132 kV tower. After the highest value, the electric field strength decreases as the distance X increases. The curves pattern of the electric field strength is similar to the curves pattern of the potential voltage. The similarity of the curves pattern is because the same value of electrical charge q_k is applied in order to calculate the potential voltage and electric field strength.

Figure 9 shows the magnetic flux density versus distance for both power lines. For 132 kV, the highest value of the magnetic flux density is 0.425 µT at distance X = 1 m. The highest value of magnetic flux density for 275 kV is 0.648 µT at distance X = 2 m. The highest value of magnetic flux density for 275 kV is about 1.5 times greater than the highest magnetic flux density value for 132 kV. By referring to Fig. 9, it can be observed that the magnetic flux density is drastically decreases after the highest value and reaches the minimum value approximately 0 iT at distance X = 28 m. The calculation of the magnetic flux density is influenced by the amount of current, I at the conductor of the overhead power lines.

Electric and magnetic fields exposure for live-line workers: This study was conducted for 6 different exposure scenarios near a power line which represent actual working conditions where live-line workers are likely to be exposed for activities such as live insulator washing or live visual inspection (SEC, 2005). These scenarios were selected based on the coordination of live-line worker while on the site. These scenarios are illustrated in Fig. 10. The calculations of electric and magnetic fields have been conducted for all the scenarios.

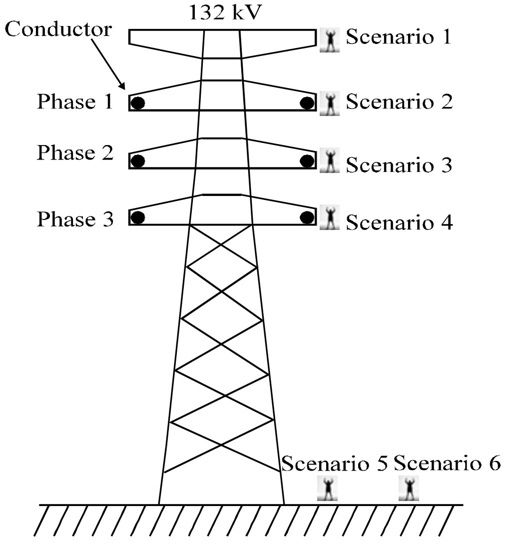


Fig. 10: Coordinate for 6 scenarios live line worker for 132 and 275 kV towers

The value of electric and magnetic fields of these six calculated values for each scenario was selected as the exposure level for that scenario and is presented in Table 2.

For the 132 kV tower, the highest exposure level is at scenario 4, where the electric field strength E and magnetic flux density B are equal to 413.747 kV m^{-1} and 73482.4 µT, respectively. This corresponds to a worker standing close to the conductor at phase 3, which is about 0.1 m away from it. For the 275 kV tower, the highest exposure level for both E and B are equal to 1047.8 kV m^{-1} and 92014 µT, respectively, which is at scenario 2. It is corresponding to a worker standing close to conductor phase 1 and about 0.16 m away from the conductor. The value of electric field and magnetic flux density decreases as the distance increases (Yeo *et al*., 2008).

The American Conference of Government Industrial Hygienists (ACGIH) has recommended limitations on the exposure to magnetic fields, electric fields and contact currents in the frequency of 50/60 Hz. The exposure limits are for both controlled (occupational, live-line workers) and uncontrolled (publicly accessible) environments (NIEHS-NIH, 2002). The Maximum Permissible Exposure (MPE) for the electric fields and magnetic fields (magnetic flux density) for exposure to the whole body as per the ACGIH Standards are 25.5 kV m^{-1} and 1000 µT, respectively for a controlled (occupational) environment. Thus, electric fields and magnetic fields exposure level at scenario 1, 5 and 6 for both power lines are much lower than the limit set by the standard. This corresponds to a

Table 2: The electric field strength and magnetic flux density calculated at the 6 scenarios for live-line worker at 132 and 275 kV towers

	132 kV tower				275 kV tower			
Scenario	Coordinate X,Y	Distance to the nearest conductor (m)	Electric field strength (kV m^{-1})	Magnetic flux density (μT)	Coordinate X,Y	Distance to the nearest conductor (m)	Electric field strength (kV m^{-1})	Magnetic flux density (μT)
1	4.42, 29	2.78	0.486	215.329	6.55, 34	3.16	2.86	355.07
2	4.42, 26	0.22	57.697	20081.5	6.55, 31	0.16	1047.8	92014
3	4.42, 23	0.44	47.472	4655.43	6.55, 26	0.34	213.23	17621.4
4	4.42, 19	0.1	413.747	73482.4	6.55, 20	0.48	116.96	6994.23
5	4.42, 1	17.9	0.00583	0.4149	6.55, 1	19.48	0.0357	0.625
6	12, 1	17.9	0.0099	0.3185	12, 1	19.48	0.0485	0.5295

worker who is far from the conductor, or standing on the ground and at the edge of the right of-way of the transmission line.

CONCLUSIONS

This study presents analytical calculus method of the potential voltage, electric field strength and magnetic field around the 132 and 275 kV overhead power lines. The results show that the exposure to the public is low if they stay at least 30 m away from the power lines. The results also present the position that could be dangerous to the live-line worker. For the live-line worker, the exposure to the high electric and magnetic field could endanger their body if they stay at that particular position for a long period. This study is important and the results could be a benchmark for the evaluation of potential voltage, electric field and magnetic field for the overhead power lines in Malaysia.

A user-friendly windows application for the evaluation of potential voltage, electric field and magnetic field based on the analytical calculus method has been developed. The simulation indicates that the developed visualization is helpful to understand analysis results and can be used as a simple tool to estimate the fields for the overhead power lines.

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