Study on the Extremely Low Frequency (ELF) Electromagnetic Field (EMF) emission from overhead High-Voltage Transmission Lines

Shamesh Raj Parthasarathy, Roha Tukimin, Wan Saffiey Wan Abdullah,
Zulkifli Yusof, Mohd Azizi bin Mohd Jali
Radiation Health and Safety Division, Malaysian Nuclear Agency,
Bangi, 43000 Kajang, Selangor
shamesh@nuclearmalaysia.gov.my

Abstract

The paper highlights the study on the Extremely Low Frequency (ELF) Electromagnetic Field (EMF) emission performed at an overhead 275-kV High-Voltage Transmission Lines. The study comprised of assessment at the transmission lines on 3 different cases and locations in Klang Valley, specifically on a vacant land near the transmission line, inside and around the house at the vicinity of the transmission line and the area directly under the transmission line. The instrument setup and measurement protocols during the assessment were adopted from standard measurement method and procedures stipulated under the Institute of Electrical and Electronics Engineers (IEEE) Standard. The results were compared with the standards recommended in the International Commission on Non-Ionizing Radiation Protection (ICNIRP) guidelines. The results showed that the measured field strengths are within the safety limit with the highest measured exposure was 10.8 % and 1.8 % of the permissible exposure limit for the electric and magnetic field respectively. Both the field strengths were found to drop significantly against distance from the transmission lines where closer distances showed higher field strengths. Furthermore, the study revealed that buildings and other object such as trees and shrubs screen out the electric field, resulting in a lower value at indoor measurements and near the stated objects. In addition, higher value of electric and magnetic field strengths were recorded when assessment was being done directly under the transmission line compared to the lateral measurement.

Key words: Extremely low frequency, ELF, electromagnetic fields, EMF, High-Voltage Transmission Lines

Introduction

Everyone is exposed to various combinations of electromagnetic fields (EMF) of different frequencies that exist in our environments. Consistent with the advancement of technology, the rate of exposures to various EMF frequencies becomes increasingly significant. In spite of the fact that the colossal benefits of using electricity in everyday life are undeniable, the general public has become increasingly concerned about the potential adverse health effects of the exposure to electric and magnetic fields at extremely low frequencies (ELF). The stated exposures arise mainly from the transmission and use of electrical energy at the power frequencies of 50Hz as for the case of Malaysia.

Due to public complaint and concern, a study has been conducted to assess the extremely low frequency (ELF) radiations from the 275 kV High-Voltage Transmission Lines. The study comprised of assessment at the transmission lines on 3 different cases and locations in Klang Valley, specifically on a vacant land near the transmission line, inside and around the house at the vicinity of the transmission line and the area directly under the transmission line. The objective of the study is to determine the ELF levels emitted by the High-Voltage Transmission Lines and compare the results with the international recommendations of standard and guidelines issued by the International Commission on Non-Ionizing Radiation Protection (ICNIRP). In addition, the study intended to identify other factors that influence the electric and magnetic field strengths in all the three different cases.

Extremely Low Frequency (ELF) Electromagnetic Field (EMF)

Extremely low frequency (ELF) radiation is positioned at the low-energy end of the electromagnetic spectrum and is a type of Non-Ionizing Radiation (NIR). This particular non-ionizing radiation has sufficient energy only to move atoms in a molecule around and cause them to vibrate, but not enough energy to remove charged particles such as electrons and damage the DNA directly. ELF radiation has even lower energy than other types of non-ionizing radiation like radio frequency (RF) radiation, visible light, and infrared [1,2]. In order to characterize ELF fields, the strength, frequency, and orientation of the electric and magnetic fields have to be determined. Under high voltage transmission line, the electric field has its major component oriented vertically (perpendicular to the Earth's surface), while the main magnetic field component is horizontal (parallel to the Earth's surface). In practical situations, the electric and magnetic fields act independently of one another and therefore are measured separately [1-6].

Electromagnetic fields consist of electric and magnetic waves traveling together. They travel at the speed of light and are characterized by a frequency and a wavelength. Electric fields are produced by electric charges. They administer the motion of other charges situated in them. The electric field strength is measured in units of volt per meter (V/m) or kilovolt per meter (kV/m) [1]. When the charges accumulate on an object, they create a tendency for like or opposite charges to be repelled or attracted, respectively. The strength of that tendency is characterized by the voltage and is measured in units of volt (V). Any device connected to an electrical outlet, even if the device is not switched on, will have an associated electric field that is proportional to the voltage of the source to which it is connected. Electric fields are strongest close to the device and diminish with distance. The common shielding materials against the electric field are wood, concrete and metal [1-6].

Magnetic fields are produced by moving charges and thus are proportional to electric currents in a system, irrespective of the voltage used. Their strength is measured in units of ampere per meter (A/m) but is usually expressed in terms of the corresponding magnetic induction measured in units of gauss (G) and tesla (T) [1]. Any device connected to an electrical outlet, when the device is switched on and a current is flowing, will have an associated magnetic field, the strength of which is directly related to the current drawn from the source. Magnetic fields are strongest close to the device and become lower with distance. Most common materials do not shield them [1-6].

Health Effects of ELF EMF from High-Voltage Transmission Line

Numerous studies have been conducted through the past decades in order to find the existence of any relationship between the electromagnetic field emitted from high voltage transmission lines and major impacts on health such as cancer and other diseases. Most of the researches and studies performed, established that no relationship exists between chronic diseases and the electromagnetic field emitted from the transmission lines. A study conducted by National Institute of Environmental Health Sciences (NIEHS) stated that through experiments in laboratories, the probability of the exposure to the electromagnetic field (EMF) from transmission lines causing health hazard is currently small. Study conducted by World Health Organization (WHO) declared that the evidence of an association between EMF exposure and childhood leukemia is not strong enough to be considered causal, but sufficiently strong to remain a concern. In addition, an experiment performed in Canada showed the uncertainty of having a causal relationship between the magnetic fields developed by the transmission lines as well as that around the homes and the risk of having leukemia [2-6].

Overall, most scientists are convinced that the evidence of ELF EMF emanated from the transmission line to cause or contribute to chronic diseases or health hazards is weak to nonexistent. The biological studies conducted to date have not been able to establish a cause and effect relationship between exposure to magnetic field and human disease. Scientists have been unable to identify any plausible biological mechanism by which EMF exposure might cause human disease or deterioration in human health [5-8].

Permissible Exposure Limit

The maximum permissible exposure limits were developed to protect workers and the general population from harmful exposure to ELF EMF. Based on scientific knowledge and information available at the moment, prolonged exposure at or below the levels recommended by these standard guidelines is considered as safe and acceptable for the purpose of protection of human health. The permissible exposure limits for both workers and members of the public are excerpted from the ICNIRP and World Health Organization (WHO) guidelines. The exposure limits are set differently for workers and members of the public. Public being more critical to EMF because of longer exposure time involved, unknown exposure situation and more diverse in term of health status and age groups represented, has had the limits established at much lower levels (by 2 to 5 times) than the workers [5-9]. Based on these guidelines, the public exposure limit for electric and magnetic fields of ELF EMFs are 5,000 V/m and 1000 mGauss respectively for the frequency of 50Hz [6,8,9].

Description of Assessment Site

The study comprised of assessment at the high voltage transmission lines on 3 different cases and locations in Klang Valley, specifically;

i. On a vacant land near the transmission line,
ii. Inside and around the house at the vicinity of the transmission line, and
iii. Area directly under the transmission line

For the ease of reference, the 3 locations will be classified as TL1 for the location on a vacant land near the transmission line, TL2 for the location inside and around the house at the vicinity of the transmission line and TL3 for the area directly under the transmission line.

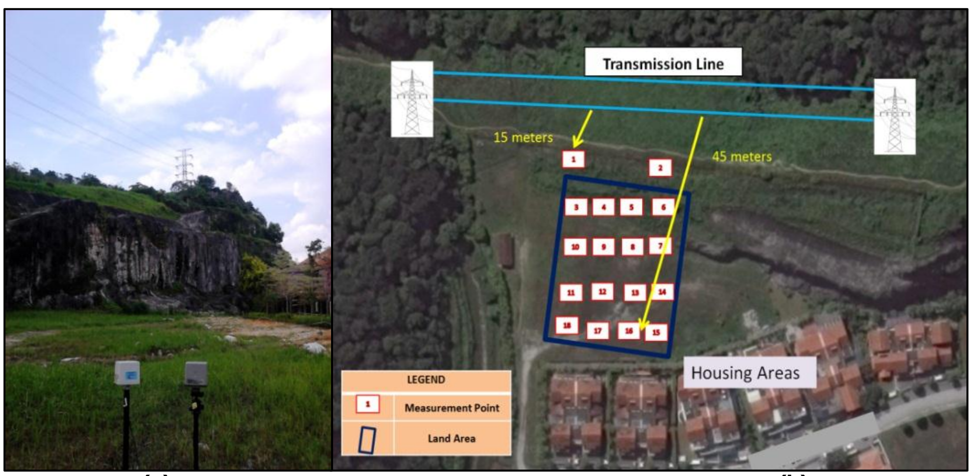
Measurement Method and Standard

Both the international and national standards provide exposure limits in terms of electric field strength E (V/m) and magnetic field strength H (mGauss) at power line frequencies. The instrument setup and measurement protocols during the assessment were adopted from standard measurement method and procedures stipulated under the Institute of Electrical and Electronics Engineers (IEEE) Standard. The electric and magnetic fields strengths must be measured accurately in order to fully assess the health implications of the field on humans. Free body probes and ground reference instruments are the two methods used for electric and magnetic field measurement [2,7-9]. In this study, free body probe was used for the measurement of the fields because it does not require a known ground reference for measurements anywhere above the ground [7-9].

Measurements of the field strengths were carried out using PMM instrument Model 8053 with an attached probe Model PMM EHP-50C (5Hz-100kHz) and Emdex II attached with the Linear Data Acquisition System (LINDA) measurement wheel. The PMM Instrument Model EHP-50C can measure both electric and magnetic fields simultaneously and the EMDEX II attached with LINDA was used to measure the the spatial distribution of the magnetic field. Readings were taken in miliGauss (mGauss) for the magnetic fields and volt per meter (V/m) for the electric fields.

The PMM Instrument Model EHP-50C were mounted on plastic tripods and set at one and a half (1.5) meter above ground to account for more representative condition of personnel exposure and to minimize interference (refer figure 1(a), 2(a) and 4(a)). The instruments were placed away from any objects and people to minimize perturbation of the fields. At each location, measurements were taken for a period of 20 minutes to minimize error due to fluctuation of the ELF EMF. The maximum, the minimum and the average readings over the measurement period were recorded. The distance measured was from the outermost conductor of the transmission line to the point of measurement. In addition to stationary measurements of the field strengths at the selected locations, Linear Data Acquisition System (LINDA), which includes a measurement wheel and an attachment to EMDEX II, was also used to measure the spatial distribution of the magnetic fields for the case of TL2 and TL3. It should be noted that measurement using the EMDEX II attached with LINDA was not performed on the location TL1 (On a vacant land near the transmission line) as the land was muddy and was having uneven terrain.

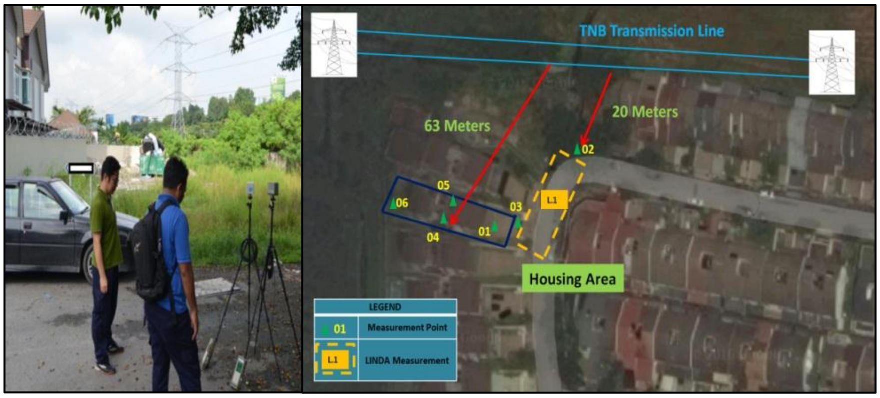
For the first case ,TL1, the measurements locations of electric and magnetic field using PMM EHP50C are labelled as point 1 to point 18 as shown in figure 1(b)



(a) **(b)**

Figure 1: (a) Setup of equipment and (b) layout of the measurement point locations for Case TL1

For the second case TL2, the measurement locations electric and magnetic field using PMM EHP50C are labelled as point 1 to 17 and magnetic field measurement using Emdex II with LINDA wheel is labelled as L.1 to L.5 as shown in figure 2(b) and figure 3.



(a) **(b)**

Figure 2: (a) Setup of equipment and (b) layout of the measurement point locations for Case TL2

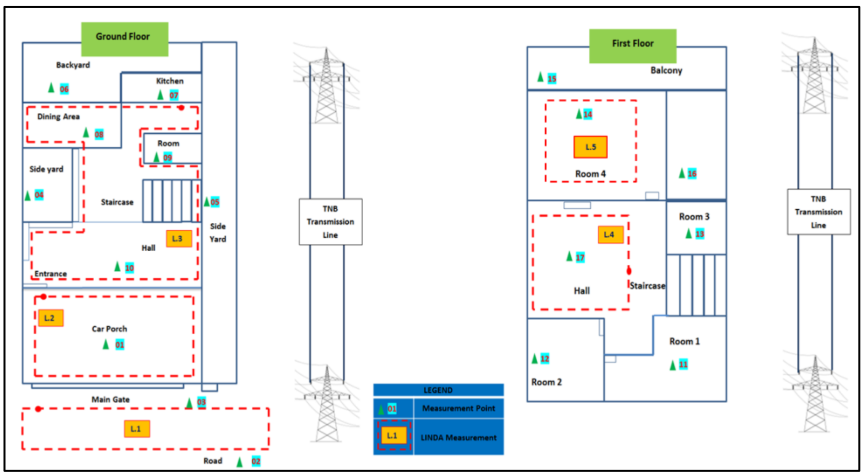
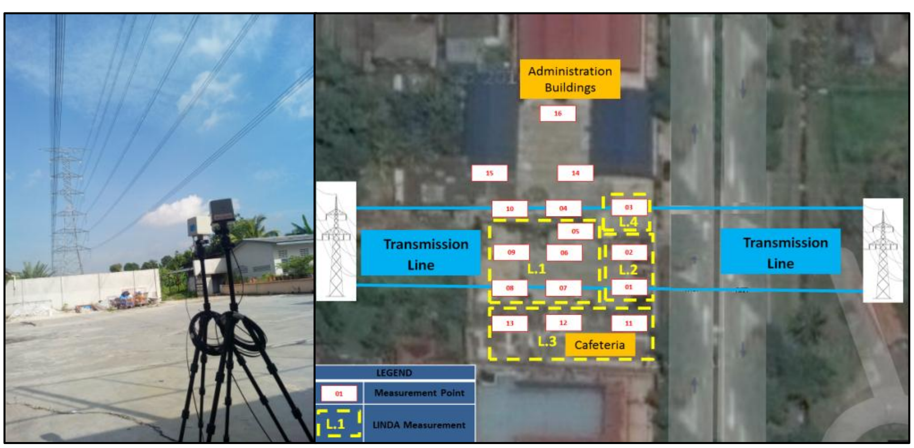


Figure 3: Layout of the measurement point locations inside the house for Case TL2

For the third case TL3, the measurement locations electric and magnetic field using PMM EHP50C are labelled as point 1 to 16 and magnetic field measurement using Emdex II with LINDA wheel is labelled as L.1 to L.4 as shown in figure 4(b).

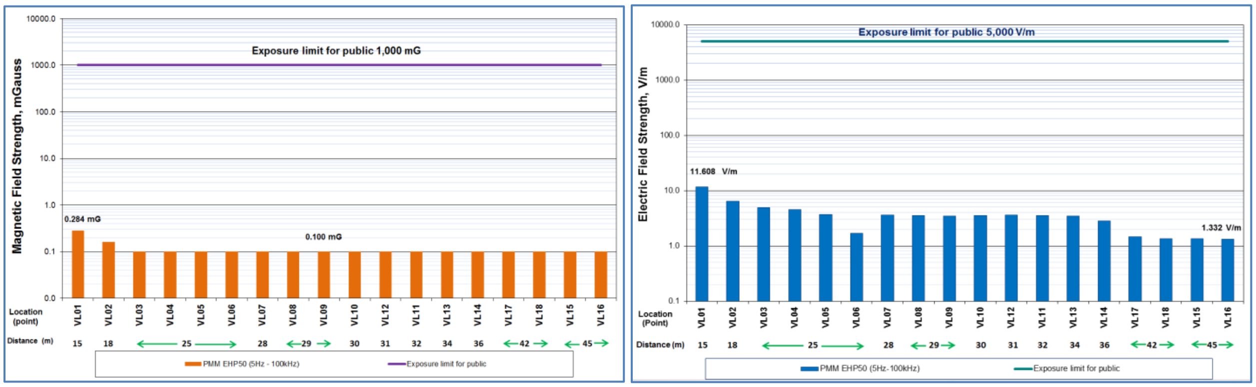


(a) **(b)**

Figure 4: (a) Setup of equipment and (b) layout of the measurement point locations for Case TL3

Results and Discussion

For the first case TL1, the averaged magnetic field strengths were found to vary from 0.100 mGauss to 0.284 mGauss. The highest averaged value was at 0.284 mGauss, which was measured at point 1(VL01), with the distance of 15 meters from the transmission line. The value is about 0.03% or around 3521 times lower than the permissible exposure limit recommended by ICNIRP for members of the public (1000 mGauss). The other significant magnetic field strengths value was at point 2 (VL02) with the value at 0.159 mGauss, measured at 18 meters from the source. For the points of measurement from the distance from 25 meters to 45 meters, the magnetic field strength remained constant at 0.1 mGauss .The main reason for the reduction is primarily due to the distance. For this case, with the increase in distance, the magnetic field strength reduced. In addition, after a particular distance the value will be very low and will gradually become zero when it is far enough from the source [2-3].
The plots of figure 5(a) indicate the magnetic field strength against distance and point of measurement and their comparison with the public exposure limits.



(a) **(b)**

Figure 5: Plot of ELF (a) magnetic field strength and (b) electric field strength against distance and point of measurement and their comparison with the public exposure limits

The electric field strengths were found to vary between 1.332 V/m to 11.608 V/m. The highest averaged level of the electric field strengths was at 11.608 V/m measured at point VL01, by which the distance from the transmission line was at 15 meters. The value is about 0.23% or around 430 times lower than that of the exposure limit recommended by ICNIRP for member of public (5000 V/m). Similar to the magnetic field strength, the electric field strength decreases as the distance increases. In addition, it should be noted that at certain points, although having the same distance or further than the other points, the electric field strength is higher as the field strength is influenced by the trees and shrubs at the area of assessment [2,3]. An example would be assessment at VL03 and point VL06, whereby both the points are at the distance of 25 meters from the source, but have different electric field strength recorded. The difference is due to the other tall object influencing the reading, as for this case is due to the shielding by the trees and tall shrubs at the point of measurement. The presence of trees and shrubs screen out the electric field, resulting in lower electric field strength at point VL06. The plots of figure 5(b) indicate the electric field strength against distance and point of measurement and their comparison with the public exposure limits.

For the second case TL2, the averaged magnetic field strengths were found to vary from 0.100 mGauss to 0.823 mGauss. The highest averaged value was at 0.823 mGauss, which was measured outside of the property at the road (point IH02), whereby the distance from the transmission line was 20 meters. The value is about 0.08% or around 1215 times lower than the permissible exposure limit recommended by ICNIRP for members of the public (1000mGauss). This value is significant as the point of measurement is the nearest compared to the other points. Another significant value was recorded at point IH03 with the value recorded was 0.803 mGauss, which was 60 meters from the transmission line. For this situation, the field strength was more influenced by the TNB power box which provides and controls the electrical supply to the house. Magnetic field strength increases with current, hence, a stronger magnetic field would be detected near an appliance when it runs on high compared when it runs on low. [1-3]. As for areas inside the house, the highest averaged magnetic field strength recorded was at 0.1 mGauss at all the points in the house. The value recorded inside the house is was about 0.01% or about 10000 times lower than that of the permissible exposure limit. The values recorded from the distance of 56 meters onwards reduced drastically with the increase in distance. The plots of figure 6 (a) indicate the magnetic field strength against distance and point of measurement and their comparison with the public exposure limits.

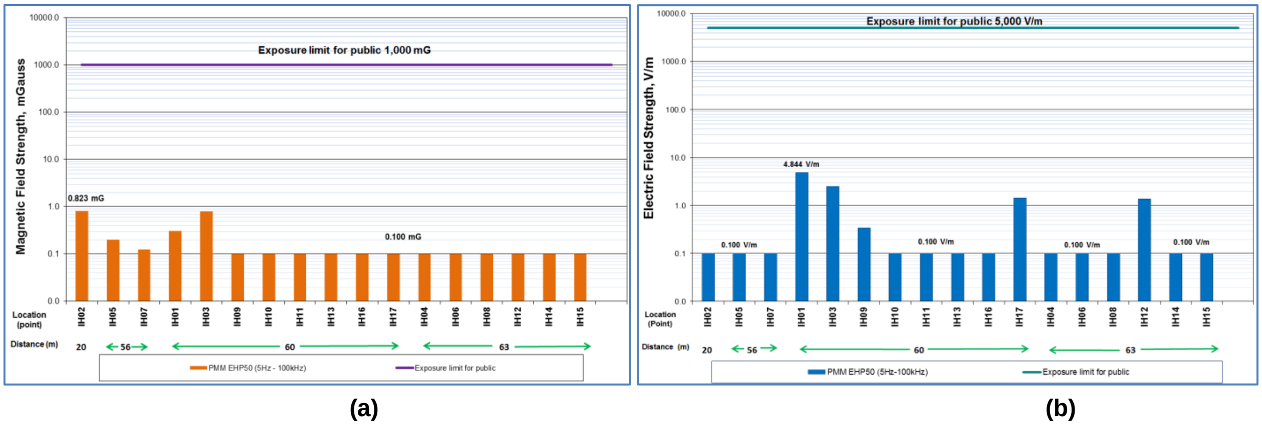


Figure 6: Plot of ELF (a) magnetic field strength and (b) electric field strength against distance and point of measurement and their comparison with the public exposure limits

The electric field strengths were found to vary between 0.100 V/m to 4.844V/m. The highest averaged level of the electric field strengths was at 4.844 V/m measured at the car porch of the house, point IH01. The value is about 0.10% or around 1032 times lower than that of the exposure limit recommended by ICNIRP for member of public (5000 V/m). The value is significant mainly due to the open space of the car porch without any shielding. In addition, the electrical field strength is influenced by the electrical cables and lighting points installed in that stated area. For areas inside the house, the highest averaged level of the electric field strengths was at 1.438 V/m measured at the first floor hall of the house. The value recorded at the location was about 0.03% or about 3477 times lower than that of the permissible exposure limit. It should be noted that the electrical field strength value measured inside the house reduced drastically as the field strength from the transmission line is shielded by the walls of the house. For this particular condition, the electric field strength is influenced mostly by the electrical cables and electrical appliances in the house. It should be noted that at the points IH09, IH12 and IH17, the electric field strength was slightly higher due to presence of electrical power points and electronic appliances such as television, desktop computers and in-built electronic alarm system. House wiring can produce electric fields, which are clearly strongest close to the wiring [2,3]. The value at point 3 was influenced by the TNB power box. Field strength at points IH02, IH05 and IH07 remained constant at 0.100 V/m due to shielding by concrete walls and trees. For other points, the increase in distance from the transmission line resulted in a lower reading of the field strength. The plots of figure 6(b) indicate the electric field strength against distance and point of measurement and their comparison with the public exposure limits.

The spatial distribution of the field strengths around the house was captured using the LINDA system and the areas are presented in contour maps in figure 7. The plots clearly indicate the spatial variation of the field strengths against space around the selected area. The magnetic field strength from the contour maps around the selected area indicated that the highest field strength was 0.822 mGauss, recorded along the road near the house, indicated as L.1 in the layout map. The value is 0.08% of the exposure limit for public or 1216 times lower compared to the limit. As mentioned earlier, this significant value is due to the close proximity of the measurement area to the transmission line. The other values recorded are as summarized in table 1 below.

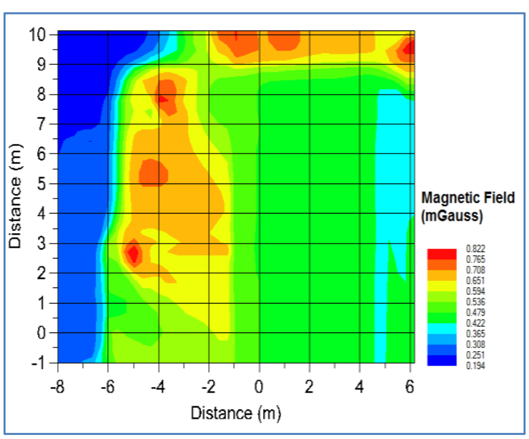
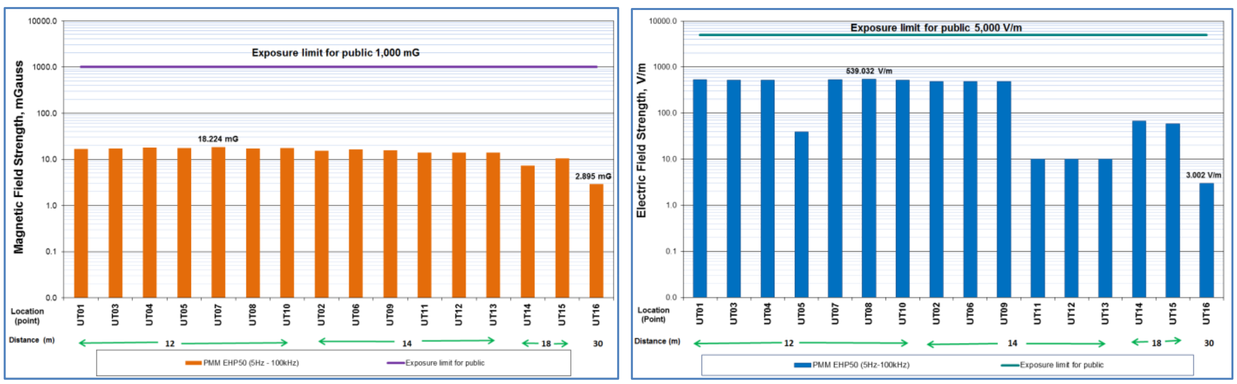


Figure 7: Contour map of magnetic field strengths at location L.1 (case TL2)

Table 1: Results of spatial distributions of magnetic field strengths at measurement locations for case TL2

Location	Highest Magnetic Field (mGauss)	Comparison of Exposure level for public (1000 mGauss) in percentage (%)
L.1	0.822	0.08
L.2	0.431	0.04
L.3	0.706	0.07
L.4	0.256	0.03
L.5	0.367	0.04

For the third case TL3, the averaged magnetic field strengths were found to vary from 2.895 mGauss to 18.224 mGauss. The highest averaged value was at 18.224 mGauss, which was measured at the point UT07 whereby the distance from below the transmission line was 12 meters. The value is about 1.8 % or around 54 times lower than the permissible exposure limit recommended by ICNIRP for members of the public (1000mGauss). It should be noted that the other points measured at the same distance had a slightly different value but with the difference between the highest and lowest was 1.356 mGauss. The values measured from this distance are significant as the point of measurement is the nearest (12m) compared to the other points. The magnetic field strengths value recorded at 14 meters from the transmission line started to decrease gradually with the increase in distance regardless of being shielded by concrete as for the case of indoor measurement at the café [2,3]. This shows that concrete or roof shielding does not influence the magnetic field strength. The strength of the field is usually greatest immediately underneath the transmission line [2,3]. The lowest field strength value was recorded at the point UT16, which was 30 meters from the transmission line. As expected, the magnetic field strength is reduced when getting further from the source [1-6]. The plots of figure 8(a) indicate the magnetic field strength against distance and point of measurement and their comparison with the public exposure limits.



(a) (b)

Figure 8: Plot of ELF (a) magnetic field strength and (b) electric field strength against distance and point of measurement and their comparison with the public exposure limits

The electric field strengths were found to vary between 3.002 V/m to 539.032 V/m. The highest averaged level of the electric field strengths was at 539.032 V/m measured at the area directly under the transmission line (UT08). The distance was at 12 meters from the lowest conductor of the transmission line. The value is about 10.8 % or around 9 times lower than that of the exposure limit recommended by ICNIRP for member of public (5000 V/m). Although this value is very significant compared to other points, it still indicates that even below the overhead lines, the electric field strength are still within the exposure limit recommended by ICNIRP. As stated earlier, the increase in distance from the transmission line resulted in a lower reading of the field strength. In addition, it should be noted that the electrical field strength value measured at the guard house (UT05) and café (points UT11-UT13) reduced drastically as the field strength from the transmission line were shielded by the walls of the building [2,3]. The plots of figure 8(b) indicate the electric field strength against distance and point of measurement and their comparison with the public exposure limits.

The spatial distribution of the field strengths around the area under the transmission line was captured using the LINDA system and the areas are presented in contour maps in figure 9. The plots clearly indicate the spatial variation of the field strengths against space around the selected area. The magnetic field strength from the contour maps around the selected area indicated that the highest field strength was 15.90 mGauss, recorded below the transmission line at the location L.1. The value is 1.6% of the exposure limit for public or 62 times lower compared to the limit. This significant value is due to the close proximity of the measurement area to the transmission line [2,3]. The other values recorded are as summarized in table 2 below.

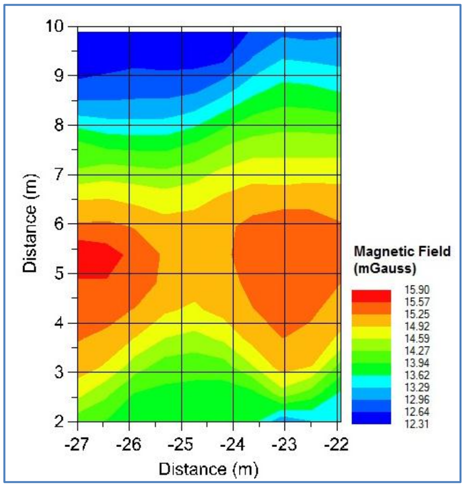


Figure 9: Contour map of magnetic field strengths at location L.1 (case TL3)

Table 2: Results of spatial distributions of magnetic field strengths at measurement locations for case TL3

Location	Highest Magnetic Field (mGauss)	Comparison of Exposure level for public (1000 mGauss) in percentage (%)
L.1	15.90	1.6
L.2	15.00	1.5
L.3	12.02	1.2
L.4	13.90	1.4

Conclusion

In this study, the magnitude of electric and magnetic field strengths of 275 kV High Voltage Transmission line have been analyzed for general public exposure using ICNIRP, 1998 and WHO reference levels. The assessment was based on three cases namely 1. On a vacant land near the transmission line, 2. Inside and around the house at the vicinity of the transmission line and 3. Area directly under the transmission line. The study showed that:

1. The highest measured exposure was at 10.8 % and 1.8 % of the permissible exposure limit for the electric and magnetic field respectively.
2. The overall results indicates that the electric and magnetic field strengths were very much lower than the maximum permissible exposure limit recommended by International Committee on Non-Ionizing Radiation (ICNIRP) and WHO, hence will not lead to any significant exposure received by members of the public.
3. With the increase in distance, the magnetic and electric field strength is reduced. At most cases in this study, the field strength value decreased proportionally with the increase in distance. It should be noted that other factors such as influences of objects such as concrete walls, trees and shrubs contribute to the variations of the electric field strength measured as will be explained in the next point.
4. The ELF EMF present within the assessment area is generated mainly from the high voltage transmission line. As for the case of inside and around the house at the vicinity of the transmission line (case TL2), the measurement outside property are predominantly from the transmission line whereas the measurement inside the property are from the electrical wiring cable. It should be noted that electrical wiring and electrical appliances influences the electric field measurements, thus resulting in a higher value. This is in line with the study done by WHO [2,3].
5. Materials such as wood and concrete provided shielding against the electric field. As for the indoor measurements and assessments near trees and shrubs, the value of electric field strength was lower compared to other points without any shielding. In contrary to the electric field, materials such as wood and concrete do not provide shielding against the magnetic field. The value of the magnetic field strength at the locations of measurement for each case remained constant for a particular distance from the transmission line. This statement is supported by the study performed by WHO [2,3].
6. Higher electric and magnetic field strength were recorded at the area directly below the transmission line compared to measurement performed lateral to the transmission line. The report published by WHO supports this statement [2,3]. Even though both the field strength value is lower than the maximum permissible exposure, public are advised to keep a safe distance from the transmission line to minimize the exposure to electric and magnetic field.

REFERENCES

[1] Classic, K. (2015, May 29). Extremely Low Frequency Radiation/Power Lines. Retrieved from http://hps.org/hpspublications/articles/elfinfosheet.html

[2] World Health Organization, Environmental Health Criteria 238, Extremely Low Frequency Fields, 2007

[3] World Health Organization, Environmental Health Criteria 35, Extremely Low Frequency Fields, 1984

[4] IARC Working Group on the Evaluation of Carcinogenic Risks to Humans. Nonionizing radiation, Part 1: Static and extremely low frequency (ELF) electric and magnetic fields. Lyon, IARC, 2002 (Monographs on the Evaluation of Carcinogenic Risks to Humans, 80).

[5] Electric power research Institute (EPRI), EMF and Your health, 2012

[6] International Commission on Non-Ionizing Radiation Protection (ICNIRP); Guidelines for limiting exposure to time-varying electric, magnetic and electromagnetic fields (up to 300 GHz), Health Physics Vol. 74 No 4 April 1998

[7] International Commission on Non-Ionizing Radiation Protection (ICNIRP), Guidelines for limiting exposure to time varying Electric and Magnetic Fields (1Hz-100 kHz), 2010

[8] Australian National Health and Medical Research Council ; Interim guidelines on Limits of exposure to 50/60 Hz electric and magnetic fields, Radiation Health Series No. 30 1989

[9] Institute of Electrical and Electronics Engineers (IEEE); Recommended Practice for Measurements and Computations of Electric, Magnetic and Electromagnetic Fields with Respect to Human Exposure to Such Fields, 0Hz to 100 kHz.