Effects of parameter adjustment on the electromagnetic field of an overhead power transmission line model

Sharin Ab Ghani[1], Mohd Shahril Ahmad Khiar[1], Imran Sutan Chairul[1], Nor Hidayah Rahim[1], Syahrun Nizam Md Arshad@ Hashim[2]
[1]High Voltage Engineering Research Laboratory, Faculty of Electrical Engineering, Universiti Teknikal Malaysia Melaka, Melaka, Malaysia
[2]School of Electrical Systems Engineering, Universiti Malaysia Perlis, Pauh Putra Campus, Perlis, Malaysia

Article Info

Article history:

Received Mar 2, 2022
Revised Jan 2, 2023
Accepted Jan 9, 2023

Keywords:

Electromagnetic field
Finite element model
Power transmission line
Right-of-way
Safety

ABSTRACT

Studies have shown that high-voltage power transmission lines emit electromagnetic radiation, which has adverse effects on human health. This paper presents the effects of parameter adjustment on the electric and magnetic fields of an overhead power transmission line model at human height. A finite element software, COMSOL multiphysics, was used to simulate the electric and magnetic fields. The electric and magnetic fields generated by the 1200-kV and 220-kV overhead power transmission line models were first computed and the models were validated by comparing the simulation results with those of previous studies. Numbers of parameter were adjusted in order to investigate their effects on the electric and magnetic field distributions. Based on the results, the electric field intensity increases with an increase in the voltage of the conductors. The magnetic field density increases with an increase in the current carried by the conductors. A voltage of 700 kV results in an electricity field intensity that exceeds the residential safety limit (50 kV/m) set by the International Commission on Non-Ionizing Radiation Protection. Hence, a proper right-of-way is needed to ensure that residential areas are at a safe distance away from transmission towers.

Corresponding Author:

Sharin Ab Ghani
High Voltage Engineering Research Laboratory, Faculty of Electrical Engineering
Universiti Teknikal Malaysia Melaka
Hang Tuah Jaya, 76100 Durian Tunggal, Melaka, Malaysia
E-mail: sharinag@utem.edu.my

1. INTRODUCTION

High-voltage power transmission lines, which act as a key link between electricity generation and consumers, play a vital role in power networks. These days, power transmission lines are located closer to urban and residential areas, resulting in an increase in the electromagnetic field [1], [2]. Electromagnetic radiation can have undesirable effects on human health as it can lead to cancer and leukaemia [3], [4]. Electrical workers in charge of maintaining power transmission lines to ensure uninterrupted electricity supply to consumers are particularly at risk owing to direct exposure to electromagnetic radiation generated by the power transmission lines. In general, the electric field intensity is proportional to the voltage of the power transmission lines. Hence, the higher the voltage of the power transmission lines, the higher the electric field intensity will be. In addition, the electric field is still present in the absence of current flow. The magnetic field is directly proportional to the current carried by power transmission lines and thus, a magnetic field will be generated in the presence of current flow [5]-[8]. Studies have shown that the maximum body current induced by the electric field from a transmission line is significantly higher than the body current or current density induced by the magnetic field [9]. The World Health Organization (WHO) has stipulated the maximum exposure times to minimize health hazards resulting from exposure to electromagnetic radiation [10]. Hence, to minimize the adverse effects of electromagnetic radiation on human health, many studies have been carried out worldwide to analyse the electromagnetic field generated by power transmission lines in order to ensure that the electromagnetic field does not exceed the safety limits set by standards [5], [7]-[9]. Some of these studies are shown in Figure 1. Figure 1(a) and 1(b) shows transmission lines model in Indonesia and Malaysia whilst Figure 1(c) and 1(d) are model located at Algeria and Iran. These studies have evaluated the electromagnetic field generated by high-voltage power transmission lines and assessed the effect of electromagnetic field on humans using various computational methods.

(a) (b) (c) (d)

Figure 1. Photographs of studies related to the evaluation of electromagnetic field within proximity of high-voltage power transmission lines: (a) 150-kV compact SUTT transmission tower model in Indonesia [11], (b) 132-kV overhead power transmission line model in Malaysia [5], (c) multi-line 60-kV parallel transmission line model in Algeria [12], and (d) two bundle single-circuit 400-kV transmission tower model in Iran [10]

According to Kuffel *et al.* [13], the only viable approach to solve problems related to high-voltage engineering structures with complex geometry is numerical methods. The electric field of high-voltage power transmission lines can be determined by using the finite element method (FEM), boundary element method (BEM), monte carlo method (MCM), finite difference method (FDM), and charge simulation method (CSM) [14]-[16]. The most common methods used to solve the electric field of high-voltage power transmission lines are FEM and CSM [17]. FEM is a method used to solve partial differential equations after applying Green's theorem to Maxwell's equations of electromagnetism [18]. FEM divides the continuous functions (indicating the physical phenomena to be investigated and represented by partial differential equations) into minute finite elements-a process known as discretization. The advantage of the FEM is that the method can automatically satisfy the boundary conditions when the functions in the field change sharply [19], [20]. Das *et al.* [9] determined the electric field by using analytical and numerical methods and the results are presented in Table 1. Simulations of the electric field within vicinity of a human body model standing at a certain horizontal distance away from 400-kV overhead power transmission lines were carried out using a FEM software, ANSYS. The electric field intensity at the surface of the human body when the human model is directly underneath the 400-kV overhead power transmission lines (distance=0 m) is 5.11 kV/m and 5.28 kV/m using the FEM and analytical method, respectively. In general, the simulation and analytical results show good agreement.

Table 1. Comparison of the electric field determined using a FEM software, ANSYS, and analytical method [9]

Distance (m)	Electric field (kV/m)	
	ANSYS	Analytical method
0	5.11	5.28
1	4.77	4.74
2	4.35	4.37
3	4.05	4.09
4	3.77	3.72
5	3.55	3.59

According to Balaji [21], the electromagnetic fields can have various effects on the human body and these effects may be short term or long term. When an individual is exposed to electromagnetic radiation within a short period, the individual may experience short-term effects such as headache, dizziness, vomiting, irritation, fatigue, and insomnia. The International Commission on Non-Ionizing Radiation Protection (ICNIRP) is a non-governmental organization in official collaboration with the WHO [22]-[25]. Although power transmission lines benefit consumers in terms of electricity supply, they also emit electromagnetic radiation, which is undesirable since the exposure to this electromagnetic radiation can lead to health hazards [26]. This is particularly true for long exposures above the exposure limits specified by standards. Exposure to electromagnetic radiation is a growing concern among the public, even more so when transmission towers are built closer to residential areas. The electric and magnetic fields generated by power transmission lines vary in magnitude depending on several parameters. Hence, this study is carried out to investigate the effects of parameter adjustment (voltage of the conductors, current carried by the conductors, conductor radius, and horizontal spacing between the phase conductors) on the electric and magnetic field distributions of an overhead power transmission line model using COMSOL Multiphysics FEM software. It is believed that this study will provide insight on the electrical and magnetic field distributions within proximity of power transmission lines and determine whether the electric and magnetic fields are within the safety limits set by the ICNIRP.

2. METHOD

The main goal of this study is to examine the electric field intensity and magnetic flux density distributions of an overhead power transmission line model at human height. The methodology adopted in this study is divided into two phases. In Phase 1, two-dimensional overhead power transmission line models were developed using COMSOL Multiphysics Version 6.0 software in order to determine the electric and magnetic field distributions at human heights. The overhead power transmission line models were validated by comparing the simulation results with those of Arora and Deshpande [27] and Rachedi *et al.* [28]. In Phase 2, the parameters (voltage of the conductors, current carried by the conductors, conductor radius, and horizontal spacing between the phase conductors) were adjusted to investigate their effects on the electric and magnetic field distributions of the overhead power transmission line model.

A. Phase 1

Two overhead power transmission line models were developed in this study, one to assess the electric field distribution, and the other to assess the magnetic field distribution. The first step involves defining the dimensions of the transmission tower. The materials of the transmission lines were then defined as the boundary conditions. The computational domains of both models were then meshed. Finally, the electric and magnetic field distributions were generated using the Electrostatics module and Magnetic Field module in COMSOL Multiphysics software, respectively. The overhead power transmission line models were validated by comparing the simulation results with those of previous studies as shown in Figure 2.

To determine the electric field distribution, the model was developed based on the work of Arora and Deshpande [27], which is a 1200-kV overhead power transmission line model with D/C vertical configuration, as shown in Figure 2(a). Each phase consists of two cables and the conductor radius is 0.518 m. The distance from the ground to the lowest conductor is 24.3 m while the vertical distance between the phase conductors is 26 m. To determine the magnetic field distribution, the overhead power transmission line model was developed based on the work of Rachedi *et al.* [28]. The transmission lines carry 270 A of current and the conductor radius is 0.572 cm. Each phase consists of two cables and the spacing between these cables is 40 cm. The vertical distance from the ground to the conductors is 20.2 m. The guard cables are located 24.8 m away from the ground and the guard cables are assumed to have the same radius as that of the conductors. Figure 2(b) shows the overhead power transmission line model developed by Rachedi *et al.* [28].

B. Phase 2

The same overhead power transmission line model was used for the parameter adjustment study. The form union function was used for the overhead power transmission line model developed in the magnetic field module and the model was then exported to the electrostatics module, where the models in these modules were unified to form a single object. The following parameter of voltage of the conductors was adjusted in order to investigate their effects on the electric field distribution of the overhead power transmission line model. The default voltage was set at 100 kV while the default conductor radius was 0.01 m (0.1 cm). The electric field intensity was then computed. The cut line was plotted from ($x = -30$ m, $y = 1.8$ m) to ($x = 30$ m, $y = 1.8$ m) to examine the electric field intensity at human height. The residential safety limit set by the ICNIRP was also plotted, which serves as a benchmark to compare the results. Likewise, the following parameter of current carried by the conductors was adjusted in order to investigate their effects on the magnetic field distribution of the overhead power transmission line model.

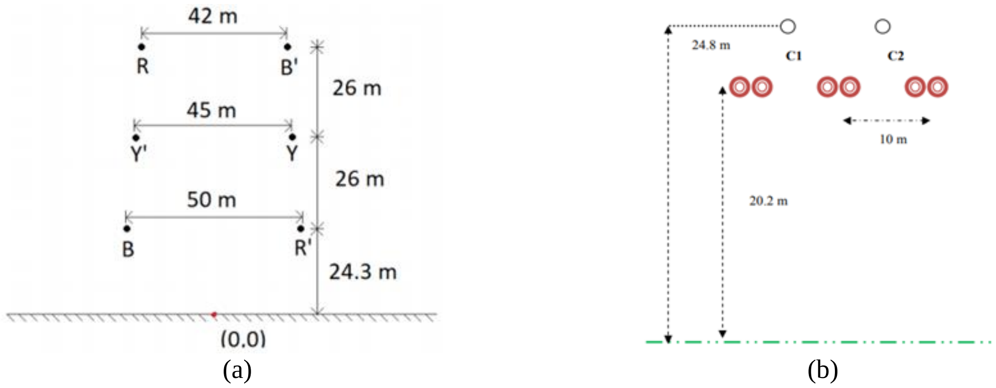


Figure 2. Diagram of power transmission line model: (a) 1200-kV overhead power transmission line model with D/C vertical configuration developed by Arora and Deshpande [27] used to determine the electric field distribution and (b) Figure 5 220-kV overhead power transmission line developed by Rachedi *et al.* [28] used to determine the magnetic field distribution

3. RESULTS AND DISCUSSION

The simulation results for Phase 1 (electric and magnetic field distributions for different overhead power transmission line models) are presented and discussed in this section. The simulation results include a contour map of the electric field intensity and two-dimensional line plots of the electric field intensity and magnetic flux density at various heights above the ground. The results were compared with those of previous studies in order to validate the overhead power transmission line models. Next, the simulation results for Phase 2 (effect of parameter adjustment on the electric and magnetic field distributions) are presented and discussed. The results were compared with the residential safety limits established by the ICNIRP.

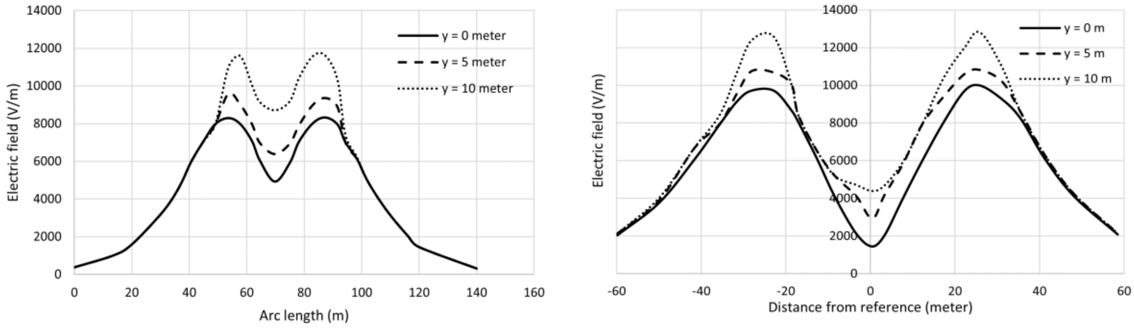
A. Validation of the overhead power transmission line models

Figure 3 shows diagram of simulation results based on electric field. Figure 3(a) shows the two-dimensional line plot of the electric field intensity at various heights above the ground ($y = 0$ m to $y = 10$ m with a step size of 1 m). The arc length of 140 m represents the horizontal distance from $x = -70$ m to $x = 70$ m. It can be observed that there are two peaks, which correspond to the geometry of the overhead power transmission line model. One peak occurs at an arc length of 57 m while the other occurs at an arc length of 83 m, indicating that the peak occurs at $x = -13$ m and $x = 13$ m, respectively. This is likely due to the positions of the conductors, which are located on the same x-axis. The lowest peak (electric field intensity: 8.3 kV/m) occurs at a height of $y = 0$ m, which is expected as this is the furthest distance from the conductors. Based on the trend, the electric field intensity increases with an increase in the height from the ground and thus, the electric field intensity is highest at a vertical distance closest to the conductors. Indeed, the highest peak (electric field intensity: 11.8 kV/m) occurs at $y = 10$ m, which is the vertical distance closest to the conductors.

Figure 3(b) shows the simulation results of Arora and Deshpande [27]. The electric field intensity is 8.7 kV/m at $y = 0$ m and the electric field intensity is 12.5 kV/m at $y = 10$ m. The trend is similar to that for the simulation results in this study, where the electric field intensity increases with an increase in height above the ground. The simulation results in this study are similar to those of Arora and Deshpande [27], with only a small difference in magnitude, which is probably due to the difference in the version of COMSOL multiphysics software and limitation of data. Owing to the small difference in magnitude of the simulation results, the overhead power transmission line model is validated.

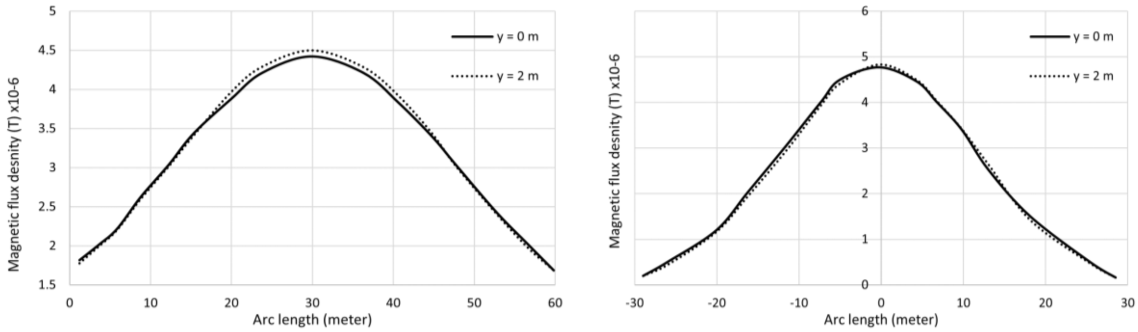
Figure 4 shows diagram of simulation results based on magnetic field. To analyse the magnetic field distribution of the 220-kV overhead power transmission line model, a two-dimensional line plot of the magnetic flux density was plotted, as shown in Figure 4(a). It can be seen that the magnetic flux density is lowest at $y = 0$ m and an arc length of 30 m, with a value of 4.4 µT. The cut line is taken from $x = -30$ m to $x = 30$ m and therefore, an arc length of 30 m represents $x = 0$ m, which is the centre of the overhead power transmission line model. Hence, the highest magnetic flux density occurs at the centre of the overhead power transmission line model. The magnetic flux density slightly increases as the height above the ground is increased from $y = 1.5$ m to $y = 1.8$ m. The magnetic flux density at $y = 1.8$ m is only 4.6 µT.

Figure 4(b) shows the simulation results [28]. In general, the peaks occur at $x = 0$ m. The highest peak occurs at $y = 1.8$ m, with a value of 4.8 µT. The magnetic flux density is slightly less than 4.8 µT at $y = 0$ m and $y = 1.5$ m. The simulation results of this study show good agreement with those of [28], thereby validating the overhead power transmission line model.



(a) (b)

Figure 3. Diagram of simulation results: (a) variation of the electric field intensity with respect to the arc length for different heights and (b) simulation results of Arora and Deshpande [27]



(a) (b)

Figure 4. Diagram of simulation results: (a) variation of the magnetic field density with respect to the arc length for different heights and (b) simulation results of Rachedi *et al.* [12]

B. Effect of voltage on the electric field distribution

Figure 5 shows the two-dimensional line plot of the electric field distribution when the voltage of the conductors is varied from 100 kV to 1000 kV while the other parameters are kept constant. The horizontal distance is taken from $x = -70$ m to $x = 70$ m with an arc length of 70 m representing $x = 0$ m. It can be seen from Figure 5 that the electric field intensity is the lowest (0.7 kV/m) when the voltage of the overhead power transmission line model is 100 kV and the height is $y = 1.8$ m. In contrast, the electric field intensity is the highest (7 kV/m) when the voltage is 1000 kV. The trend shows that increasing the voltage of the conductors increases the electric field intensity at human height. The results conform with the formula $\vec{E} = -\vec{\nabla} V$, which indicates that the electric field is directly proportional to the gradient of the electric potential. When the voltage of the conductors is set at 700 kV, the electric field intensity exceeds the residential safety limit (5 kV/m) established by the ICNIRP. Hence, a proper right-of-way is necessary to protect residential areas from the harmful effects of electromagnetic radiation when the voltage of the conductors exceeds 700 kV.

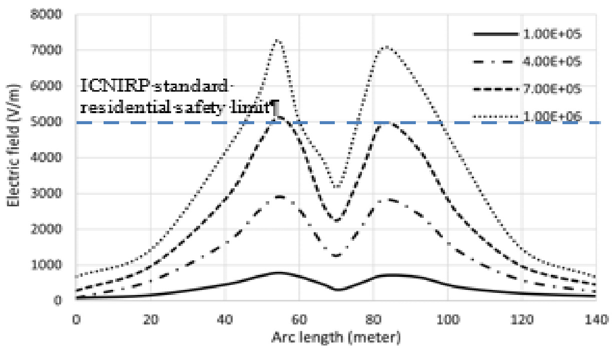


Figure 5. Effect of voltage on the electric field distribution of the overhead power transmission line model

C. Effect of current carried by the conductors on the magnetic field distribution

Figure 6 shows the two-dimensional plot of the magnetic flux density at a human height of *y*=1.8 m, where the current carried by the conductors is varied from 100 A to 1,000 A. It can be observed that the peak magnetic flux density is lowest (1.8 μT) when the current is set at 100 A. When the current is set at 1000 A, the peak magnetic flux density is highest, with a value of 16.3 μT. In general, the trend indicates that the magnetic flux density increases with an increase in the current carried by the conductors. The trend can be explained by the formula $B = \frac{\mu_0 \mathrm{I}}{2\pi \mathrm{r}}$, where the current is directly proportional to the magnetic field. However, it is worth noting that the magnetic flux density is still well below the residential safety limit of 100 μT set by the ICNIRP for the range of current (100–1,000 A) investigated in this study.

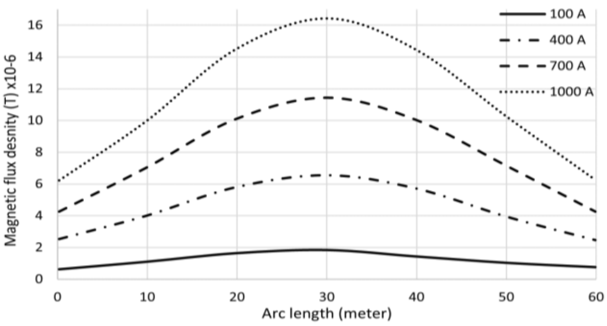


Figure 6. Effect of current carried by the conductors on the magnetic field distribution of the overhead power transmission line model

4. CONCLUSION

The increase in electricity demands over the years has led to an increase in the number of transmission towers within proximity of residential areas. Transmission lines emit electromagnetic radiation, which is hazardous to human health in the short term and long term. For this reason, it is important to investigate how different parameters of the transmission tower affect the electric and magnetic fields and determine if the electric and magnetic fields are well below the residential safety limits, which is the focus of this study. In this study, overhead power transmission line models were first developed using COMSOL multiphysics software and the models were validated by comparing the simulation results (electric field intensity and magnetic flux density distributions) with those of previous studies. The simulation results show good agreement with those of previous studies, validating the overhead power transmission line models. Next, the effect of voltage on the electric field distribution and the effects of current carried by the conductors on the magnetic field distribution were investigated by adjusting these parameters. Based on the results, it can be concluded that the electric field intensity at human height increases with an increase in the voltage of the conductors of the overhead power transmission line model. The magnetic flux density increases with an increase in the current carried by the conductors. In general, the electric field intensity and magnetic flux density are well below the residential safety limits set by the ICNIRP. However, such is not the case for voltage adjustment, where a voltage of more than 700 kV results in an electric field intensity above the residential safety limit established by the ICNIRP. This will be hazardous to human health in the short term and long term. Hence, a proper right-of-way is needed to ensure that the residential areas are at a safe distance away from the transmission towers.

ACKNOWLEDGEMENTS

The authors gratefully acknowledge the financial support provided by the Universiti Teknikal Malaysia Melaka (UTeM). The authors also thank Mr. Lee Zher Ye for aiding on the preparation and simulation works used in this study.

REFERENCES

[1] M. Talaat, "Calculation of electric and magnetic induced fields in humans subjected to electric power lines," *Journal of Electrostatics,* vol. 72, no. 5, 2014, doi: 10.1016/j.elstat.2014.06.008.
[2] D. M. Petković, D. D. Krstić, and V. B. Stanković, "The effect of electric field on humans in the immediate vicinity of 110 kV power lines," *Working and Living Environmental Protection,* vol. 3, no. 1, 2006.
[3] P. Faeghi, M. Narimani-rad, and E. B. Pour, "Electromagnetic fields and its effect on chicken embryo," *Biological Forum – An International Journal,* vol. 7, no. 1, 2015.

[4] P. A. Kokate, A. K. Mishra, S. K. Lokhande, and G. L. Bodhe, "Extremely low frequency electromagnetic field (ELF-EMF) and childhood leukemia (CL) near transmission lines: A review," *Advanced Electromagnetics*, vol. 5, no. 1. 2016, doi: 10.7716/aem.v5i1.348.

[5] S. A. Ghani, M. S. A. Khiar, I. S. Chairul, M. Y. Lada, and N. H. Rahim, "Study of magnetic fields produced by transmission line tower using finite element method (FEM)," in 2014 2nd *International Conference on Technology, Informatics, Management, Engineering & Environment, Aug.* 2014, pp. 64–68, doi: 10.1109/TIME-E.2014.7011593.

[6] R. Patidar, A. Kumar, and M. Dubey, "Analysis of electromagnetic pollution due to high voltage power transmission line interference on human health," *Analysis of Electromagnetic Pollution Due To High Voltage Power Transmission Line Interference on Human Health,* vol. 5, no. 4, 2015.

[7] H. W. Adams and J. D. Trivette, "Evaluation of magnetic field and system loss considerations for changes in transmission network configuration," *IEEE Power Engineering Review*, vol. 16, no. 10, 1996, doi: 10.1109/mper.1996.4311054.

[8] A. Ma and J. Chen, "Analysis of the three-dimensional hybrid electric fields and the related electrostatic induction effects of 800 kV DC and 500 kV AC parallel transmission lines considering environmental factors," *Electric Power Systems Research*, vol. 163, 2018, doi: 10.1016/j.epsr.2017.11.008.

[9] H. Das, K. Gogoi, and S. Chatterjee, "Analysis of the effect of electric field due to high voltage transmission lines on humans," In 2015 1st *Conference on Power, Dielectric and Energy Management at NERIST (ICPDEN)*, 2015, pp. 1-4, doi: 10.1109/ICPDEN.2015.7084491.

[10] H. Javadi, A. Mobarhani, and A. Ameli, "Electric field evaluation of 400KV overhead transmission lines on the earth surface," in *IET Conference Publications*, vol. 2010, no. 567, 2010, doi: 10.1049/cp.2010.0841.

[11] T. Akmal, U. Khayam, and L. S. Lumba, "Study of electromagnetic effect of 150 kV transmission line," In *2019 2nd International Conference on High Voltage Engineering and Power Systems (ICHVEPS)*, 2019, doi: 10.1109/ICHVEPS47643.2019.9011094.

[12] B. A. Rachedi, A. Babouri, A. Lemzadmi, M. Nemamcha, and F. Berrouk, "Evaluation of electromagnetic field produced by multi-parallel high voltage lines," *In 2014 IEEE International Conference on Intelligent Energy and Power Systems (IEPS)*, 2014, pp. 33-39, doi: 10.1109/IEPS.2014.6874197.

[13] E. Kuffel, W. S. Zaengl, and J. Kuffel, "*High Voltage Engineering Fundamentals*," Second Edition, vol. 1, no. c, 2000.

[14] Z. Anane and F. Aouabed, "Electromagnetic fields analysis on OTL with presence of human body model using comsolmultiphysics," in *2017 5th International Conference on Electrical Engineering - Boumerdes*, 2017, doi: 10.1109/ICEE-B.2017.8191985.

[15] G. A. Kulkarni and W. Z. Gandhare, "Numerical calculation of internal induced fields in humans due to high voltage transmission lines," *Acta Electrotechnica et Informatica,* vol. 14, no. 3, 2014, doi: 10.15546/aeei-2014-0024.

[16] C. J. Papachristou, "Introduction to electromagnetic theory and the physics of conducting solids," *Springer Nature*, 2019, doi: 10.1007/978-3-030-30996-1.

[17] L. Q. Shang and M. Li, "Simulation study on electric field of UHV transmission lines with different numbers of sub-conductors," *In 2016 IEEE International Conference on High Voltage Engineering and Application (ICHVE),* 2016, pp. 1-4, doi: 10.1109/ICHVE.2016.7800588.

[18] J. Bilbao, E. Bravo, O. Garcia, C. Rebollar, and C. Varela, "Numerical analysis of electromagnetic fields," in *Power Systems*, 2021, doi: 10.1007/978-3-030-62191-9_19.

[19] Z. Liu, J. Wang, M. S. Wang, Y. Lu, R. Huang, and Y. Chen, "Finite element method and charge coupling method for distortion field of AC transmission line," in *2019 IEEE Sustainable Power and Energy Conference (iSPEC),* pp. 1049-1053, 2019, doi: 10.1109/iSPEC48194.2019.8975080.

[20] M. M. Samy, "Computation of electromagnetic fields around HVDC transmission line tying EGYPT and KSA," in *2017 19th International Middle-East Power Systems Conference, MEPCON 2017 - Proceedings,* 2018, doi: 10.1109/MEPCON.2017.8301345.

[21] A. Balaji, "Effect of high voltage transmission lines on human health, plant life, and animal activity," *International Research Journal of Engineering and Technology,* 2015.

[22] G. Ziegelberger, "ICNIRP statement on the 'guidelines for limiting exposure to time-varying electric, magnetic, and electromagnetic fields (UP to 300 GHz)," *Health Physics,* vol. 97, no. 3. 2009, doi: 10.1097/HP.0b013e3181aff9db.

[23] A. Ahlbom *et al*., "Guidelines for limiting exposure to time-varying electric, magnetic, and electromagnetic fields (up to 300 GHz)," *Health Physics,* vol. 74, no. 4. 1998.

[24] A. Siriwitpreecha and P. Rattanadecho, "Numerical analysis of biological effects on several organs inside human body exposed to electric field from 500 kV OHTLs," *Songklanakarin Journal of Science and Technology,* vol. 41, no. 3, 2019, doi: 10.14456/sjst-psu.2019.85.

[25] B. M. Alameri, "Electromagnetic interference (EMI) produced by high voltage transmission lines," *EUREKA, Physics and Engineering,* vol. 2020, no. 5, 2020, doi: 10.21303/2461-4262.2020.001398.

[26] M. Talaat, "Calculation of electrostatically induced field in humans subjected to high voltage transmission lines," *Electric Power Systems Research,* vol. 108, 2014, doi: 10.1016/j.epsr.2013.11.004.

[27] A. A. Arora and A. S. Deshpande, "Analysis of the electric field of the 1200kv power transmission line using the finite element method," in *2019 International Conference on Communication and Electronics Systems (ICCES),* 2019, pp. 1648-1653, doi: 10.1109/ICCES45898.2019.9002251.

[28] B. A. Rachedi, A. Babouri, and F. Berrouk, "A study of electromagnetic field generated by high voltage lines using COMSOL MULTIPHYSICS," in *2014 International Conference on Electrical Sciences and Technologies in Maghreb (CISTEM)*, 2014, pp. 1-5, doi: 10.1109/CISTEM.2014.7076989.

BIOGRAPHIES OF AUTHORS

Sharin Ab Ghani received his BEng. (Hons.) degree in Electrical Engineering from Universiti Teknikal Malaysia Melaka (UTeM) in 2008, MEng. Degree in Electrical Engineering from Universiti Tenaga Nasional in 2012, and Ph.D degree in Electrical Engineering from Universiti Teknologi Malaysia in 2019. Currently, he is serving as Senior Lecturer at Faculty of Electrical Engineering, UTeM and head of energy and power systems (EPS) Research Group. His research interests are centered on high voltage engineering, condition monitoring of power equipment, eco-friendly electrical insulation, design of experiments, and optimization. He also has experience in consultation work with industries related to electrical installation design, transformer condition assessment, and partial discharge analysis. He can be contacted at email: sharinag@utem.edu.my.

Mohd Shahril Ahmad Khiar received his BSc. in Electrical and Electronics Engineering from Korea University in 2008, Master's degree in Electrical Engineering from Universiti Tenaga Nasional in 2012, and Ph.D degree from University of Southampton, UK in 2019. He is currently serving as Senior Lecturer at Faculty of Electrical Engineering, UTeM and Head of High Voltage Engineering Research Laboratory in UTeM, where he is also the Deputy Head of Energy and Power Systems (EPS) Research Group. His research interests include high voltage engineering and insulation materials, sensors, condition monitoring for power equipment, and asset management. Since 2013, he has published over 20 refereed conference and journal papers associated with the transformer condition monitoring and asset management. He can be contacted at email: mohd.shahril@utem.edu.my.

Imran Sutan Chairul was born in Kuala Lumpur, Malaysia, in 1984. He received his BEng. (Hons.) degree in Electrical Engineering from Universiti Teknikal Malaysia Melaka (UTeM) in 2008 and MEng. degree in Electrical Engineering from Universiti Tenaga Nasional in 2012. He is currently pursuing his Ph.D degree at UTeM, where his research is focused on vegetable-based transformer dielectric liquids. He can be contacted at email: imransc@utem.edu.my.

Nor Hidayah Rahim received her BEng. in Electrical Engineering from Universiti Teknologi Malaysia in 2008 and her M.Eng. degree in Electrical Engineering from Universiti Tenaga Nasional, Malaysia in 2012. She recently completed her Ph.D degree at Universiti Teknologi Malaysia. She is now a Senior Lecturer at Faculty of Electrical Engineering, Universiti Teknikal Malaysia Melaka. Her research interests include high voltage engineering and dielectric materials. She can be contacted at email: hidayah.rahim@utem.edu.my.

Syahrun Nizam Md Arshad@ Hashim received his BEng. in Electrical Engineering from Universiti Teknologi Malaysia in 2008, MEng. Degree in Electrical Engineering from Universiti Teknologi Malaysia (UTM) in 2011, and Ph.D degree in Electrical Engineering from Universiti Putra Malaysia (UPM) in 2017. Currently, he is serving as Associate Professor at Faculty of Electrical Engineering Technology, UniMAP and Head of High Voltage and Transient (HVTrans) Research Group. Previously he was an Electrical Engineer at Minconsult Sdn. Bhd. and involved in many project developments. His current research interests including lightning protection system, renewable energy. He can be contacted at email: syahrun@unimap.edu.my.