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Magnetic Field Exposure Assessment of Electric Power Substation in High Rise Building

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Abstract: This study investigated the magnetic field survey of two electric power substations with power capacity of 1500 kVA, 11/0.4 kV which resided in a typical high rise office building in Kuala Lumpur, Malaysia. The purpose of a survey is to examine the exposure levels of magnetic radiation from its electric substation. The method used in this study includes comparative analysis of measured data using EMDEX meter and interfaces with EMCALC software for linear data acquisition. Results of two substations, which located in the basement floor and 15th floors were obtained throughout normal working hours. The measurements were arranged by applying two separate protocol conditions which is near and far fields. The specifications of measuring instruments used in this assessment were also displayed. Final conclusions were made based on the reduction rate calculation as an indicator values to determine the safety levels and comparison to the international standard guidelines.

Key words: Magnetic field, exposure assessment, electric substation, high rise building, EMCALC software, EMDEX meter

INTRODUCTION

The issue of ELF magnetic field has been elongated controversial through a lengthy discussion and review at the international level. Currently, the recommended international standard limitation or restrictions formed by International Commission Non Ionizing Radiation Protection (ICNIRP) had suggested 100 μT for public exposure and 500 μT for occupational exposure (ICNIRP, 1998). Brief observations showed that several countries are still following the official ICNIRP restrictions. Whilst, others are planning to establish a stricter limits than the standard practice. In Malaysia, public confidence on international limits is wedged into reasonable doubt as of numerous health effect reports emerged in associated journals. One example of recent epidemiological study in Malaysia given by Rahman *et al.* (2008) have concluded that a significant increased risk has been hypothetically linked with events of childhood acute leukemia on children live within a distance of less than 200 m. A similar study conducted in Iran by Feizi and Arabi (2007) is also revealed identical consequences on health problems which associates distances as its major key parameter. These two studies are relatively significant with the outcome acquired by Ahlbom *et al.* (2000) published in the British Journal of Cancer. However, the above studies are still inconclusive since it had not used dose exposure as part of its critical examined parameters. Recent progress on the epidemiological study conducted by Kroll *et al.* (2010) had further improved the previous results by incorporating the magnetic field exposure and distance parameters as part of its research analysis. The study reveals that there is a little increment in relative risks for childhood leukemia but statistically, it is still remain insignificant and consistent with the previous study which was conducted in the year 2005. Engineering branches had consistently monitored the dose exposure with the use of measurement survey protocol to those ELF source. Recent engineering study given by Joseph *et al.* (2009) showed that the ELF-EMF research are still remain a relevant subject to be investigated. Joseph *et al.* (2009) has performed ELF-EMF magnetic exposure by executing measurements on large substations 150 and 36/11 kV situated in prominent urban areas. The outcome shows that the exposure values between 0.051 to 13.17 μT for electric and magnetic fields which approximately are still within the ICNIRP standard. Similar study had also been conducted by Safigianni and Tsompanidou (2005, 2009) which evaluated ELF exposure specifically within the indoor and outdoor electric power substation rated at 20/0.4 and 150/20 kV. Authors of these papers had greatly elaborated the electric and magnetic fields exposure survey with special intention to examine the safety levels by comparing their findings to the international standard guidelines. Holbert *et al.* (2009) determine the magnetic field exposure produced by

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underground residential distribution system including exposure from the pad-mount transformer, junction boxes and service entrance panels. The result concludes that magnetic field is reduced to less than 0.3 μT at typical distance of 1 m. More comprehensive data can be viewed given by Farag *et al.* (1999) where occupational exposure assessments were conducted for various types of ELF sources and conditions. These include the exposure values from substations, power lines, underground cable, manhole, low voltage risers etc. Hamza *et al.* (2005) evaluated the magnetic induction inside human at high voltage substations in Egypt of 220/66 kV open-air substation. It also performs calculation of induced electric field and current densities to the human body using approximation to human body parameters such as width and height. Higher voltages of 380/154 kV substations and power lines in Turkey were studied by Ozen (2008). Detail measurements were performed at the switchyard area, control room, incoming and outgoing power lines. Data on exposure values were analyzed and the final results are satisfying with the ICNIRP values. Burnett and Yaping (2002), ESAA (1996), Baishiki and Deno (1987) and Sandstrom *et al.* (1993) had indicated problems with ELF exposures from the electrical installations in high-rise buildings. The paper discusses ELF magnetic field exposure as a problem source to equipment interference issues prior to propose mitigation for field reductions. Latest developments of magnetic field exposure evaluation are still continued until today with various approaches and interest in characterizing the fields. For example, Proios *et al.* (2010) proposed a study on magnetic field exposure near to the compact kiosk type substation, Ellithy (2010) and Said *et al.* (2010) had continued with the standard methods on magnetic exposure from the 220 kV gas insulated substation and distribution substation respectively, while Mazzanti (2010) had proposed with innovative heuristic formulas for predicting magnetic exposure from the transmission lines. All these studies have proved that the ELF magnetic field exposures are still valid among the scientific community with curiosity to understand the relationship between magnetic exposure and human health. In this study examination of the ELF magnetic field caused by the operation of power substation 11/0.4 kV in high-rise office building located in Kuala Lumpur was carried out. Twenty multi-storey office building were due to the reports of interference problems near to the substation. This study of magnetic exposure is crucial because of its nature which is quite unusual to be conducted on high-rise office building environment. The average current consumption in the high rise building is relatively high which approximately in the range of 1000 to 2000 A. Since, distance is a limiting factor for field reduction in most modern building high exposure magnetic field is expected to occur anywhere in the office environment. Due to high demand of administrative and management operations which includes reliable power supply, another substation scale was built at the upper levels simply as to ensure stability and as well as mitigating the power losses. In this study, basic data for the substation is given and a brief description of the instruments used for the measurements is also provided. The main results of the field measurements are presented in relevant tables and diagrams. These results are evaluated according to generally accepted guidelines and final conclusions concerning safe public and occupational field exposure are set out.

MATERIALS AND METHODS

Substation layout at 15th floor: A typical high-rise office building in Malaysia normally is equipped with separate rooms which are located at the upper floor of the buildings. It consists of HT switching room, Transformer room and LV switching room. Figure 1 shows the area which covering one part of the whole building on the 15th floor. Above the substation a computer server room and administrative office department which employs 20 clerical staffs. The transformer room has a dimension of 5 m height clearance and an area of (5.2×6.7) m^2 which accommodates only one power transformer. It has one opening window suit for ventilation purposes. The operating voltage for the transformer is 11/0.4 kV with 1500 KVA rated power and was dedicated to serve the

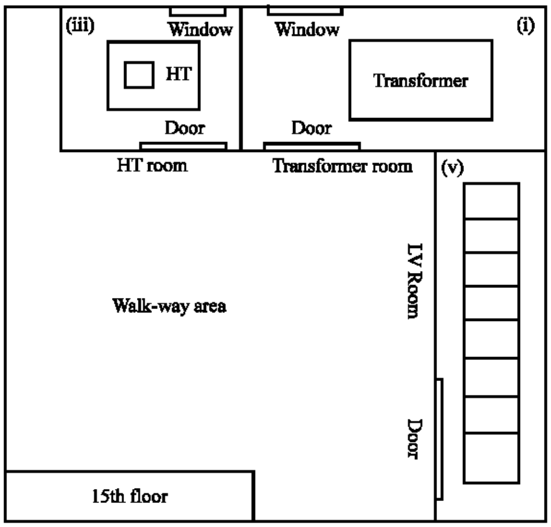

Fig. 1: Layout area of the substation located at the 15th floor

upper level units of various office departments. The transformer unit is located in an area of (1.8×2.7) m^2 with 2.5 m height and is using dry insulation type and the load reading on the low voltage side is 1200 A. Next to the transformer room is a room occupies by one unit of High Tension Vacuum Circuit Breaker (HT-VCB) system. The room of an area of (4.6×4.9) m^2 wide and 5 m height clearance is provided with a single window for air ventilation purposes. The HT-VCB unit is placed at the center of the room. The circuit breaker systems have no numerical analog or digital indicator output to be recorded. In-front of the transformer room is a Low Voltage switching panel room which consists of several switching channels for controlling transformers, bus couplers and circuit breakers. The room is (4.0×12.0) m^2 wide and same height clearance as previous room. The system was connected using Triple-pole and Neutral (TPN) bus-bar risers of low voltage distribution with large multi-core cables.

Substation layout at basement floor: Similar design substation was built at the basement floor of the building. Figure 2 shows the area of the basement substation which is divided into transformer room, HT switching room and LV switching room. The transformer room was occupied by two hermetically seal power transformers with oil insulation type as indicated in the diagram. The operating voltages of both transformers are 11/0.4 kV with rated power of 1500 KVA. The transformer unit dimension is (1.4×2.4) m^2 with 2 m height. The room has dimension of (5.0×12.0) m^2 and vertical clearance of 7 m high. In-front of the substation is a walk-way area for public and directly one floor above the substation is an office area. The HT-VCB room occupies few panels of circuit breaker systems with room size of (6.0×8.5) m^2 and 7 m height clearance. The Low Voltage room consists of few LV switch panels and occupies the room size of (2.5×12.5) m^2 and sharing the same vertical height clearance as previous room. The current values at the High Voltage is around 100 A while at the Low Voltage side is $I_a = 40$ A, $I_b = 20$ A, $I_c = 30$ A. The substation systems were connected using large multi-core cables through risers which available in each rooms.

In this project, magnetic exposure measurement was undertaken simultaneously to cater for both substation sites (namely substation located in the basement and on the 15th floor) which resides in the twenty storey new office building in Kuala Lumpur. The building is occupied by an institute under the Malaysian, ministry of education. Concern over the EMF exposure were quite significant among the staffs in 15th floor in relation to the incidents where health problems and computer jittering were prevalent. Measurement surveys were scheduled on December 05, 2008 to several points of measurement locations namely; transformer room (15th floor : 10.09 a.m); HT switch room (15th floor : 10.18 a.m); LV switch room (15th floor : 10.34 a.m) followed by transformer room (Basement : 10.55 a.m); HT switch room (Basement : 11.04 a.m); LV switch room (Basement : 11.07 a.m).

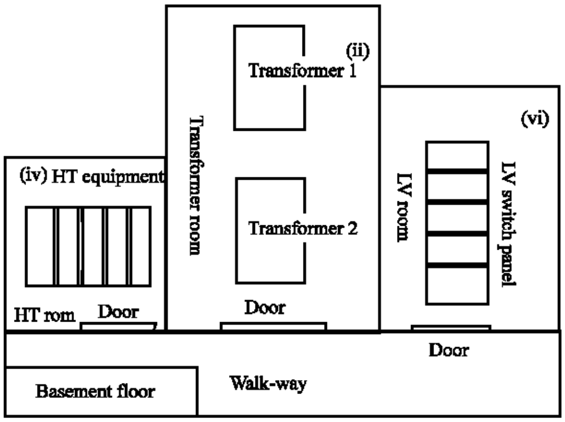

Fig. 2: Layout area of the substation located at the basement floor

Methods: The instruments which used for the low frequency magnetic field is the EMDEX-II meter. The meter was constructed by Enertech Consultant Company with technical support by EPRI, US. The meter is a portable device interfaced with EMCALC software tools as its analyzing processer. The specification of the meter is shown in Table 1. The EMDEX-II meter is steadily used for exposure assessment in substation and power lines. It can be easily to desktop office computer or laptop with EMCALC software using interface cable or adapter cables. It can store up to 20 distinct data set measurements which can be collected over a period of many days prior to downloading them from the battery operated unit. The software is used for data files transfer, storage and analysis. The EMDEX-II meter is accompanied by several accessories which will be required before starting the measurement. Two types of measurement modes can be uploaded in the software which is known as Standard mode or Linear Data Acquisition (LINDA) mode. The differences between these two modes are Standard mode is measuring the magnetic field using time based where else for LINDA is measuring the field against distance. Once the software uploading is completed, the meter is required to be fitted and connected to the special wheel which finally

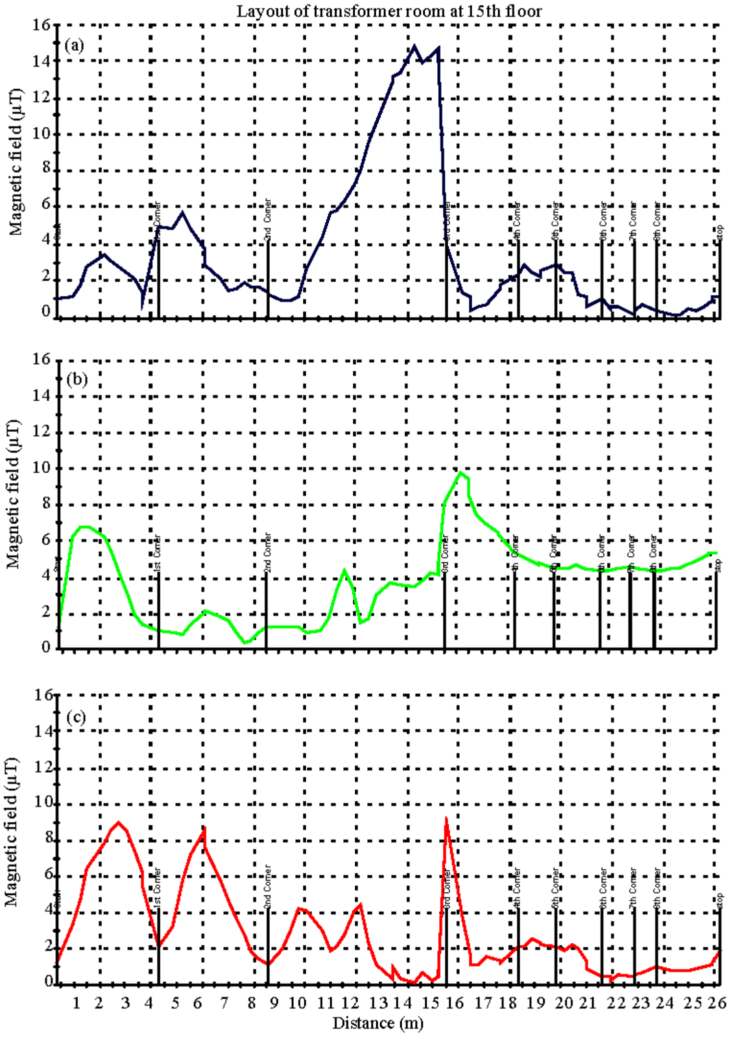

Fig. 3: (a) Sample example of magnetic field plotted resultant in x direction, (b) Sample example of magnetic field plotted resultant in y direction and (c) Sample example of magnetic field plotted resultant in z direction

Table 1: Comparison of the B resultant taken from various points

Equipment	Details
Emdex - II	• 3-Axis Magnetic Field Sensor • Multi-Functional Magnetic Field Measurement Systems • Data Sampling Rate -1.5 sec • Field Range-0.01 ~300 µT • Data Collection-Actual Measurement • Resolution-0.01 µT • Typical Accuracy - ± 1% • Frequency-40 to 800 Hz (Broadband) and 100 to 800 Hz (Harmonic) • Max. Sampling Rate-1.5 sec • Internal Memory-512 Kb • Measurement Method-True RMS

becoming a complete set for magnetic field measurement. The instrument measuring the power frequency magnetic fields use a property described by Faraday's Law in Eq. 1:

$$V_c = n\frac{d\varphi}{dt} \qquad (1)$$

Since the meter measures the B field of the 3-axis concurrently, the software is also capable of producing the resultant field of the three components as indicated by example in Fig. 3 a-c, respectively. Three phase systems normally produced multiphase fields current. If these currents are at the power system frequency, the locus of the B vector at any point is generally an elliptically polarized field. Because single phase meter is not practical to use for each phase calculation, a three-axis meter is recommended instead for immediate calculation on the resultant value of the three phase magnetic field. Determination of the resultant value is given by Eq. 2 (Horton and Goldberg, 1995):

$$B_{result} = \sqrt{\left(\frac{B_{xm}}{\sqrt{2}}\right)^2 + \left(\frac{B_{ym}}{\sqrt{2}}\right)^2 + \left(\frac{B_{zm}}{\sqrt{2}}\right)^2} \qquad (2)$$

After considering the harmonic effects, the resultant field may be redefined in terms of the rms values of the fields along the x, y and z axes given in the Eq. 3:

$$B_{result} = \sqrt{(B_{xrms})^2 + (B_{yrms})^2 + (B_{zrms})^2} \qquad (3)$$

RESULTS AND DISCUSSION

Results from this measurement survey mainly concentrated on three main areas in both substations namely; the transformer rooms, HT switch rooms and LV switch rooms. Figure 4a and b display the resultant of magnetic field profile for the transformer rooms, while Fig. 5a and b display the resultant of magnetic field profile for the HT switch rooms followed by Fig. 6a and b which display the resultant of magnetic field profile for the LV switch rooms, for both 15th floor and basement floor substations respectively. Results in the above figures were taken during normal office operation which is between 10:00 a.m. to 12:00 a.m. with 75% of power capacity loading. The above figures also represent the magnetic exposure for a typical distribution substation which is less than 20 μT and 80% lower than the ICNIRP standard (ICNIRP, 1998) for public exposures. The field characterizations can be understood more significantly by employing a set of statistical variables as shown in Table 2. Table 2 confirmed that the magnetic field produced by the substation in the upper level floor is higher than the one that resided at the basement floor. Special interests of the statistical variables that is the mean and median values has to be addressed since these values representing the total exposure of flux density distributions in the whole substations area. It is noted that from the table, most of the maximum magnetic field flux density values recorded at 15th floors are far below the reference level for safe public and occupational exposure which is from 55.84 to 10.79 μT, with its standard deviation ranges of 3.08 to 11.10 μT. The results for mean and median values for the international standards are also relatively consistence with lower limit ranges from 3.91 to 28.69 and 3.08 to 26.72 μT, respectively. While substation in basement floor renders mean exposure value ranges from 1.23 to 19.75 μT; maximum exposure range is between 3.93 to 34.72 μT; median range is between 0.76 to 18.24 μT with its standard

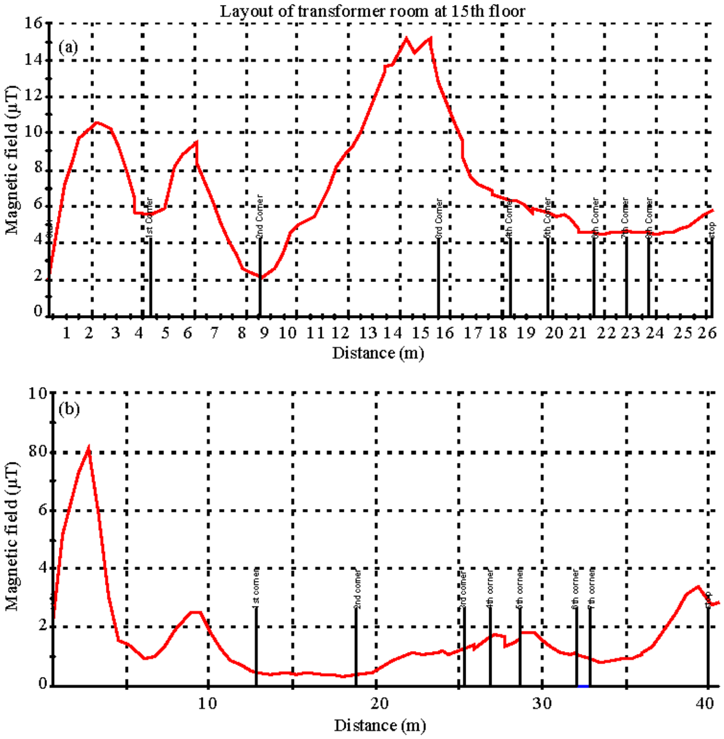

Fig. 4: (a) Magnetic field profiles of transformer room located at 15th and (b) Magnetic field profiles of transformer room located at the basement floor

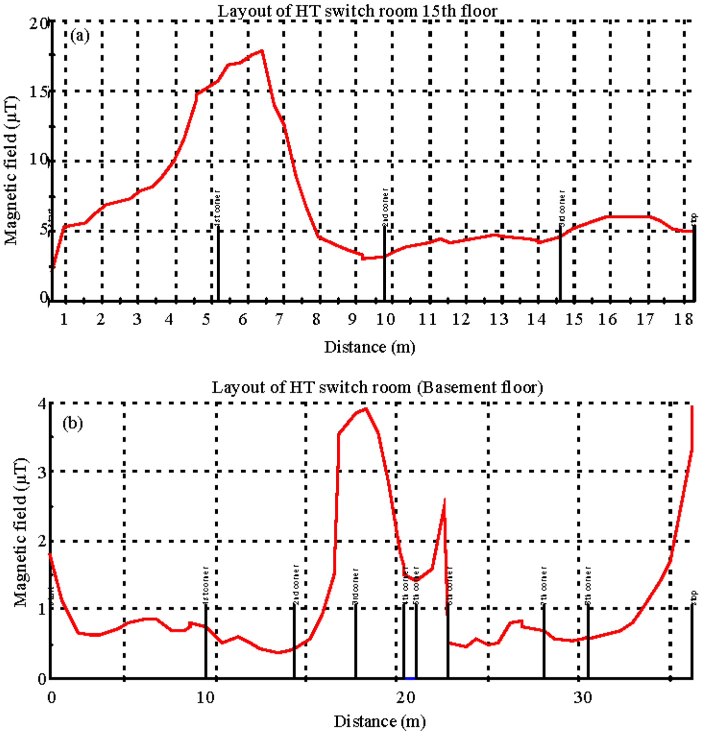

Fig. 5: (a) Magnetic field profiles of HT room located at 15th and (b) Magnetic field profiles of HT room located at the basement floor

Table 2: Comparison of the B resultant taken from various points

	Descriptive statictics				
Charctertistics	Min (µT)	Max (µT)	Mean (µT)	SD (µT)	Median (µT)
Transformer room (15th floor)	2.05	15.15	7.08	3.35	5.39
Field near to Transformer	2.20	55.84	28.69	11.10	26.72
HT-VCB room (15th floor)	2.15	17.91	7.25	4.37	5.57
Field near to HT-VCB switch panel	2.20	18.37	10.93	3.46	10.25
LV room (15th floor)	0.91	10.79	3.91	3.08	3.08
Field near to LV switch panel	1.81	46.56	11.64	9.22	9.80
Transformer room (basement floor)	0.31	8.15	1.63	1.44	1.19
Field near to Transformer 1	2.2	25.76	12.04	5.94	10.98
Field near to Transformer 2	2.2	17.91	9.14	3.88	8.11
HT-VCB room (basement floor)	0.37	3.93	1.23	1.02	0.76
Field near to HT-VCB switch panel	0.71	5.13	1.99	1.20	1.75
LV room (basement floor)	0.41	18.01	3.94	3.65	2.73
Field near to LV switch panel	2.2	34.72	19.75	7.95	18.24
At the perimeter of server room	0.36	3.59	1.96	1.11	2.48
Inside the server room	0.37	3.29	1.90	1.14	1.89
Office area 1	0.06	3.35	0.88	0.95	0.40
Office area 2	1.47	3.11	2.32	0.54	2.13

deviations between 1.02 to 7.95 µT. Even in the case of proximity exposure to the equipment as shown in Table 2, the magnetic flux density values are still remaining low and ensure safe condition for the technicians. In Table 3, the reduction rate calculation also shows that the magnetic flux density of both substations is greatly reduced by certain numbers of percentages. The calculation values were taken from the nearest point of HV equipment and at the point of room perimeter. From the Table 3, great intention is given to the transformer room since both transformers are different type design. For example, the transformer rooms in the 15th floor shows reduction rate of 75.3% while in the basement floor reduction rate are much higher with 86.5% for transformer 1 and 82.2% for transformer 2 while other rooms have shown variety of magnetic exposures. In this case, the reduction rate is used as a variable to monitor and control the hazardous effects of magnetic field to the

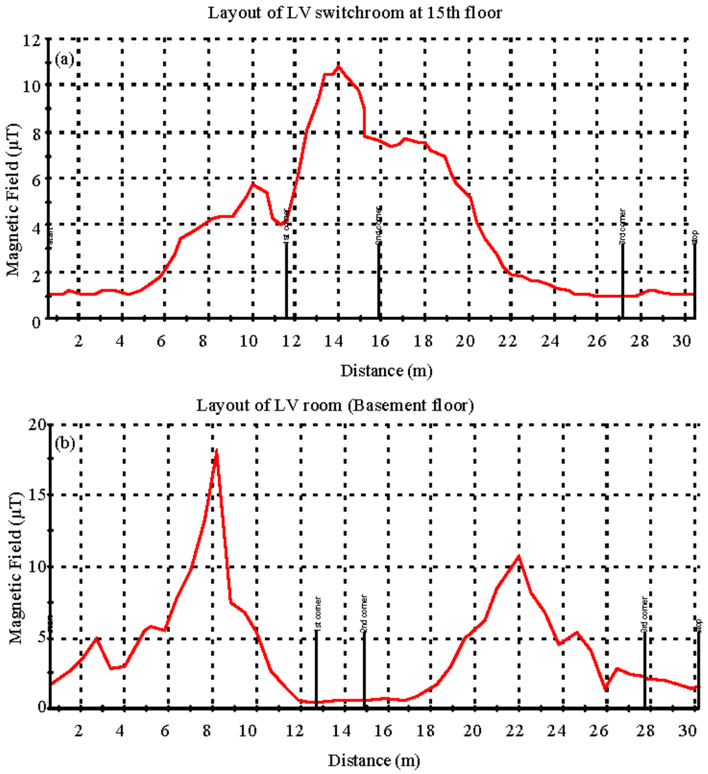

Fig. 6: (a) Magnetic field profiles of LV room located at 15th and (b) Magnetic field profiles of LV room located at the basement floor

Table 3: Reduction rate by distances

Measured points	Reduction rate (%)
Level 15th floor	
Transformer to layout perimeter	75.3
HT-VCB to layout perimeter	33.7
LV to layout perimeter	66.4
Basement floor	
Transformer (1) to layout perimeter	86.5
Transformer (2) to layout perimeter	82.2
HT-VCB to layout perimeter	38.2
LV to layout	80.1

environment. Higher reduction rate means better magnetic exposure and reduce any physical risks to the other regions. Table 3 had also indicated that electric substation installed with hermetically seal oil-insulation transformer producing lower exposure magnetic field in comparison to the substation installed with cast resin dry-insulation transformer. The results obtained from these measurement surveys were also correlated and significantly agree with the findings obtained from Said *et al.* (2010) and Ellithy (2010). Said *et al.* (2010) had reported in statistics that the mean value for all four substations were in the ranges between (1.67-4.99 μT); median range between (12.7-1.0 μT); and its maximum exposure range between (61.6-44.7 μT), except one outliers taken from substation P.E 8.17 which having 200 μT in one of its measurement points. By looking into lower resultant values of standard deviations which are ranged between (5.21-17.8 μT), the measurements conducted by Said *et al.* (2010) can be considered as within the acceptable levels. While Ellithy (2010) in his statistical analysis had observed the mean values is between (0.39-7.73 μT); maximum exposure is between (2.14-67.52 μT); and its standard deviation spans well in the range between (0.32-9.69 μT). This also exhibits example of normal magnetic exposures for a typically large substation. In terms of distance measurements, relative results were observed even though the capacity and layouts of substations were in different scale. For example, Joseph *et al.* (2009) had indicated that safety distances for such typically large substation able to reach 0.4 μT when the average distance is 7.4 m (substation type 1) and 8.1 m (substation type 2) while Proios *et al.* (2010) observed that for a typically compact substation requires distance clearances of 1.5 m to reach magnetic exposure at 2.1 μT (when door closed) and 3.0 μT (when door opened). These results are significant with the outcome shown in Fig. 4a-b, 5a-b and 6a-b as observed by the author which is varied within the range between 1.4 m to 2.0 m for low magnetic exposure in typical distribution substation. Nevertheless, the results are merely contradictive with the studies conducted by Rahman *et al.* (2008), Feizi and Arabi (2007) and Ahlbom *et al.* (2000) which observed far distance requirements in determining safety magnetic exposure. Rahman *et al.* (2008) in his result suggests that distance as far (>200 m) is necessary to clarify as safety zones while Feizi and Arabi (2007) suggest much farther (>500 m). Ahlbom *et al.* (2000) had emphasized for lower magnetic exposure (0.4 μT) which many had considered as unreasonable case since the suggested values are categorized as background exposures. Another factor of harmful effect from magnetic exposure is the compatibility studies as performed by Burnett and Yaping (2002). Magnetic exposures which are above 1 μT as mentioned by Burnett and Yaping (2002) served more than human effects mainly because of computer jittering case in offices. Their exposure value findings are identical with the third party reports such as Vitale (2008) which also had indicated the same figures. The said dosimetric value requires more than 95% of reduction rate to arrive at 1 μT which finally commits layout problems for building designers. In fact, it is purely difficult on normal condition to obtain such dosimetric values as stated in Table 3 which refers to highest reduction as much as 86%. Therefore, other forms of mitigation methods should be sought out in relation with the proposed dosimetric value for new safety design for substation resided in building.

CONCLUSION

Magnetic field measurement survey on ELF exposure is considered to be one of important approaches in assessing the public and occupational safety. While some studies are suggesting certain effects as lower as 0.4 μT (Ahlbom *et al.*, 2000) for humans and 1 μT for computer appliances (Burnett and Yaping, 2002), more data is required in order to further assessing the risk and its significant effects. This study reports the results of magnetic field exposure from electric substation which resided within the high-rise office building having close proximity to the office area. Primarily the measurements were made to ensure that the magnetic field exposure does not violate the international standard and guidelines. Secondly to investigate the exposure levels in response to any problems or effects aroused from this cause to the nearer offices. The findings obtained from a series of measurements concluded that the measured field values are within the international acceptable reference values, indicating that the field is harmless and safe for the working personnel.

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